GHG Platform INDIA

Methodology Note National & State Level

Greenhouse Gas Estimates

2005 to 2015

September 2019

Waste Sector

Authors
Nikhil Kolsepatil
Anandhan Subramaniyam
Achu Sekhar
Soumya Chaturvedula

Sector Lead

I.C.L.E.I Local Governments for Sustainability

CEEW THE COUNCIL | CIMMYT | CSTEP CENTER FOR STUDY OF SCIENCE, TECHNOLOGY & POLICY | I.C.L.E.I Local Governments for Sustainability | VASUDHA FOUNDATION Green ways for a good earth! | WRI INDIA

An initiative supported by

SHAKTI SUSTAINABLE ENERGY FOUNDATION

Usage Policy	Any re-production or re-distribution of the material(s) and information displayed and published on the Website/GHG Platform India/Portal shall be accompanied by appropriate citation and due acknowledgment to ICLEI South Asia and the GHG Platform India for such material(s) and information. You must give appropriate credit, provide a link, and indicate if changes were made. You may do so in any reasonable manner, but not in any way that suggests the GHG Platform India endorses you or your use. Data sheets may be revised or updated from time to time. The latest version of each data sheet will be posted on the website. To keep abreast of these changes, please email us at info@ghgplatform-india.org so that we may inform you when data sheets have been updated.
Citation	Kolsepatil, N., Anandhan, S., Sekhar, A., Chaturvedula, S. (2019). Greenhouse Gases Emissions of India (subnational estimates): Waste Sector (2005-2015 series) dated September 25, 2019, Retrieved from: http://www.ghgplatform-india.org/waste-sector In instances where economy-wide estimates have been used from the GHG Platform India website, the recommended citation is "GHG platform India 2005-2015 Sub-National Estimates: 2005-2015 Series"
Disclaimer	The data used for arriving at the results of this study is from published, secondary sources, or wholly or in part from official sources that have been duly acknowledged. The veracity of the data has been corroborated to the maximum extent possible. However, GHG Platform India shall not be held liable and responsible to establish the veracity of or corroborate such content or data and shall not be responsible or liable for any consequences that arise from and/or any harm or loss caused by way of placing reliance on the material(s) and information displayed and published on the website or by further use and analysis of the results of this study. During peer review, inquiries and analytical procedures were followed to ascertain whether any or no material modifications to the findings are necessary and whether the methods followed are in conformity with generally accepted guidance and GHG accounting principles. The findings and conclusions in this methodology note are those of the author(s) and do not necessarily represent the views of the peer reviewers or WRI India.

Version Information / Revision history

Version	*Date*	*Brief Description on changes from previous version*
3.0	September 25, 2019	This document includes an estimation and analysis of India's annual national-level GHG emissions for the period 2005-2015 for the Waste Sector, prepared by ICLEI South Asia under the phase-II of the GHG Platform India initiative (www.ghgplatform-india.org).
2.2	April 1, 2018	This document has been updated based on the peer review process. The revision includes • Improving the document in general for better readability, understanding and to avoid duplication of messages. • Improving the consistency of citation and referencing throughout the report. • Revising the 'Introduction' section to make it more concise. • Adding additional details for clarity on aspects of qualitative assessment of data and emission factors, recommended improvements for sub-sectors, quality assurance and quality control. • Inclusion of sample calculation for the 3 sub-sectors (solid waste disposal, domestic wastewater treatment and discharge, and industrial wastewater treatment and discharge) in the Annexures to enable readers to better understand computation of emissions.

		It should be noted that the revision does has not led to any changes in the emission estimates.
2.1	September 28 2017	This document includes an estimation and analysis of India's annual national-level GHG emissions for the period 2005-2013 for the Waste Sector, prepared by ICLEI South Asia under the phase-II of the GHG Platform India initiative (www.ghgplatform-india.org). The framework of the methodology note has been revised to facilitate improved understanding and transparency with regard to the approach, activity data collection, methodologies, emission factors, gaps, uncertainties and other aspects relating to the emission estimation for the Waste sector.
1.0	July 12, 2017	This document includes an estimation and analysis of India's annual national-level GHG emissions for the period 2007-2012 for the Waste Sector, prepared by ICLEI South Asia under the phase-I of the GHG Platform India initiative (www.ghgplatform-india.org). .

Foreword

On December 2015, the international community took a significant step towards addressing the global challenge of climate change by endorsing the Paris Agreement at the 21st session of the Conference of Parties (COP) to the United Nations Framework Convention on Climate Change. The milestone Paris Agreement will serve as a foundation for concerted international action to address the threat posed by climate change.

It is now more than clear that climate change is not the responsibility of national government only. It will impact every aspect of the society and therefore, role of non-state actors are more crucial in these testing times. Non-state actors like civil societies and research organizations can inform and help national government in devising robust climate actions and strategies. The first step to devise a robust climate action plan is creating greenhouse gas (GHG) estimates for all relevant economic sectors for recent years.

With the above background, few Indian research organizations came together to form GHG Platform – India, which is a civil society initiative providing independent estimation and analysis of India's GHG emissions. The platform is conceptualized with a noble intention to assist the national government by helping address existing data gaps and data accessibility issues, extending beyond the scope of national inventories, and increasing the volume of analytics and policy dialogue on India's GHG emissions sources, profile, and related policies.

The platform hosted GHG estimates for all key economic sectors for the period of 2005 – 2013 by accounting carbon dioxide, methane and nitrous oxide, both at national and state level. In the present edition, the time series have been extended and the report now presents GHG estimates for the period 2005 – 2015 across all key economic sectors. The report also highlights the trend in GHG emissions across the sectors and transparently documents all the assumptions, activity data and emission factors that were used to arrive at GHG estimates.

The GHG estimates presented in the report follows 2006 IPCC guidelines for national GHG inventories and associated good practice guidance. Further, the report went through rigorous peer review and independent technical review process to ensure accuracy, transparency, consistency, completeness and relevance. On behalf of the platform, we hope that the report will be useful to all relevant stakeholders.

Credits

Led and coordinated by

Emani Kumar
Soumya Chaturvedula
Nikhil Kolsepatil

Sub-Sector Lead

Anandhan Subramaniyam – Domestic Wastewater sub-sector
Nikhil Kolsepatil – Industrial wastewater sub-sector and Municipal Solid Waste sub-sector

Peer Reviewer

The authors would like to express their sincere gratitude to Mr Subrata Chakrabarty and Mr Chirag Gajjar from World Resources Institute India (WRI India) for their valuable contribution towards preparing the guidance document.

Funder

Special thanks to Shakti Sustainable Energy Foundation (SSEF) for providing financial support towards this endeavor.

Editing & Design

Designed and formatted by Priya Kalia – Communications, Vasudha Foundation.
Design reviewed by Communications Team (All partner Organisations), GHG Platform India
Cover Image Photo by Mica Asato from Pexels

Contributors

Waste Sector
Nikhil Kolsepatil (ICLEI,SA)
Anandhan Subramaniyam (ICLEI,SA)
Achu Sekhar (ICLEI,SA)
Soumya Chaturvedula (ICLEI SA)

Compilation of report
Samiksha Dhingra (Vasudha Foundation)
Deepshikha Singh (Vasudha Foundation)

Reviewers
Chirag Gajjar (WRI India)
Subrata Chakrabarty (WRI India)

Editorial work
Priya (Vasudha Foundation)

Acknowledgement

We express our gratitude to Shakti Sustainable Energy Foundation for their continuous grant support to the GHG Platform India initiative. We sincerely appreciate the invaluable contributions of our partners Council on Energy, Environment and Water (CEEW), Center for Study of Science, Technology and Policy (CSTEP), the International Maze and Wheat Improvement Center (CIMMYT), Vasudha Foundation, and the World Resources Institute India (WRI India), towards this exercise. We also thank the SEEG (System for Estimation of Greenhouse Gases Emissions) for their enriching inputs and support extended to this platform based on experiences from Brazil and Peru.

The project team would like to thank the Ministry of Environment, Forest and Climate Change for its efforts towards preparation and submission of India's National Communication Reports and the Biennial Update Reports, which were invaluable resources that helped in initiating this exercise. We acknowledge the inputs of the Ministry of Urban Development for information on waste management in states. We would also like to extend our appreciation towards the efforts undertaken by the Central Pollution Control Board (CPCB), various State Pollution Control Boards, and the National Environmental Engineering Research Institute (NEERI) to collate and publish technical information on the Waste sector in India. We extend our sincere thanks to the Office of the Registrar General & Census Commissioner and the National Sample Survey Office for providing key information on population and domestic wastewater.

We would also like to thank the Ministry of Food Processing Industries, Ministry of Statistics and Programme Implementation, Department of Industrial Policy and Promotion, Ministry of Commerce & Industry, Central Board of Excise and Customs - Central Excise, the Coffee Board of India, the Specialty Coffee Association of India, the Central Pulp & Paper Research Institute (CPPRI), the Indian Paper Manufacturers Association, All India Brewers Association (AIBA), the Rubber Board, and the Indiastat team for inputs on industrial datasets. We deeply appreciate the expert guidance provided by Mr. Mandtu Chowdhary (Scientist-E, CPCB), Dr. D.R. Babu Reddy (Dy. Director, Coffee Board of India) and Ms. Lizy M. (Deputy Director(S&P)) Rubber Board).

Contents

Foreword 2
Contents 5
Executive Summary 7
1. Introduction and Background 9
1.1 Context 9
1.2 GHG Coverage 9
1.3 Key economic sectors covered 9
1.4 Boundary of GHG estimates 10
1.5 Reporting Period 10
1.6 Outline of GHG estimates 10
1.7 Institutional Information 11
1.8 Data collection process and Storage 11
1.9 Quality Control (QC) and Quality Assurance (QA) 12
1.10 General assessment of completeness 13
1.11 Recommended Improvements 14
2. Trends in GHG emissions 16
2.1 Trend in aggregated GHG emissions 16
2.2 Trend in GHG emissions by type of GHG 17
2.3 Key drivers of the emission trends in Waste sector 18
3. Waste 19
3.1 Overview of the sector 19
3.2 Analysis of sectoral emissions 20
3.2.1 4A Solid Waste Disposal 21
3.2.2 4D1 Domestic Wastewater Treatment and Discharge 23
3.2.3 4D2 Industrial Wastewater Treatment and Discharge 24
3.3 State-wise analysis of emissions 26
3.3.1 4A Solid Waste Disposal 28
3.3.2 4D1 Domestic Wastewater Treatment and Discharge 29
3.3.3 4D2 Industrial Wastewater Treatment and Discharge 33
3.4 Sectoral Quality Control (QC) and Quality Assurance (QA) 34
3.4.1 4A Solid Waste Disposal 34
3.4.2 4D1 Domestic Wastewater Treatment and Discharge 35
3.4.3 4D2 Industrial Wastewater Treatment and Discharge 35
3.5 4A2 Unmanaged Waste Disposal Sites 36
3.5.1 Category description 36
3.5.2 Methodology 38

3.5.3 Recalculation 50
3.6 4D1 Domestic Wastewater Treatment and Discharge 51
3.6.1 Category description 51
3.6.2 Methodology 54
3.6.3 Recalculation 85
3.7 4D2 Industrial Wastewater Treatment and Discharge 86
3.7.1 Category description 86
3.7.2 Methodology 91
3.7.3 Recalculation 107
3.8 Uncertainty 110
3.9 Recommended Improvements 114
Comparison with national inventories 117
Additional Information 122
Appendix 123
6.1 4A2 Unmanaged Waste Disposal Sites 123
6.2 4D1 Domestic Wastewater Treatment and Discharge 125
6.3 4D2 Industrial Wastewater Treatment and Discharge 129
6.4 Sample Calculations for Emission Estimation 130
References 149
Abbreviations 150
List of Tables 151
List of Figures 152

Executive Summary

Key Highlights

- The major contributing key source category over the reporting period (2005 to 2015) in the Waste Sector is domestic wastewater (64.8%) followed by industrial wastewater (23.4%) and municipal solid waste (11.8%).
- Majority of the emissions from 2005 to 2015 come from CH_4 (78.4%) released followed by N_2O (21.6%).
- The states of Uttar Pradesh, Maharashtra, Gujarat, Andhra Pradesh, Tamil Nadu, and West Bengal contribute to 56% of the total Waste sector emissions from 2005 to 2015, which can be correlated to higher population size in these large states resulting in higher generation of solid waste and domestic wastewater, and significant organic wastewater generation from Pulp & paper, Meat and Dairy industries.

Background Information of GHG emissions in the Waste Sector

India's total GHG emissions for the Waste sector are estimated to be 96.92 Mil. tonnes of CO_2e in 2015. The primary source of emissions was wastewater treatment and discharge with 85.25 Mil. tonnes of CO_2e emitted in 2015. Emissions from domestic wastewater and industrial wastewater amounted to 61.03 Mil. tonnes of CO_2e and 24.22 Mil. tonnes of CO_2e, with solid waste disposal contributing to emissions of 11.67 Mil. tonnes of CO_2e.

Waste management activities such as collection, treatment and disposal of solid waste and wastewater lead to GHG emission in the form of CH_4 and N_2O gases. Waste sector emissions are a result of the degradation of organic material under anaerobic conditions.CH_4 is the primary GHG emitted from solid waste disposal, domestic wastewater, and industrial wastewater and accounts for 80.4% of the cumulative Waste sector emissions in 2015. N_2O emissions make up the remaining 19.6% of emissions from the sector in 2015.

Table 1: Snapshot of GHG estimates by gas and source category for Waste sector

IPCC ID	Key Source category	GHG Emissions in 2015		
		Million tCH_4	Million tN_2O	Million tCO_2e
4	**Waste**	**3.71**	**0**	**96.92**
4A	Solid Waste Disposal	0.56	0	11.67
4A2	Unmanaged waste disposal sites	0.56	0	11.67
4D	Waste water treatment & discharge	3.15	0.061	85.25
4D1	Domestic wastewater treatment & discharge	2.00	0.061	61.03
4D2	Industrial wastewater treatment & discharge	1.15	0	24.22

Summary of GHG sources and sinks

- GHG emissions from domestic wastewater treatment and discharge (4D1) have accounted for the highest share in the sector over the reporting period, with a contribution of 63% in 2015. The higher emissions for this source category stem from rising volumes of domestic wastewater in urban and rural areas across states as a result of growing population coupled with 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.

- Industrial wastewater treatment and discharge (4D2) had the 2nd largest contribution (25%) to the aggregate Waste sector GHG emissions in 2015, with Pulp and paper, Meat and dairy Sectors observed to be critical industries having high organic wastewater generation and GHG emission.
- Disposal of solid waste (4A) contributed to 12% of the aggregate emissions from the Waste sector in 2015, with emissions across states driven by higher waste generation, changing waste composition, and inadequate levels of waste processing leading to higher quantum of municipal solid waste going to disposal sites.

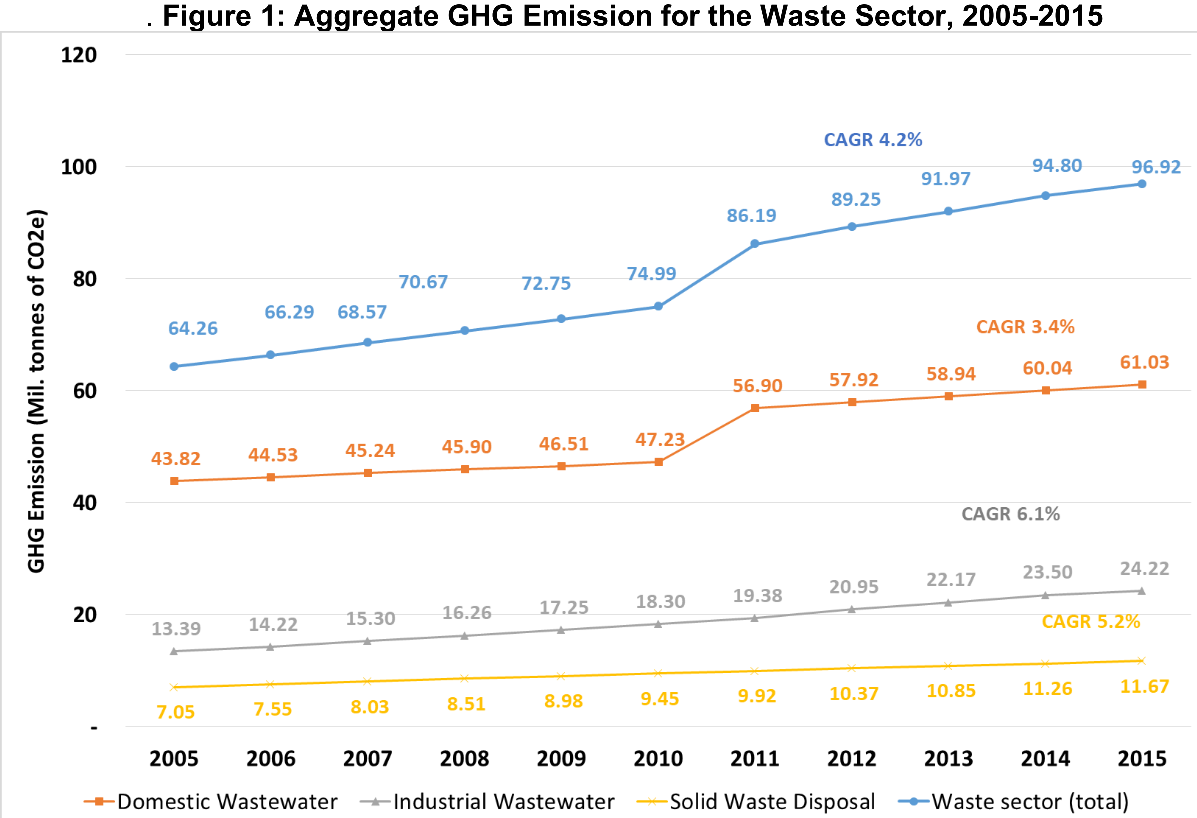
Summary of GHG trends

GHG emissions from the Waste sector have risen at a compound annual growth rate (CAGR) of 4.2% for the reporting period of 2005-2015.

- Emissions from industrial wastewater have registered the highest CAGR of 6.1% among the 3 sub-sectors.
- GHG emissions from solid waste disposal have grown at CAGR of 5.2% while domestic wastewater emissions have increased at CAGR of 3.4% from 2005 to 2015.

The trend of the aggregate state-level emission is observed to be quite steady with a relatively higher rise seen between the year 2010 and 2011 (see Figure 1) largely due to the corresponding increase in the estimated domestic wastewater emissions.

. **Figure 1: Aggregate GHG Emission for the Waste Sector, 2005-2015**



Source: Author's analysis

1. Introduction and Background

1.1 Context

This report is developed as part of GHG Platform India and helps readers understand the process followed by ICLEI South Asia in calculating state level emission estimates and aggregating these further to estimate the national level emissions for the Waste Sector for the period 2005 to 2015.

The entire exercise of reporting GHG emission estimates from the Waste sector aims to contribute towards analyzing and putting together all the existing activity data and emission factors that could be used for Waste sector GHG emission estimations under the GHG Platform India. The various sources used for gathering activity data for estimation, gaps identified in the datasets, and recommendations to improve reliability and accuracy of emission estimation processes will be put forward to the Government of India for further actions. The Platform aims to support the existing efforts of the Indian government in activities such as the process of submitting National Communications to the UNFCCC.

1.2 GHG Coverage

The emission estimation scope covers three GHGs currently: Carbon Dioxide (CO_2), Methane (CH_4), and Nitrous Oxide (N_2O). Activities in the Waste sector lead to emission of two GHGs, namely CH_4 and N_2O, both of which are accounted under the estimates reported herein.

The 100-year Global Warming Potential (GWP) values for CO2, CH_4 and N_2O gases respectively, as provided by the Intergovernmental Panel on Climate Change (IPCC) in its Second Assessment Report, 1996 and the latest updated GWP values in IPCC's Fifth Assessment Report, 2014 have been referred while reporting the emission estimates in terms of CO_2 equivalent (CO_2e) (see Table 2).

Table 2: Global warming potential as per IPCC assessment reports

Name of the gas	Formula	Global Warming Potential (GWP)	
		SAR	AR5
Carbon dioxide	CO_2	1	1
Methane	CH_4	21	28
Nitrous oxide	N_2O	310	265

Source: IPCC Second Assessment Report, 1996 and Fifth Assessment Report, 2014

1.3 Key economic sectors covered

As per IPCC reporting structure, the following source categories and sub-categories under the Waste sector have been considered in the emission estimation. The relevant gases considered under each sub –category is also indicated below.

- 4A Solid Waste Disposal
    - 4A2 Unmanaged Waste Disposal Sites: CH_4
- 4D Wastewater treatment and discharge
    - 4D1 Domestic Wastewater Treatment and Discharge: CH_4 & N_2O
    - 4D2 Industrial Wastewater Treatment and Discharge: CH_4

The source categories and sub-categories considered for the state-level estimates are in line with India's national reporting documents i.e., (i) INCCA report[1] with estimates for the year 2007 (MoEFCC, 2012), (ii) 1st Biennial Update Report[2] to UNFCCC (BUR 1) with estimates for the year 2010 (MoEFCC, 2015), and (iii) 2nd Biennial Update Report[3] to UNFCCC (BUR 2) with estimates for the year 2014 (MoEFCC, 2018).

1.4 Boundary of GHG estimates

The geospatial boundary of State-level GHG emission estimates for the Waste sector includes all the 36 states and union territories in India (referred to as 'states' throughout this document), spanning a geographical area of 3.28 million sq. km and housing a population of 1.2 billion as per Census 2011. Within this geographical boundary, emissions of CH_4 and N_2O from the source categories of '4A Solid waste disposal' and '4D Wastewater treatment and discharge' are included in this assessment.

The scope of emission estimation from solid waste disposal is limited to the urban areas within India given that rural areas lack the requisite waste management and disposal systems and thereby GHG emission generation can be insignificant in the absence of controlled/semi-controlled anaerobic conditions, in line with India's three national reporting reference documents indicated in section 1.3

1.5 Reporting Period

The time period for the state-level GHG emission estimations and subsequently aggregated national level GHG estimates is from 2005 to 2015. Through its Nationally Determined Contribution under the Paris Agreement, 2016, India has targeted reducing the emission intensity of its economy by 33–35% by the year 2030 as compared to that in the base year of 2005 (GoI, 2016). Therefore, this emission estimation exercise for the Waste sector has selected the same base year of 2005.

1.6 Outline of GHG estimates

The outline of this note is as follows:

- Chapter 1 introduces this GHG estimation exercise and provides an overview of the source categories covered, scope and reporting period, exclusions, data collection and quality control and quality assurance (QC/QA) methods, along with suggestions to improve data quality and emission estimation for the Waste sector.
- Chapter 2 captures the key trends of the aggregate emissions and briefly discusses key drivers of the trends observed.
- Chapter 3 delves deeper into the trends and related analysis for each source category, with insights from state-level estimates highlighted. Detailed information on specific emission sources and scope, calculation methodology, data sources, QC/QA, assumptions used to close data gaps, any emission recalculations, uncertainty, and

[1] Available at: https://www.iitr.ac.in/wfw/web_ua_water_for_welfare/water/WRDM/MOEF_India_GHG_Emis_2010.pdf
[2] Available at http://unfccc.int/resource/docs/natc/indbur1.pdf
[3] Available at: https://unfccc.int/sites/default/files/resource/INDIA%20SECOND%20BUR%20High%20Res.pdf

challenges in emission estimation and recommendations for improvement is provided for each source category.

- In Chapter 4, emission estimates are compared with official inventory estimates published by Government of India and reasons for deviation are discussed.
- Chapter 5 provides additional information pertaining to waste sector GHG emission estimates.

1.7 Institutional Information

ICLEI South Asia has been a partner of the GHG Platform-India since the platform's inception and has been leading the Platform's work on the Waste sector. Further information on ICLEI South Asia can be found at http://southasia.iclei.org/

The following staff members from ICLEI South Asia's Energy & Climate team, which handles ICLEI's portfolio of energy and climate mitigation projects, have been involved in the preparation of the emission estimates and this methodology note:

- Emani Kumar, Deputy Secretary General of ICLEI Global and Executive Director, ICLEI South Asia: Provided strategic inputs towards methodological approach for emission estimation and finalization of the methodology note.
- Soumya Chaturvedula, Deputy Director: Provided expert inputs to steer the process to help prepare and finalize this document including methodological approach, identification of datasets, assumptions to close data gaps, finalization of emission estimates and this document for all sub-sectors.
- Nikhil Kolsepatil, Manager- Energy & Climate: Led overall preparation and finalization of the emission estimates and the methodology document. Coordinated and led tasks towards methodology preparation and finalization, data identification, collection and estimate preparation, review and finalization of data and inventory estimates.
- Anandhan Subramaniyam, Manager- Energy & Climate: Undertook data collection, research, developing methodology for rural and urban domestic wastewater estimates, data validation and estimate preparation for the domestic wastewater sub-sector and drafted related sections in this note.
- Achu Sekhar, Senior Project Officer - Sustainability Management: Undertook data collection, research, data validation and estimate preparation for the municipal solid waste sub-sector and drafted related sections in this document.

1.8 Data collection process and Storage

To ensure that the estimates from the emission source categories represent the existing condition of waste management across the states in India, it has been sought to use Tier 1 and Tier 2 country-specific and state-level data in the assessment to the extent possible. The emission estimates are based primarily on aggregated secondary data collected by ICLEI South Asia from published documents and reports of relevant government departments, nodal agencies, and research institutions at the state as well as national level, including the Central Pollution Control Board (CPCB) and corresponding State Pollution Control Boards (SPCB), the National Environmental Engineering Research Institute (NEERI), various industry departments and associations, and the Ministry of Urban Development among others. Telephonic interactions were held with experts and representatives from NEERI, industry bodies such as the Coffee Board, Central Paper & Pulp Research Institute among others to seek inputs on data availability and the emission estimation approach where required. Outcomes have been recorded as notes and can be made available on request.

The data collected was in various forms and units and has been assessed to ensure its applicability within the emission estimation boundaries and subsequently processed for further use. The emission estimation method, reporting period, boundaries, year-wise activity data, emission factors and relevant parameters along with data sources and any assumptions to address gaps, and state-level emission results have been transparently recorded in this reporting document and in excel spread sheets to provide clear understanding and to enable reconstruction of the emission estimations as required. All information collected and compiled for the emission estimates has been archived electronically in separate folders for future use as needed along with copies of relevant references or data sources. The final emission estimates and reporting documents are published and available on the GHG Platform India website (www.ghgplatform-india.org).

1.9 Quality Control (QC) and Quality Assurance (QA)

Internal quality control (QC) procedures applied to the emission estimates include generic quality checks in terms of the calculations, processing, consistency, and clear recording and documentation as follows:

- The input activity data for each emission source sub-category has been selected from that available in different datasets by duly factoring in its relative time-series consistency and temporal and spatial applicability.
- The input data in the calculation sheets has been checked internally for transcription errors on a sample basis for all the three sub-sectors.
- The calculation spread sheets have been checked for correct application of formulae, activity and factors and to ensure that calculations are correct. Manual calculations have been carried out for a part of the state emission estimates in all 3 sub-sectors to verify the spread sheet results.
- Appropriate recording, conversions, processing and consistency of measurement units for parameters and emission has been checked across the reporting period.
- The state-wise emission estimates of each year of the reporting period have been compared to check for consistency in trends and detect any major deviations which cannot be correlated with corresponding changes in activity data and/or emission factors.
- A sheet providing an overview of sector, level of aggregation, reporting period, authors, reporting entity, version and usage policy has been included in the source category emission calculation spread sheets that are linked to the main emission reporting spread sheet. The state emission calculation equations, relevant data and parameter values used, intermediate formulae and cells wherein these are linked, and emission results are clearly depicted in the calculation spread sheets for all 3 sub-categories.
- The reporting document has been checked to confirm all relevant references and secondary sources for activity data and emission factors have been included and cited along with web links in line with the platform's citation policy.
- Emission source categories and sub-categories included and excluded in the emission estimates have been transparently reported in section 1.10 of this note. Any known gaps in the state emission estimates along with rationale of assumptions used to address data gaps have been clearly indicated for each of the sub-sectors in sections 3.5, 3.6 and 3.7.

Once the draft emission estimates and methodology notes have been prepared, these have been peer reviewed by the WRI India and feedback from the peer review process has been incorporated before finalization.

1.10 General assessment of completeness

Emissions from the source categories ‘4B Biological treatment of solid waste’ and ‘4C Incineration and open burning of waste’ are not included in the GHG estimates due to the lack of reliable data for these sources and the absence of considerable number of waste incineration and composting facilities for a large part of the reporting period, especially pre-2010.

Emissions from source category ‘4A Solid waste disposal’ are limited to disposal of municipal solid waste in urban areas in this assessment. Given the lack of solid waste management systems in rural areas, a majority of the solid waste in rural areas does not decompose under controlled/semi-controlled anaerobic conditions and thereby does not contribute to significant GHG emissions. Further, most of the solid waste disposal sites across Indian states are not scientifically constructed and are inadequately managed as per national government guidance. The sites are also observed to be shallow[4] in general. Therefore, the emission estimates account for the source category ‘4A2: Unmanaged waste disposal sites’ which is deemed applicable for India. Possible emissions from industrial waste and other waste such as clinical waste and hazardous waste are not considered under this source category due to the lack of published information from reliable sources on the generation and management of these solid waste streams in the states.

Given that during the reporting period, an insignificant quantum of waste is disposed in scientifically designed and managed waste disposal sites within the states, the source category of ‘4A1: Managed waste disposal sites’ is not yet applicable in the Indian context and therefore not considered in the present estimation. The prevalent mode of waste disposal in India is through unmanaged open disposal sites (ICRIER, 2018) and hence ‘4A3: Uncategorized waste disposal sites’ is also not considered.

With regard to the industrial wastewater estimates, 11 industry sectors having significant organic load in their effluent and thereby generating significant GHG emission are included. These sectors are identified using India’s National Communication reports, the 2006 IPCC guidelines for National GHG inventories, literature from NEERI and largely include the significant industrial wastewater related GHG emission sources in the country. Estimates for domestic wastewater cover both the urban as well as rural population in the states and are considered to sufficiently capture the relevant emission sources.

Details of key source categories that are not covered in the present analysis due to lack of activity data or low activity levels not leading to significant GHG emission contributions are tabulated below.

Table 3: Details of key source categories excluded from present GHG estimates

Sector	IPCC ID	Category description	Reason for exclusion
Waste	4A	Solid waste disposal (for rural areas)	Most of the solid waste does not decompose under controlled/semi-controlled anaerobic conditions due to lack of solid waste management systems in rural areas, thereby leading to insignificant GHG emissions
	4B	Biological treatment of solid waste	Lack of reliable activity data and absence of considerable number of waste composting facilities for

[4] Unmanaged solid waste disposal sites having depths of less than 5 meters are classified as shallow as per IPCC 2006 Guidelines, Vol. 5, Chapter 3: Solid Waste disposal.
Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

Sector	IPCC ID	Category description	Reason for exclusion
			a large part of the reporting period, especially pre-2010
	4C	Incineration and open burning of waste	Lack of reliable data and absence of considerable number of waste incineration facilities for a large part of the reporting period, especially pre-2010

1.11 Recommended Improvements

The unavailability of published state-specific and regularly updated information on the activity data, emission factors and related coefficients has been a challenge in the emission estimation process for all three source-categories in the Waste sector. The limited availability of reliable state-level data has necessitated the use of national average values or IPCC default values in the emission estimates. The data gaps are further noted below along with the recommendations for periodic reporting of better quality data.

Partners of the GHG Platform India initiative do not envisage collecting primary data. The Platform seeks to engage further with the Ministry of Environment, Forests and Climate Change (MoEFCC) to gain access to the underlying datasets and assumptions used for the official National GHG emission estimates. This will greatly help in improving the accuracy of this assessment, enable better comparability, and help identify and address any limitations in the estimates prepared under this assessment as well as the official emission estimates. In addition, the Platform can engage with relevant nodal agencies/data owners to help promote and provide technical inputs towards recording and reporting of relevant activity data in an accurate, consistent and transparent manner to ultimately lend itself to improved GHG emission estimation.

To optimize efforts, specific data gathering and data disaggregating processes may be integrated within existing and ongoing processes that may need further strengthening as indicated below.

- Updated and reliable state-level data on solid waste generation, changes in composition, operational status of processing/treatment facilities is not available, leading to approximations that impact accuracy of the emission estimates. Inconsistencies are observed in year-on-year information that is being reported by states. To capture better information, the annual reporting by state pollution control boards (SPCBs) and under national programmes such as Swachh Bharat Mission can be strengthened and expanded to capture accurate information on solid waste composition along with updated status of operational and non-operational solid waste processing plants.
- Year-on-year information on the distribution of domestic wastewater treatment facilities within states is lacking. This presents a challenge in accurately capturing any impacts on emission due to on-ground deployment of such systems in urban and rural areas of states. Furthermore, annually reported and comprehensive information on the status and performance of all STPs in the states is also lacking. To improve availability and quality of data, wastewater treatment status reports by the CPCB and SPCBs can include information on the operational status and type of wastewater treatment technologies being used. This will help to capture updated status of technological improvements and functionality. Reporting on associated activities that is collated by Ministries, such as the information on domestic wastewater collection and treatment facilities collated under the programmes such as AMRUT could also be considered to capture accurate state level activity data.
- With regard to industrial wastewater estimates, a number of issues exist with regard to availability, reliability and quality of state-level activity data related to industrial production data. A few revisions in the ASI methodology and subsequent assimilation of its information

in inventory calculations could even help the MOEFCC moving up in the tier ladder. The merit in the use of ASI data sets has already been already demonstrated in the emission estimates prepared for the manufacturing sector under the GHG Platform India. The ASI could prove to be a useful information source for industrial wastewater generation, and hence, estimation of associated GHG emission. However, this is restricted by industrial output data in the ASI datasets not being in the requisite metric (i.e. tonnes) to help compute accurate emissions from industrial wastewater. The ASI can promote reporting in metrics that better conform to accurate GHG emission estimation. For example, production of beverages is better reported in volume basis (liters/kiloliters) instead of 'no. of bottles' or production of fertilizers can be reported on mass basis (kg/tonnes) instead of 'no. of bags'. It is also prudent to tap into the knowledge-base and networks of technical institutes and industry associations by involving them in development of technical guidance and resources for standardization and conversion of reported metrics for industrial products.

- For industrial wastewater, information on changes in specific wastewater generation per unit industrial product due to expected improvements in technology is not recorded and therefore ensuing impacts do not reflect in the state emission estimates. It is suggested that SPCBs increase accessibility to the data on volume of wastewater generated, its physio-chemical characteristics such as COD, and treatment processes used that is collected from all the registered industries within their jurisdiction, particularly for industry sectors that generate substantial volumes of organic wastewater. It is also critical to enhance reliability and consistency of such data in terms of time-series trends and reported metrics, and providing sufficiently disaggregated data that enables identification of product sub-classes, technology variations, and scale of operation across the industry sectors.

2. Trends in GHG emissions

2.1 Trend in aggregated GHG emissions

India's Waste sector is estimated to contribute to GHG emission of 96.92 Mil. tonnes of CO_2e in the year 2015 (see Figure 3). Cumulative GHG emissions from the Waste sector have shown an increasing trend, rising at a CAGR of 4.2% between 2005 and 2015.

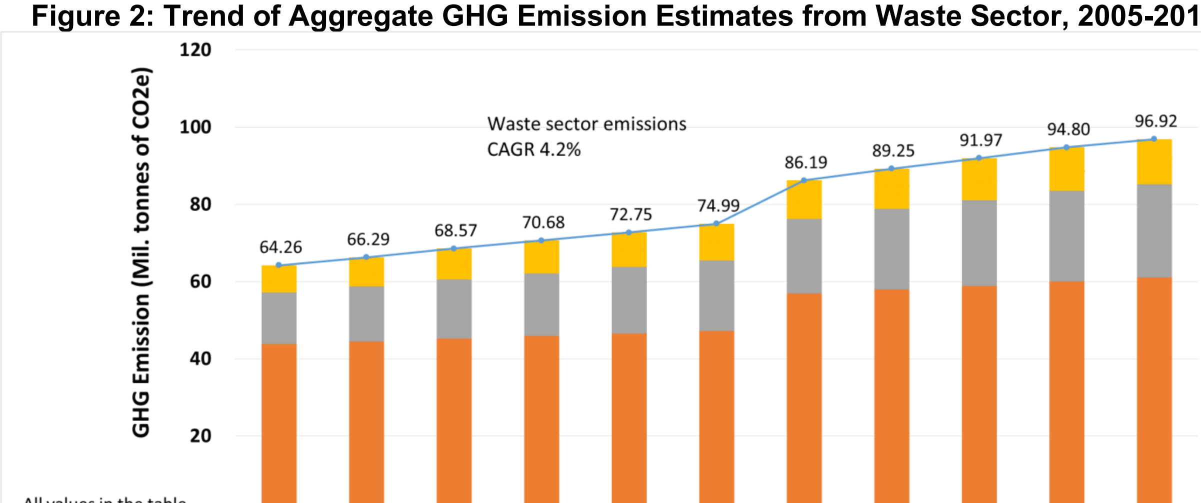
Emissions from industrial wastewater have registered the highest CAGR of 6.1% per year among the 3 sub-sectors. GHG emissions from solid waste disposal and domestic wastewater have grown at CAGR of 5.2% and 3.4% respectively from 2005 to 2015.

Table 4: Trend of GHG emission estimates by source categories

Source Category	Emissions in Mil. tonnes of CO_2e				Percent change		
	2005	2007	2010	2015	2005-2007	2005-2010	2005-2015
4. Waste	64.26	68.57	74.99	96.92	6.7%	16.7%	50.8%
4A2. Unmanaged Waste Disposal Sites	7.05	8.03	9.45	11.67	5.8%	14.5%	65.6%
4D1. Domestic Wastewater Treatment and Discharge	43.82	45.24	47.23	61.03	3.2%	7.8%	39.3%
4D2. Industrial Wastewater Treatment and Discharge	13.39	15.30	18.30	24.22	14.3%	36.7%	80.9%

Source: Author's analysis

Figure 2: Trend of Aggregate GHG Emission Estimates from Waste Sector, 2005-2015



All values in the table in mil. tonnes of CO2e	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Solid Waste Disposal	7.05	7.55	8.03	8.51	8.98	9.45	9.92	10.37	10.85	11.26	11.67
Industrial Wastewater	13.39	14.22	15.30	16.26	17.25	18.30	19.38	20.95	22.17	23.50	24.22
Domestic Wastewater	43.82	44.53	45.24	45.90	46.51	47.23	56.90	57.92	58.94	60.04	61.03
Waste sector (total)	64.26	66.29	68.57	70.68	72.75	74.99	86.19	89.25	91.97	94.80	96.92

Source: Author's analysis

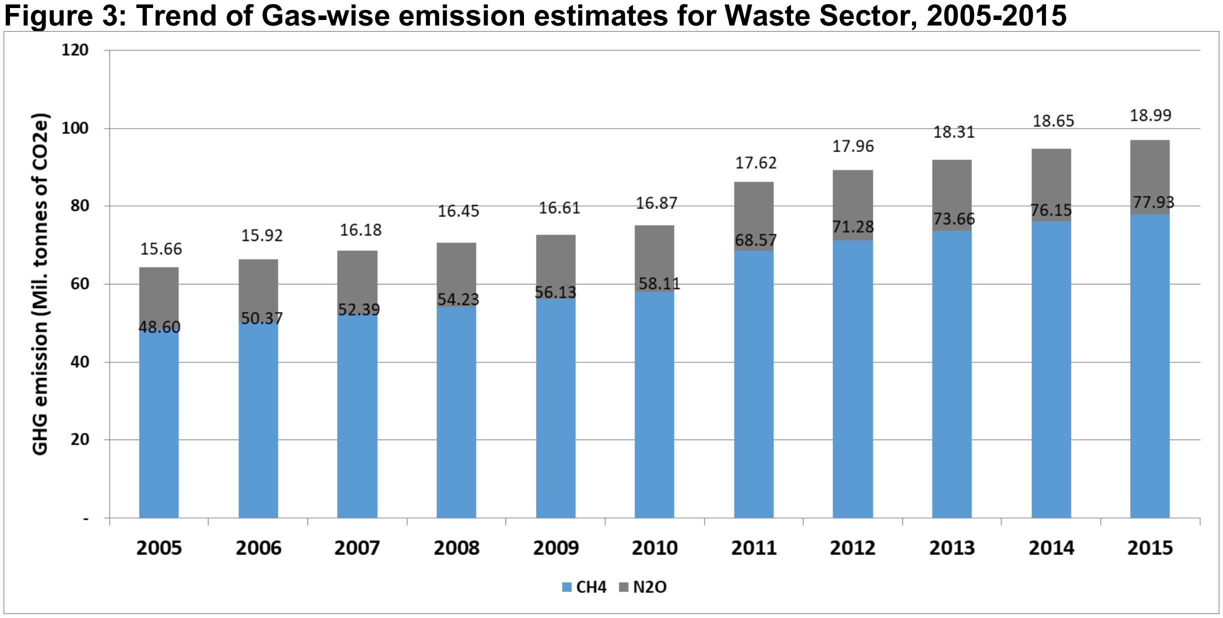
GHG emissions from treatment and discharge of domestic wastewater have accounted for the highest share of the Waste sector emissions over the reporting period, contributing to 63% of the aggregated state-level emissions from the Waste sector in 2015. Industrial wastewater treatment and discharge was the 2nd largest contributor to the total Waste sector GHG emissions, with a share of 25% in 2015, followed by solid waste disposal which contributed to 12% of the country's cumulative Waste sector GHG emissions.

2.2 Trend in GHG emissions by type of GHG

The source categories covered in the assessment for the Waste sector results in emissions of two GHGs, CH_4 and N_2O, as indicated in Chapter 1. CH_4 is the primary GHG emitted and accounts for 78.4% of the cumulative emissions between 2005 and 2015. The remaining 21.6% of the emissions over this time period result from emission of N_2O gas, which occurs due to the protein content present in domestic wastewater and from its disposal into waterways, lakes or seas domestic wastewater.

In 2015, total CH_4 emissions from the Waste sector amounted to 77.93 mil. tonnes of CO_2e while estimated N_2O emissions stood at 18.99 mil. tonnes of CO_2e. Emissions of both CH_4 and N_2O have shown an increasing trend, with a CAGR of 4.8% and 1.9% respectively from 2005 to 2015. Given that CH_4 from the three source categories have grown at a faster rate than N_2O emissions from domestic wastewater, the gas-wise distribution of emissions is observed to have changed gradually over the years. CH_4 and N_2O emissions contributed to 80.4% and 19.6% of the sector's total GHG emissions respectively in 2015, as compared to a share of 75.6% from CH_4 emissions and 24.4% from N_2O emissions in 2005.

Figure 3: Trend of Gas-wise emission estimates for Waste Sector, 2005-2015



Source: Author's analysis

Table 5: Distribution of GHG emission contribution by source category for 2015

IPCC ID	Key source category	Share of CH_4 emission	Share of N_2O emission
4D	**Waste Sector**	**80.4%**	**19.6%**
4A2	Unmanaged waste disposal sites	100%	0%
4D1	Domestic Wastewater Treatment and Discharge	68.9%	31.1%
4D2	Industrial Wastewater Treatment and Discharge	100%	0%

Source: Author's analysis

2.3 Key drivers of the emission trends in Waste sector

The trend of increase in Waste sector emission is observed to be quite steady with a relatively higher rise between 2010 and 2011, which results from a corresponding increase in the estimated emissions from domestic wastewater across states[5]. Increase in domestic wastewater emissions is driven by rising volumes of wastewater to be handled treated in both urban and rural areas given the increase in population and by rising nutritional intake of protein. Dependency of population on discharge/treatment systems with high GHG emission generation potential such as septic tanks, inadequately managed aerobic treatment plants, and untreated discharge of domestic wastewater is leading to higher emissions.

GHG emission from solid waste disposal is observed to be rising due to growing population, increase in per capita waste generation, changing waste composition, and inadequate levels of waste processing over the emission estimation period. Growth in industrial wastewater related emissions stems from higher level of industrial activity (i.e. industrial production) across states, particularly for the Pulp and paper industry along with the Meat and Dairy sectors. Details of the trends for each source category are further provided in sections 3.2 and 3.3.

[5] The overall increase in GHG emissions from domestic wastewater over the reporting period from 2005-2015 is driven by the growing population and changing patterns of use of different treatment systems such as septic tanks, which have a higher methane generation potential. Constraints in availability of data and assumptions used to address the same contribute to the step change observed in emissions from 2010 to 2011. In the domestic wastewater emission calculations, Census 2001 data on the use of different wastewater discharge/treatment systems by rural households in each of the states has been used in the estimation from year 2005-2010 since data is not available for these years. For the estimates from 2011 until 2015, Census 2011 data on use of different wastewater discharge/treatment systems has been used. Since the proportion of population using different wastewater treatment systems (such as septic tanks, latrines, sewer systems, direct discharge without treatment) changes in year 2011 across the states as compared to the preceding years, the relatively higher change in observed for this year.

3. Waste

3.1 Overview of the sector

Waste management activities such as collection, treatment and disposal of solid waste and wastewater lead to GHG emission in the form of CH_4 and N_2O gases. Waste sector emissions are a result of the degradation of organic material under anaerobic conditions. Based on the reporting structure of the 2006 IPCC Guidelines for National GHG inventories, key sources of GHG emission in the Waste sector include 4A2 Unmanaged waste disposal sites, 4D1 domestic wastewater treatment and discharge and 4D2 industrial wastewater treatment and discharge.

- The aggregated GHG emissions from the Waste sector in India in the year 2015 were 96.92 Mil. tonnes of CO_2e, an increase of 50.8% (or 32.66 Mil. tonnes of CO_2e) from 2005.
- Within the sector, domestic wastewater treatment and discharge emissions grew by 39.3% (or 17.20 Mil. tonnes of CO_2e).
- GHG emissions from industrial wastewater treatment and discharge in 2015 were 24.22 Mil. tonnes of CO_2e. Industrial wastewater related emissions increased by 80.9% (or 10.83 Mil. tonnes of CO_2e) from 2005 to 2015.
- Solid waste disposal contributed to GHG emission of 11.67 Mil. tonnes of CO_2e in the year 2015. Emissions from solid waste disposal have increased by 65.6% (an absolute increase of 4.62 Mil. tonnes of CO_2e) from the base year 2005.

Table 6: Aggregated GHG emission estimates for the Waste sector for 2005 and 2015

IPCC ID	Source Category	GHG Emission (Mil. tonnes of CO_2e) based on Global Warming Potential values from IPCC Second Assessment Report (SAR)[6]			GHG Emission (Mil. tonnes of CO_2e) based on Global Warming Potential values from IPCC Fifth Assessment Report (AR5)[7]		
		2005	2015	Percent change (2005-2015)	2005	2015	Percent change (2005-2015)
4	**Waste**	**64.26**	**96.92**	**50.8%**	**78.19**	**120.14**	**53.7%**
4A	**Solid Waste Disposal**	**7.05**	**11.67**	**65.6%**	**9.39**	**15.56**	**65.6%**
4A2	Unmanaged Waste Disposal Sites	7.05	11.67	65.6%	9.39	15.56	65.6%
4D	**Wastewater Treatment and Discharge**	**57.21**	**85.25**	**49.0%**	**68.79**	**104.58**	**52.0%**
4D1	Domestic Wastewater Treatment and Discharge	43.82	61.03	39.3%	50.94	72.28	41.9%
4D2	Industrial Wastewater Treatment and Discharge	13.39	24.22	80.9%	17.85	32.30	80.9%

Source: Author's analysis

[6] 100-year GWP values specified for the 3 GHGs considered for the Waste Sector are CO_2: 1, CH_4: 21, N_2O: 310 as per the IPCC Second Assessment Report, 1996, Technical Summary, Table 4.
Available at https://www.ipcc.ch/ipccreports/sar/wg_I/ipcc_sar_wg_I_full_report.pdf

[7] 100-year GWP values specified for the 3 GHGs considered for the Waste Sector are CO_2: 1, CH_4: 28, N_2O: 265 as per the IPCC Fifth Assessment Report, 2014, Climate Change 2014: Synthesis Report, Box 3.2, Table.
Available at https://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full.pdf

3.2 Analysis of sectoral emissions

Treatment and discharge of domestic wastewater is the largest source of GHG emissions in India's Waste Sector, contributing to 63% of the aggregated state-level emissions from the sector in 2015. With a share of 25% in 2015, industrial wastewater treatment and discharge was the second largest contributor to the total Waste sector GHG emissions. Solid waste disposal accounted for 12% of the country's cumulative Waste sector GHG emissions in 2015.

GHG emissions from all three source categories have shown an increasing trend from 2005 to 2015, with cumulative emissions from the Waste sector rising at a CAGR of 4.2% in this period. The trend of the overall aggregate emission is observed to be quite steady with a relatively higher rise between for the year 2010 and 2011 (see Table 7), which can be correlated with the corresponding increase in the estimated state-level domestic wastewater emissions[8].

Table 7: Waste Sector GHG emission estimates by source category, 2005-2015

IPCC ID	Source Category	GHG Emission (Mil. tonnes of CO_2e)										
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
4	**Waste**	**62.79**	**64.73**	**66.92**	**68.91**	**70.87**	**72.99**	**84.08**	**86.94**	**89.52**	**92.20**	**94.26**
4A	Solid Waste Disposal	7.05	7.55	8.03	8.51	8.98	9.45	9.92	10.37	10.85	11.26	11.67
4A2	Unmanaged Waste Disposal Sites	7.05	7.55	8.03	8.51	8.98	9.45	9.92	10.37	10.85	11.26	11.67
4D	**Wastewater Treatment and Discharge**	**57.21**	**58.75**	**60.54**	**62.16**	**63.76**	**65.54**	**76.28**	**78.87**	**81.11**	**83.54**	**85.25**
4D1	Domestic Wastewater Treatment and Discharge	43.82	44.53	45.24	45.90	46.51	47.23	56.90	7.92	58.94	60.04	61.03
4D2	Industrial Wastewater Treatment and Discharge	13.39	14.22	15.30	16.26	17.25	18.30	19.38	20.95	22.17	23.50	24.22

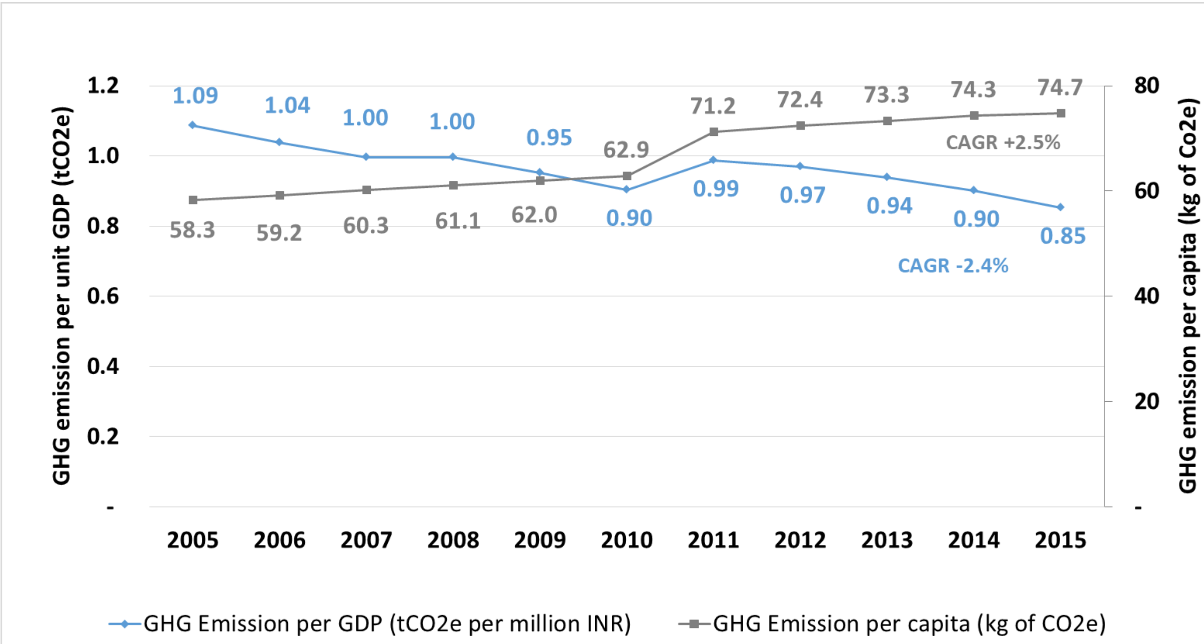
Source: Author's analysis

The emission intensity of the Waste sector emissions, in terms of aggregate GHG emission per unit GDP, is observed to have decreased by 22% in 2015 as compared to the base year of 2005, falling at a CAGR of -2.4% over the reporting period between 2005 to 2015 (see Figure 4). Per capita emissions from the Waste sector, estimated based on aggregated state-level emissions, increased from 58.3 kg of CO_2e in year 2005 to 74.7 kg of CO_2e in the year 2015. The per capita

[8] The overall increase in state-level GHG emissions from domestic wastewater over the reporting period from 2005-2015 is driven by the growing population and changing patterns of use of different treatment systems such as septic tanks, which have a higher methane generation potential. Constraints in availability of data and assumptions used to address the same contribute to the step change observed in emissions from 2010 to 2011. In the domestic wastewater emission calculations, Census 2001 data on the use of different wastewater discharge/treatment systems by rural households in each of the states has been used in the estimation from year 2005-2010 since data is not available for these years. For the estimates for the period from 2011-2015, Census 2011 data on use of different wastewater discharge/treatment systems has been used. Since the proportion of population using different wastewater treatment systems (such as septic tanks, latrines, sewer systems, direct discharge without treatment) changes in year 2011 across the states as compared to the preceding years, the relatively higher change in observed for this year.

emissions from the Waste sector are estimated to have increased at a CAGR of 2.5% per annum from 2005 to 2015. The higher increase in per capita emissions in year 2011 is linked to the corresponding rise in the state domestic wastewater emissions due to use of different activity dataset from this year onward as indicated earlier.

Figure 4: Trend of GHG emission per unit GDP* and per capita emissions for Waste sector, 2005-2015



Source: Author's analysis based on GDP data from MOSPI Statistics[9]

**<u>Note</u>: Since GDP is reported on financial year basis, the GDP data for 2005-06 has been used to estimate the emission intensity for 2005, GDP data for 2006-07 has been used to estimate the emission intensity for 2006 and so on. GDP emission intensity reported in tonnes of CO_2e per Million INR at constant 2011-12 prices.*

The trends observed and related analysis for each source category considered in the emission estimates is presented in the following sections here.

3.2.1 4A Solid Waste Disposal

Disposal of municipal solid waste contributed to cumulative GHG emission of 11.67 Mil. tonnes of CO_2e in 2015 as against 7.05 Mil. tonnes of CO_2e in 2005 across the Indian states, rising at a CAGR of 5.2% over this period. CH_4 emission due to solid waste disposal is estimated to have increased by 65.6% from the year 2005 to 2015.

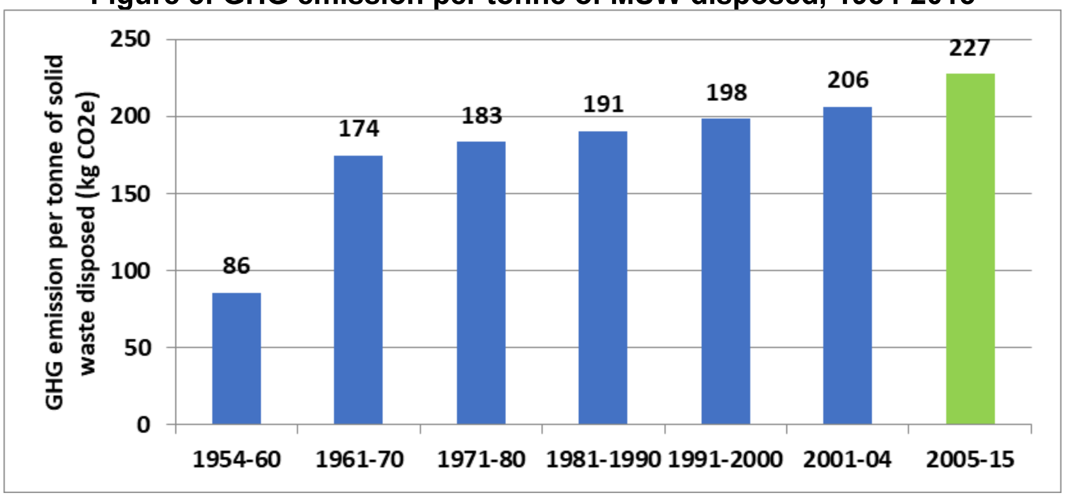
---

[9] GDP for 2004-05 to 2010-11 based on GDP data from Ministry of Statistics & Programme Implementation, 2018. National accounts Statistics: Back-Series 2004-05 to 2011-12, Statement 1.2, Page 20. Accessed from http://pibphoto.nic.in/documents/rlink/2018/nov/p2018112801.pdf. GDP for 2011-12 to 2015-16 based on GDP data from CSO, MOSPI, 2019. Press Note on First Revised Estimates of National Income, Consumption Expenditure, Saving and Capital Formation for 2017-18, Statement 1.2. Accessed from http://www.mospi.nic.in/sites/default/files/press_release/FRE%20of%20National%20Income%2C%20Consumption%20Expenditure%2C%20Saving%20and%20Capital%20Formation%20For%202017-18_0.pdf

Rising trends in GHG emission are primarily due to changes in the total quantum of solid waste, its composition, and the method of disposal and characteristics related to the disposal site. In the short-term for the reporting period from 2005-2015, the rise in solid waste disposal emissions is driven by increasing waste generation rates and growing population, resulting in higher quantum of solid waste going to disposal sites. The per capita solid waste generation has been growing by 1.2% per year[10] based on per capita generation values reported for 1991 and 2007 respectively.

Over the long-term, waste composition in Indian cities has undergone a change over the years with urbanization– leading to an increase not only in the consumption of paper, paper packaging, plastics and consumer products, but also an increase in the biodegradable waste (reflected by the total compostable matter). The changing waste composition has impacted the quantum of emissions generated due to MSW disposal over the decades, with higher emissions generated from every tonne of waste that is being disposed. The GHG emissions per tonne for solid waste disposed (on aggregated state-level basis) have increased by 2.7 times, rising from 85 kg of CO_2e per tonne of solid waste disposed on average during 1954-60[11] to 227 kg of CO_2e per tonne of solid waste disposed during 2005-2015 (refer Figure 5).

Figure 5: GHG emission per tonne of MSW disposed, 1954-2015



Source: Author’s analysis based on emission estimates

<u>Note:</u> GHG emission per tonne for solid waste disposed (state- aggregates) for the emission estimation period of this exercise is depicted by the green coloured bar in Figure 5 while the historic long term trend of GHG emission per tonne of waste disposed that results from the FOD method for the previous 50-year period is depicted by grey coloured bars.

---

[10] This number indicates simple annual growth rate as estimated in Table 17 of this note based on reported per capita waste generation for 1991 and 2005. CAGR growth rates have been indicated as such in the note and all other growth rates mentioned throughout this document refer to simple growth rates.

[11] This analysis and insight into long-term emission related trends for solid waste is a result of the first order decay (FOD) method being followed in this exercise for estimation of emissions from solid waste disposal. The FOD method considers that waste deposited in a disposal site at a point in time decomposes gradually and continues to undergo anaerobic digestion again and generate CH_4 over a long period of time (around 50 years). CH_4 emission will be generated until the waste deposited in the disposal site decomposes completely and reaches its full methane generation potential. Therefore, to fully account for emissions from solid waste disposal in our exercise for year 2005, it is necessary to estimate emissions for a 50-year period before this year i.e. from 1954-2004.

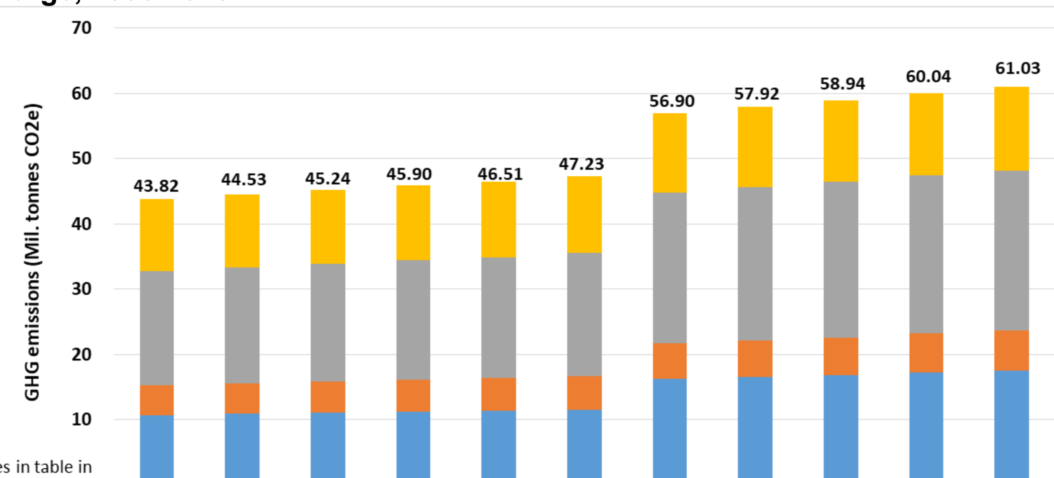
3.2.2 4D1 Domestic Wastewater Treatment and Discharge

Domestic wastewater treatment and discharge contributed to cumulative GHG emissions of 61.02 tCO_2e in 2015 as compared to 43.82 tCO_2e in 2005. Emissions from this source category have increased by 39.3% on absolute basis from the year 2005 to 2015. Aggregated state-level GHG emissions from domestic wastewater have increased at a CAGR of 3.06% from 2005 to 2015.

The total domestic wastewater related emissions from urban and rural areas are presented in Figure 6. Emissions from rural domestic wastewater are seen to contribute to around 61% to 65% of the state aggregate emissions from domestic wastewater across the period from 2005 to 2015. The rural population, however, accounted for 72.19% and 68.85% of aggregated state population of India in the year 2001 and 2011 respectively. Therefore, given that relatively smaller number of the country's population is residing in urban areas, the corresponding per capita GHG emission generated from urban domestic wastewater is considerably higher. Per capita GHG emissions from domestic wastewater for the urban population were 55.29 kg CO_2e as compared to 42.66 kg CO_2e for the rural population in the year 2015. Thus, per capita emissions from urban domestic wastewater are about 29.6% higher as compared to per capita GHG emission from rural domestic wastewater in 2015.

With regard to urban domestic wastewater, CH_4 emissions are estimated to be much higher than N_2O emissions, accounting for 73.87% of the total GHG emission in 2015. CH_4 is emitted from wastewater when it is treated or disposed anaerobically. Therefore, CH_4 emissions have a direct correlation with the percentage of wastewater that is treated or discharged through different systems or pathways. CH_4 emission is also influenced by the income-levels since the accessibility and usage of different wastewater treatment systems/pathways varies by income-groups.

Figure 6: Aggregate GHG emission from Urban and Rural Domestic wastewater treatment and discharge, 2005-2015



All values in table in Mil. tonnes of CO2e	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
N2O emission (Rural)	11.09	11.22	11.35	11.49	11.60	11.73	12.17	12.33	12.50	12.66	12.82
CH4 emission (Rural)	17.49	17.76	18.04	18.31	18.59	18.86	23.06	23.46	23.87	24.19	24.59
N2O emission (Urban)	4.57	4.70	4.83	4.96	5.01	5.14	5.45	5.63	5.81	5.99	6.17
CH4 emission (Urban)	10.68	10.85	11.02	11.14	11.31	11.50	16.22	16.49	16.77	17.20	17.44

Source: Author's analysis

CAGR of CH_4 emission from urban domestic wastewater over the reporting period of 2005-2015 is observed to be 4.56%. According to latest Census data in 2011, the proportion of urban population is 31.15% in 2011, a rise of 12%, in comparison to 2001 (27.81%). This higher proportion of urban population in 2011 also, implies an increase of 41% in the estimation of CH_4 emissions for 2011 as compared to 2010. The average annual growth rate of CH_4 emission drops down to about 1.47% from 2011-2015, in line with the steady population growth considered in the emission calculations.

N_2O emissions have a direct correlation with the human protein consumption and the size of urban population consuming this protein. Protein is a source of nitrogen and N_2O emissions occur on degradation of this nitrogen in the wastewater. Urban N_2O emissions show a steady trend in line with the steadily rising nutritional intake of protein and the increase in urban population over the years. N_2O emissions from urban domestic wastewater are observed to grow at a CAGR of 2.8% over the reporting period of 2005-2015.

Looking at rural areas, CH_4 emission from rural domestic wastewater has increased at a CAGR of 3.15% over the period 2005-2015, with CH_4 emission rising from year 2011 onwards in particular. The higher emissions are likely caused due to the increase in the volume of wastewater handled in rural areas as reported in Census 2011, especially in terms of the total percent of rural households connected to septic tanks across the states. State contribution to the overall rural domestic wastewater CH_4 emission is closely correlated with the size of the rural population. N_2O emissions from rural domestic wastewater show a steady growth, with a CAGR of 1.33% over the reporting period of 2005-2015.

3.2.3 4D2 Industrial Wastewater Treatment and Discharge

GHG emission estimates for industrial wastewater include 11 industrial sectors - Fertilizers, Meat, Sugar, Coffee, Pulp and Paper, Petroleum, Rubber, Dairy, Tannery, Iron and Steel, and Fish processing. Production in all 11 of these sectors results in generation of wastewater with significant organic load with potential to release CH_4 emissions, which is dependent on the type of wastewater treatment.

In the absence of recorded information on sector-wise volume of wastewater generated by industries across the Indian states, industrial production is a key parameter required to estimate the total wastewater generation[12] by industry sector and the CH_4 emission resulting from its degradable organic concentration and the treatment technology used. However, during the assessment it was observed that the requisite industrial production data for the 11 industrial sectors under consideration is not available in a single source dataset, thereby necessitating the use of multiple data sources for each of the industrial sectors. A number of issues have been observed with regard to the availability, reliability and quality of reported activity data on state-level industrial production in particular. This has necessitated of the use of apportionment or approximation in the emission estimation process for 9 of the 11 industry sectors. The inherent

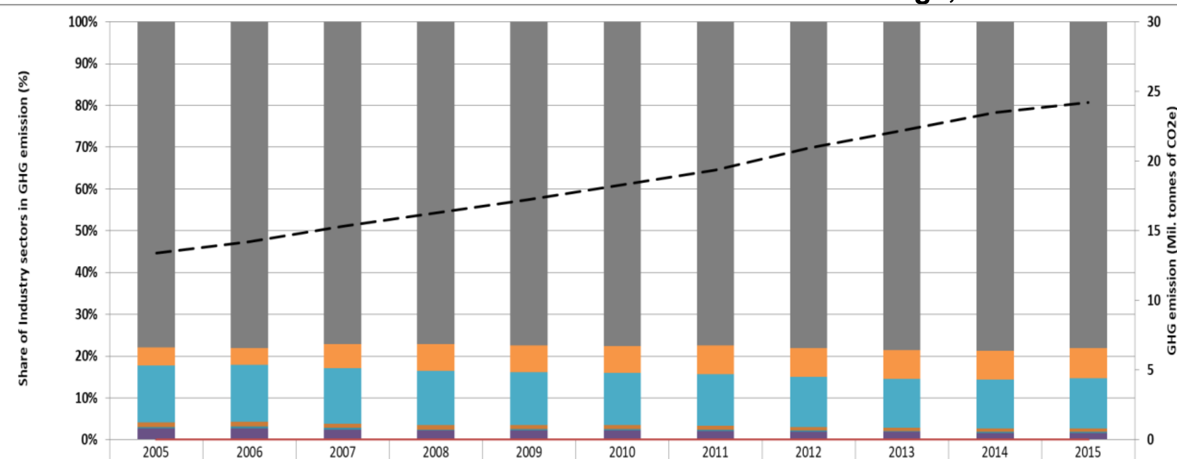
---

[12] Total annual volume of wastewater generated (in cubic meters) is estimated based on the industrial production (in tonnes) and the unit wastewater generation per tonne of product (cubic meters/tonne) based on the methodology outlined in the 2006 IPCC Guidelines for National GHG Inventories, Vol.5, Chapter 6 - Wastewater treatment and discharge, Table 6.3.
Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

inconsistencies and low reliability of data has impacted the reliability of the GHG estimates and also limits inferences that can be drawn from the emission trends.

The cumulative GHG emission from industrial wastewater treatment and discharge has increased from 13.39 Mil. tonnes CO_2e in 2005 to 24.22 Mil. tonnes CO_2e in 2015, at a CAGR of 6.1%. The Pulp and Paper sector is observed to have the highest contribution to GHG emissions from industrial wastewater treatment and discharge.

Figure 7: GHG Emission from Industrial wastewater treatment and discharge, 2005-2015



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Pulp & Paper	77.4%	77.6%	76.7%	76.8%	77.0%	77.2%	77.1%	77.8%	78.2%	78.4%	77.8%
Meat	4.3%	4.0%	5.8%	6.4%	6.4%	6.4%	6.8%	6.8%	6.8%	6.9%	7.2%
Dairy	13.5%	13.5%	13.2%	12.9%	12.6%	12.4%	12.3%	11.8%	11.6%	11.6%	12.0%
Petroleum	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Coffee	1.2%	1.1%	1.0%	1.0%	1.0%	0.9%	0.9%	0.9%	0.8%	0.8%	0.8%
Sugar	0.3%	0.5%	0.4%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
Fertilizers	2.6%	2.8%	2.4%	2.2%	2.2%	2.2%	2.1%	1.9%	1.8%	1.6%	1.6%
Iron & Steel	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Rubber	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Tannery	0.6%	0.6%	0.6%	0.5%	0.5%	0.5%	0.5%	0.4%	0.4%	0.4%	0.4%
Fish processing	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total CO2e emissions (Mil. tonnes)	13.39	14.22	15.30	16.26	17.25	18.30	19.38	20.95	22.17	23.50	24.22

Source: Author's analysis

The cumulative percentage change in emissions in 2015 over the 2005 baseline values along with corresponding increase in industrial production, for each industry sector is given in Table 8. Due to unavailability of latest year-on-year values for wastewater generation per unit of product, constant values are used for the industry sectors in this assessment (see section 3.7.2 for more details). Use of such constant values for wastewater generation per unit product results in limitations in estimations as it restricts capturing impacts of improvements in process and technology in the industry sectors on wastewater generation and GHG emissions. Thereby, the growth in estimated GHG emission matches the corresponding increase in industrial production across all the industry sectors.

Table 8: Change in Production and Wastewater emission by industry sector, 2005-2015

Industry Sector[13]	Increase in Production (2005 to 2015)	Increase in GHG emissions (2005 to 2015)
Fertilizers	8.8%	8.8%
Sugar	47.9%	47.9%
Coffee	24.9%	24.9%
Dairy	59.7%	59.7%
Meat	204.7%	204.7%
Pulp & Paper	81.7%	81.7%
Tannery	23.0%	23.0%

Source: Author's analysis

The Pulp & paper, Coffee, Meat and Tannery sectors are critical sectors, having higher GHG emission per tonne of product or per unit volume of treated wastewater.

Table 9: Average industrial wastewater GHG emission per tonne of product and per m3 of wastewater generated for Industrial Sectors in India (2005-2015)

Industry Sector[14]	GHG emission per tonne of product (kg of CO_2e)	GHG emission per m^3 of wastewater generated (kg of CO_2e)
Coffee	567.00	37.80
Pulp & Paper	1071.00	8.40
Meat	245.70	21.00
Tannery	165.37	4.72
Fertilizers	25.20	3.15
Sugar	2.52	6.30
Dairy	18.90	3.15

Source: Author's analysis

3.3 State-wise analysis of emissions

Six states of Uttar Pradesh, Maharashtra, Gujarat, Andhra Pradesh, Tamil Nadu, and West Bengal contribute to 56% of total sectoral emissions over the period from 2005 to 2015. The high share of emissions can be correlated to higher population size in these large states leading to higher volumes of solid waste and domestic wastewater being generated and thereby higher GHG emissions. These states also have higher industrial activity levels and wastewater generation, with prominence of Pulp & paper industry in particular which generates high organic wastewater volumes and results in high industrial wastewater emissions.

[13] In the assessment, the condition of the prevalent aerobic type wastewater treatment systems for Iron & Steel, Petroleum, Rubber, and Fish processing industries is assumed to be well managed, and thereby these systems have Methane Correction Factor value of zero and thereby an emission factor value of zero (based on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories), thereby leading to no CH_4 emissions from wastewater treatment. Thus, the Iron & Steel, Petroleum,Rubber, and Fish processing sectors are not included in Table 7.

[14] In the assessment, the condition of the prevalent aerobic type wastewater treatment systems for Iron & Steel, Petroleum, Rubber, and Fish processing industries is assumed to be well managed, and thereby these systems have Methane Correction Factor value of zero and thereby an emission factor value of zero (based on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories), thereby leading to no CH_4 emissions from wastewater treatment. Thus, the Iron & Steel, Petroleum, Rubber, and Fish processing sectors are not included in Table 8.

Table 10: GHG estimates by State for Waste sector, 2005-2015

Name of the state	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Andaman & Nicobar	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04
Andhra Pradesh	5.21	5.39	5.57	5.73	6.01	6.18	7.19	7.55	7.78	5.65	5.41
Arunachal Pradesh	0.06	0.06	0.07	0.07	0.06	0.07	0.08	0.08	0.08	0.08	0.09
Assam	1.30	1.33	1.36	1.39	1.42	1.44	1.58	1.65	1.71	1.79	1.84
Bihar	3.06	3.13	3.20	3.27	3.29	3.36	4.00	4.10	4.21	4.32	4.43
Chandigarh	0.09	0.10	0.10	0.17	0.17	0.18	0.25	0.26	0.26	0.26	0.27
Chhattisgarh	0.91	0.94	0.97	1.00	1.02	1.05	1.25	1.30	1.34	1.37	1.39
Dadra & Nagar Haveli	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03
Daman & Diu	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03
Delhi	1.28	1.33	1.39	1.41	1.43	1.48	1.70	1.76	1.81	1.85	1.91
Goa	0.11	0.11	0.11	0.12	0.12	0.13	0.15	0.15	0.16	0.16	0.17
Gujarat	4.68	4.87	5.05	5.20	5.42	5.69	6.47	6.89	7.22	7.47	7.60
Haryana	1.20	1.25	1.32	1.36	1.40	1.47	1.98	2.03	2.08	2.12	2.17
Himachal Pradesh	0.32	0.33	0.34	0.35	0.37	0.39	0.50	0.51	0.52	0.53	0.52
Jammu & Kashmir	0.54	0.56	0.58	0.60	0.62	0.65	0.75	0.78	0.80	0.82	0.83
Jharkhand	0.97	1.00	1.03	1.06	1.07	1.10	1.24	1.27	1.30	1.34	1.37
Karnataka	3.08	3.20	3.30	3.39	3.54	3.64	4.16	4.29	4.37	4.49	4.62
Kerala	2.56	2.62	2.68	2.74	2.81	2.89	2.95	3.02	3.10	3.23	3.31
Lakshadweep	0.02	0.02	0.03	0.04	0.04	0.04	0.09	0.11	0.11	0.03	0.01
Madhya Pradesh	2.92	3.00	3.08	3.15	3.24	3.33	3.84	3.94	4.03	4.33	4.51
Maharashtra	6.98	7.22	7.50	7.70	8.01	8.28	9.01	9.25	9.44	9.77	10.02
Manipur	0.10	0.11	0.11	0.11	0.10	0.11	0.14	0.14	0.14	0.15	0.15
Meghalaya	0.12	0.12	0.13	0.13	0.13	0.13	0.16	0.16	0.17	0.17	0.18
Mizoram	0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.09	0.09	0.09	0.09
Nagaland	0.11	0.11	0.10	0.11	0.11	0.11	0.15	0.15	0.15	0.15	0.14
Odisha	1.84	1.90	1.95	2.00	2.09	2.16	2.39	2.42	2.47	2.56	2.72
Puducherry	0.09	0.09	0.10	0.10	0.11	0.11	0.12	0.13	0.13	0.14	0.14
Punjab	2.39	2.50	2.61	2.74	2.84	2.97	3.83	3.93	4.10	4.19	4.16
Rajasthan	2.97	3.03	3.10	3.17	3.23	3.30	3.83	3.92	4.04	4.16	4.25
Sikkim	0.04	0.04	0.03	0.03	0.03	0.04	0.05	0.05	0.05	0.05	0.05
Tamil Nadu	5.04	5.22	5.43	5.60	5.87	6.08	6.54	6.82	7.18	7.46	7.67
Telangana	-	-	-	-	-	-	-	-	-	2.32	2.57
Tripura	0.14	0.15	0.15	0.16	0.17	0.17	0.19	0.19	0.20	0.20	0.21
Uttar Pradesh	9.93	10.24	10.63	10.99	11.09	11.45	13.46	14.00	14.54	14.95	15.32
Uttrakhand	1.29	1.39	1.46	1.54	1.62	1.75	2.04	2.12	2.09	2.17	2.30
West Bengal	4.77	4.83	4.98	5.11	5.19	5.14	5.93	6.11	6.20	6.31	6.39
Total GHG emissions	**64.26**	**66.29**	**68.57**	**70.67**	**72.75**	**74.99**	**86.19**	**89.25**	**91.97**	**94.80**	**96.92**

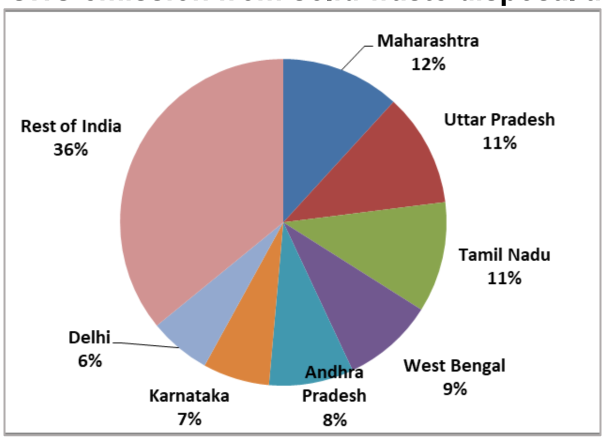
Source: Author's analysis

Key trends and insights at the state-level for each source category are presented in the sections below.

3.3.1 4A Solid Waste Disposal

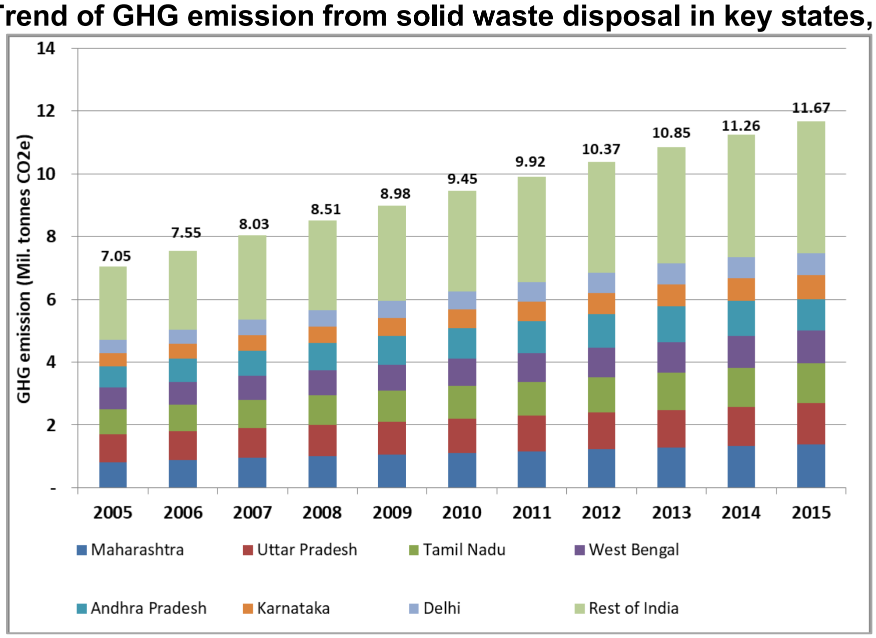
Seven states of Maharashtra, Uttar Pradesh, Tamil Nadu, West Bengal, Andhra Pradesh, Karnataka, and Delhi contribute nearly 66% of the total municipal solid waste disposal related GHG emissions from 2005 to 2015 (see Figure 8). One-third of the country's solid waste emissions in 2015 are from the three states of Maharashtra, Uttar Pradesh, and Tamil Nadu. The states with high emission share have a large population size and thereby a higher volume of solid waste being generated, which results in a large quantum of organic waste going to disposal. An increasing trend is observed in the GHG emission from solid waste disposal across the top seven states, driven by rising population, relatively higher rate of waste generation rate per capita, and inadequate levels of waste processing over the emission estimation period. State-wise GHG emission from solid waste disposal from 2005 to 2015 is given in Appendix 6.2.

Figure 8: Share of GHG emission from solid waste disposal across states, 2015



Source: Author's analysis

Figure 9: Trend of GHG emission from solid waste disposal in key states, 2005-2015

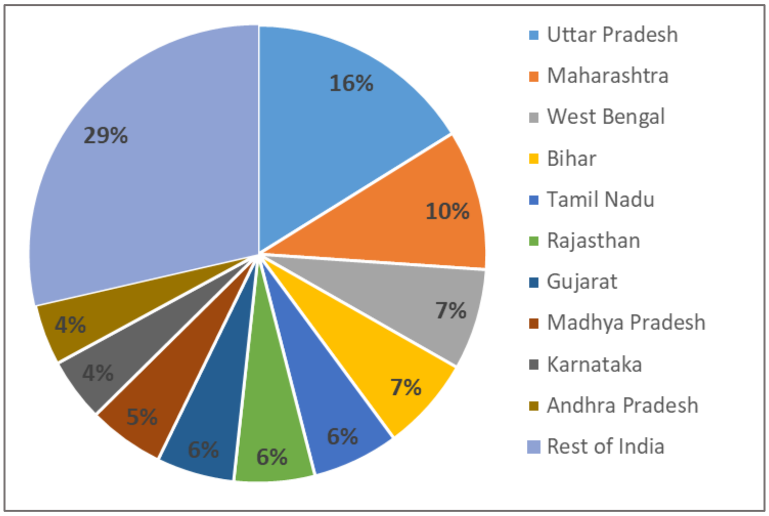


Source: Author's analysis

3.3.2 4D1 Domestic Wastewater Treatment and Discharge

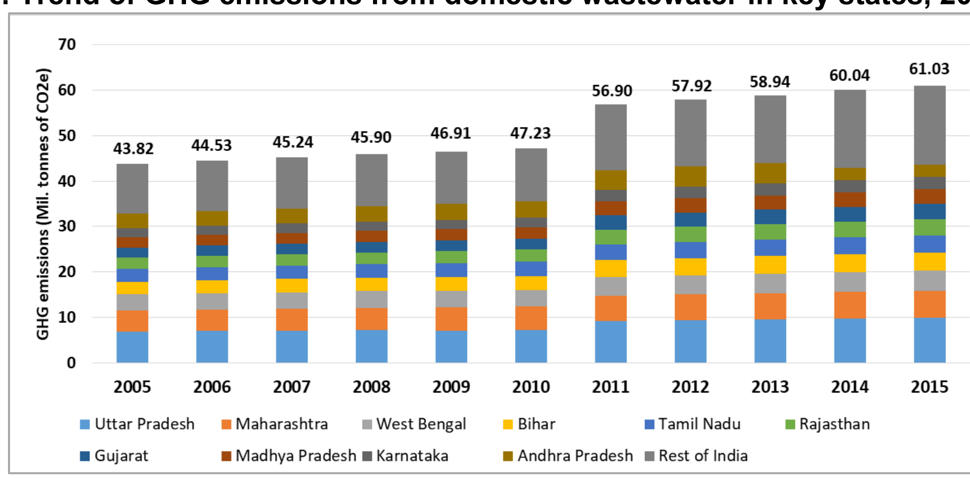
Ten states including Uttar Pradesh, Maharashtra, West Bengal, Bihar, Tamil Nadu, Rajasthan, Gujarat, Madhya Pradesh, Karnataka and Andhra Pradesh contributes to around 75% of GHG emissions during the year 2005 to 2015 (see Figure 10). Uttar Pradesh has the highest contribution at approx. 16%, followed by Maharashtra which contributes to 10% of the total GHG emissions. The key states rank high in terms of population size as well and given that the volume of wastewater generated is directly dependent on the size of the population, they generate higher emissions. GHG emission from domestic wastewater has shown an increasing trend across the top ten states (with highest GHG contribution) from 2005 to 2015, with cumulative emissions increasing at CAGR of 2.84% over this period. Year wise GHG emission due to domestic waste water disposal and treatment across the states is given in Appendix 6.8.

Figure 10: Share of GHG emissions from domestic wastewater across states, 2015



Source: Author's analysis

Figure 11: Trend of GHG emissions from domestic wastewater in key states, 2005-2015



Source: Author's analysis

CH_4 emissions are dependent on how wastewater is handled in urban and rural areas, having a direct correlation with the proportion of waste water that is discharged or treated through different systems or pathways. Over the period from 2005 to 2015, the connectivity of the sewer network has improved across the states along with the volume of wastewater that is collected and treated. The connectivity to septic tank systems has also witnessed an increasing trend in the states. The improved connectivity and increase in treatment facilities has resulted in decrease of untreated wastewater finding its way to the ground or to water bodies.

CH4 Emissions from Urban Domestic Wastewater

Distribution of CH_4 emissions in urban areas for year 2015 by type of treatment/discharge system across states that rank in the top five highest emitters is given in Table 11. It is seen that septic tanks are the largest contributor to absolute emissions in the top five states (Uttar Pradesh, Maharashtra, West Bengal, Tamil Nadu, and Gujarat), accounting for 53.80% of the aggregated CH_4 emissions in these states. Emissions from septic tanks range from 18.73% to 77.43% across the top five emitting states in 2015. These emissions are correlated to the significant utilization (i.e. the proportion of population using a certain treatment system) reported for septic tanks in these five states, ranging from 24.20% to 46.90% (see Figure 12).

About 48% of the urban households on average are connected to septic tanks across the Indian states on average as per data from Census 2011 (Ministry of Home Affairs, 2012). Septic tanks are generally on-site treatment systems having a relatively higher CH_4 emission generation potential (methane correction factor value of 0.5[15]) and thereby contribute significantly to emissions from urban domestic wastewater. Connecting septic tanks with the sewer network and treating the wastewater aerobically downstream in well-managed treatment plants can reduce emissions.

Aerobic treatment systems and public latrines rank second (15.26%) and third (11.26%) in terms of contribution to the total CH_4 emissions from urban domestic wastewater across top five emitting states. Public latrine systems have a high methane correction factor value of 0.5 and therefore are a key contributor to CH_4 emissions. CH_4 emissions from aerobic treatment systems are high because the existing aerobic treatment based sewage treatment plants in the country are not being well managed. The 'methane correction factor' value for 'not well managed aerobic systems' is 0.3 as against a 'methane correction factor' value of 0 (and therefore no CH_4 emission) for 'well managed aerobic treatment systems'[15]. Therefore, it is important to manage aerobic treatment systems effectively. Further, some portion of urban wastewater that is collected through the sewer network is not treated downstream (i.e. sewer - collected & not treated category) due to insufficient installed capacity and operational inefficiencies of STPs. Such wastewater that is collected through sewer systems but does not flow to a sewage treatment plant usually stagnates and leads to CH_4 emission contributing to 4.69% of the total CH_4 emissions from urban wastewater across the leading emission states[16].

[15] MCF values indicated in Table 38 of this note and based on the 2006 IPCC Guidelines, Vol.5, Chapter 6 - Wastewater treatment and discharge, Table 6.3.
Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

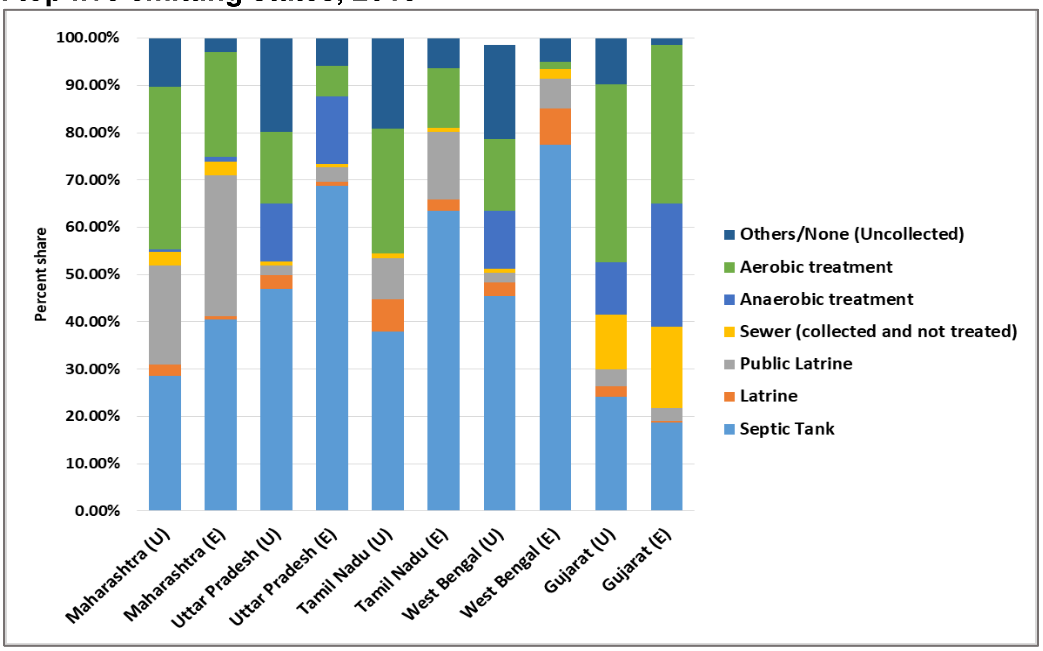
[16] Constraints in data availability limit the inferences that can be drawn from trends with regards to the implications of better access to wastewater collection and treatment systems. Year-on-year information on distribution of wastewater treatment systems is not available and constant values have been used for degree of utilization for the urban population in the states across the reporting period.

Table 11: Share of Urban CH_4 Emission in the top five emitting states by type of treatment/discharge system, 2015

State/Union Territory	Septic Tank	Latrine	Public Latrine	Sewer (collected and not treated)	Anaerobic treatment	Aerobic treatment	Others/None (Uncollected)
Maharashtra	40.50%	0.68%	29.73%	2.95%	1.00%	22.25%	2.89%
Uttar Pradesh	68.82%	0.85%	3.08%	0.63%	14.22%	6.58%	5.81%
Tamil Nadu	63.51%	2.31%	14.41%	0.83%	0.00%	12.50%	6.43%
West Bengal	77.43%	7.71%	6.31%	1.99%	0.00%	1.55%	5.01%
Gujarat	18.73%	0.33%	2.79%	17.06%	26.18%	33.42%	1.50%
Aggregate for top five emitting states	**53.80%**	**2.38%**	**11.26%**	**4.69%**	**8.28%**	**15.26%**	**4.33%**

Source: Author's analysis

Figure 12: CH_4 emissions and utilization of different treatment/discharge systems for urban areas in top five emitting states, 2015



Source: Author's analysis

CH_4 Emissions from Rural Domestic Wastewater

In rural areas, given the minimal closed sewer network (approximately 95% of domestic wastewater is either conveyed through open drains or is not collected at all as per data from Census 2011 (Ministry of Home Affairs, 2012)) and the absence of wastewater treatment facilities, domestic wastewater is not handled or treated downstream and decomposes under aerobic conditions, thereby not leading to CH_4 emissions. Emissions are largely driven by direct discharge of wastewater into 'ground' and 'rivers, lakes, estuaries, sea' without any kind of treatment (i.e. Others/None category) and by septic tank systems. This is evident in the top five CH_4 emitting states of Uttar Pradesh, Maharashtra, Andhra Pradesh, West Bengal and Bihar as well, with a large proportion of the rural population estimated to discharge wastewater without treatment in the absence of wastewater collection systems (see Figure 13).

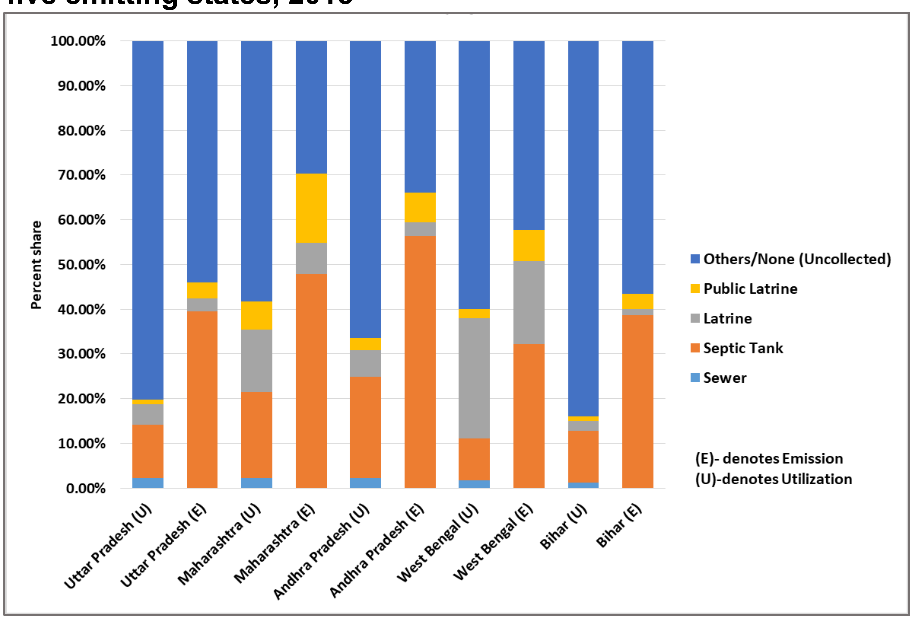
Distribution of CH_4 emissions in rural areas for year 2015 by type of treatment/discharge system across the top five highest emitting states is given in Table 12. It is seen that the 'Others/None' category contributes to 43.29% of the cumulative emissions in 2015 for the top five states. This is largely driven by the fact that 69.78% of rural households across the above-mentioned states on average are utilizing this mode of wastewater discharge in the absence of wastewater collection systems. Septic tank systems are used by 14.94% of the rural population on average to handle domestic wastewater as per Census 2011 (Ministry of Home Affairs, 2012) and contributed to 42.89% of the total CH_4 emissions from rural domestic wastewater in the top five emitting states in 2015. Latrine and public latrine systems serve 10.74% and 2.60% of rural population as per Census 2011 and contribute to 6.61% and 7.21% of emissions respectively across the Indian states. However, the emissions from public latrine are comparatively higher due to the fact that the MCF of public latrine systems as defined in the 2006 IPCC Guidelines is 0.5 as compared to a MCF value of 0.1 for latrine systems[15].

Table 12: Share of Rural CH_4 Emission in the top five emitting states by type of treatment/discharge system, 2015

State/Union Territory	Septic Tank	Latrine	Public Latrine	Others/None (Uncollected)
Uttar Pradesh	39.47%	2.96%	3.62%	53.95%
Maharashtra	47.83%	7.03%	15.45%	29.70%
Andhra Pradesh	56.37%	2.99%	6.73%	33.90%
West Bengal	32.18%	18.62%	6.92%	42.28%
Bihar	38.61%	1.46%	3.33%	56.60%
Aggregate for top five emitting states	42.89%	6.61%	7.21%	43.29%

Source: Author's analysis

Figure 13: CH_4 emissions and utilization of different treatment/discharge systems for rural areas in top five emitting states, 2015



Source: Author's analysis

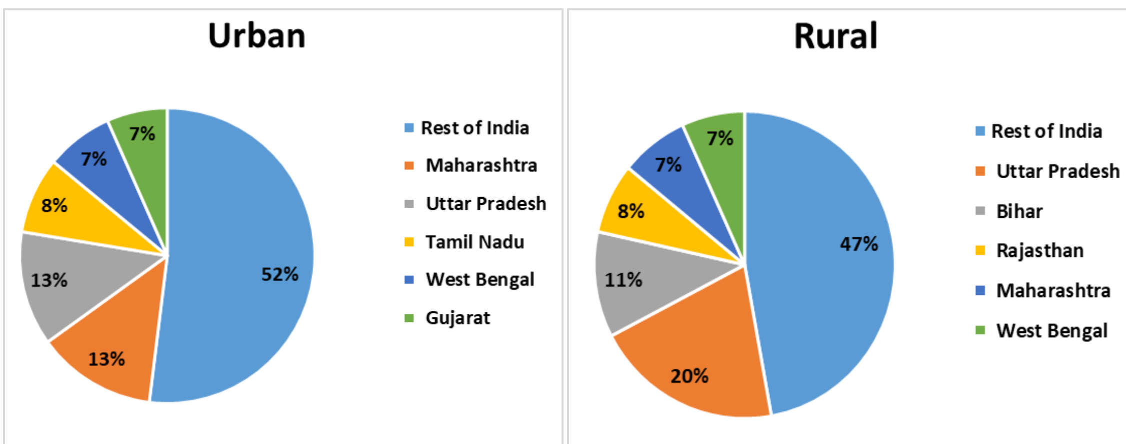
N_2O emissions from domestic wastewater

As indicated previously, N_2O emissions are dependent on the human protein consumption and the size of urban population consuming this protein. With steadily rising nutritional intake of protein and the increase in urban and rural population over the years, urban N_2O emissions have increased across the states over the reporting period.

As observed in the case of CH_4 emissions, the states having higher population are the key contributors to cumulative N_2O emission from domestic wastewater as well. With regard to N_2O emissions in urban areas, Maharashtra is the largest contributor, with an average share of 13.11% in the total urban N_2O emission from 2005 to 2015, followed by Uttar Pradesh (12.54%), Tamil Nadu (8.38%), West Bengal (7.39%) and Gujarat (6.63%).

For rural areas, Uttar Pradesh is the largest contributor with an average share of 20.19% in the total rural wastewater related N_2O emissions from 2005-2015. This is followed by Bihar (11.13%), Rajasthan (7.42%), Maharashtra (7.32%), West Bengal (6.78%), Madhya Pradesh (6.65%) and Andhra Pradesh (5.85%).

Figure 14: Share of Urban and Rural N_2O Emissions across states, 2015

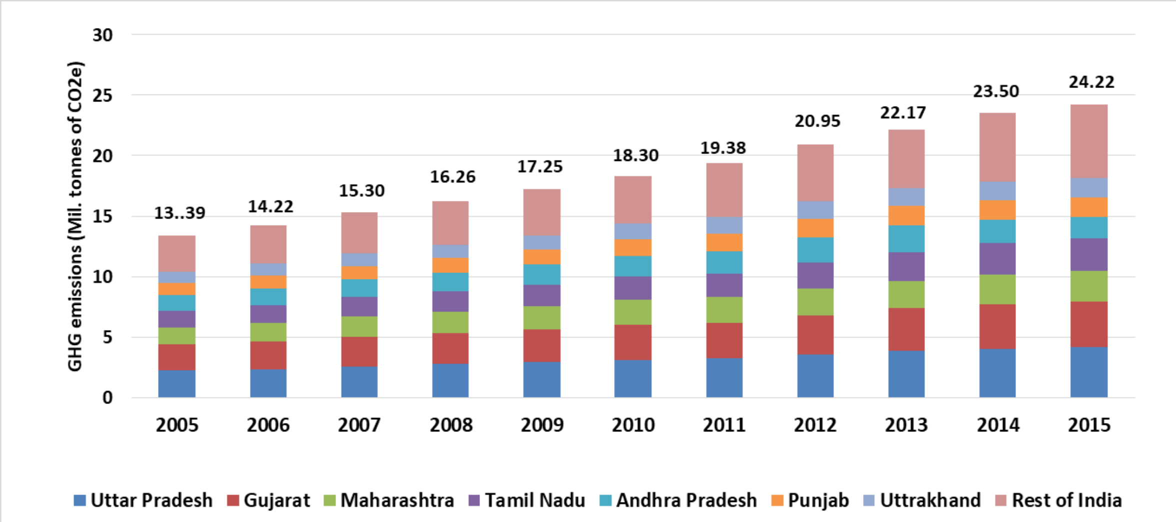


Source: Author's analysis

3.3.3 4D2 Industrial Wastewater Treatment and Discharge

Based on the estimated emissions, it is seen that the seven states of Uttar Pradesh, Gujarat, Andhra Pradesh, Tamil Nadu, Maharashtra, Punjab and Uttarakhand contribute to 77% of the total industrial wastewater emissions between 2005 and 2015, with Uttar Pradesh and Gujarat contributing about 17% and 15% respectively. This stems from the higher level of industrial activity (i.e. industrial production) reported for these states; primarily for the Pulp and paper industry along with the Meat and Dairy sectors. However, given that the reliability of state-level data used in this assessment varies across the sectors and years, due caution should be exercised while drawing conclusions from the state-wise trend.

Figure 15: GHG emission from industrial wastewater in key states, 2005-2015



Source: Author's analysis

3.4 Sectoral Quality Control (QC) and Quality Assurance (QA)

The general QC/QA procedures followed for the Waste sector have been outlined in section 1.9 of this document. Specific QC/QA procedures adopted for the three key source categories are indicated below.

3.4.1 4A Solid Waste Disposal

Discussions were conducted with expert from NEERI over the datasets available for solid waste, in particular for state-level waste generation and waste processing. These discussions contributed towards selection of year 2005 data as basis to estimate waste generation and towards assumptions for estimating proportion of waste going to landfill. Further specific considerations for the solid waste disposal category, in view of the emission estimation approach, are indicated below.

The FOD model for emission estimation from solid waste disposal considers historical disposal of solid waste (from year 1995 onwards). Since the solid waste generation and waste composition has changed over time, published state-level or national-level data available for these two parameters across the time period from 1955-2015 has been used in the state emission estimation. The state-level and national-level per capita MSW generation values for 2005 (used as a basis in this assessment) have been compared and also examined against the default 2006 IPCC Guidelines value of 0.12 tonnes/capita/year[17] to check that these fall within the IPCC specified uncertainty range of factor of 2 for MSW generation (IPCC, 2006)[18] and are therefore

[17] As per IPCC 2006 Guidelines, Vol. 5, Chapter 2: Waste Generation, Composition and Management Data, Table 2A.1. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_2_Ch2_Waste_Data.pdf
[18] As per IPCC 2006 Guidelines, Vol. 5, Chapter 3: Solid Waste disposal, Table 3.5.
Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

deemed to reasonably acceptable based on expert judgment of the authors of this note[19]. The relevant data sources and the method used to apply this data across the years have been documented in the subsequent section 3.5.2 of this reporting document. Since this assessment is limited to solid waste disposal in urban areas in the Indian states, it is checked that the applied data and emission factors refer to the urban context and to the respective state as well and are deemed to be appropriate.

3.4.2 4D1 Domestic Wastewater Treatment and Discharge

Discussions were conducted with experts from CPCB and NEERI over datasets on wastewater generation, wastewater treatment in STPs and rural areas in particular, and for state-wise BOD values. These discussions contributed towards selection of relevant datasets and assumptions to address data gaps in relation to this information. Specific considerations for the domestic wastewater treatment and discharge category, in view of the emission estimation approach, are indicated below.

The CH_4 and N_2O emissions have been estimated separately for the urban and rural population in the states and therefore, it is checked that the corresponding activity data and assumptions relating to the population, distribution of wastewater discharge/treatment pathways, and per capita protein consumption is appropriately applied for urban and rural areas and for the states.

For state-level CH_4 emission estimates relating to urban and rural domestic wastewater, the distribution of different wastewater discharge/treatment systems for the urban and rural population have been worked out based on state-specific data reported in Census of India 2001 and 2011 as indicated in section 3.6.2 of this document. The reported data on connectivity to sewer network in urban areas has been further broken down to estimate detailed degree of utilization rates using state specific data available on the extent and type of treatment in urban areas. The degree of utilization rates which indicate the distribution of wastewater flows through different treatment/discharge pathways, sums up to 100 percent for both urban and rural domestic wastewater respectively in all the states, thereby indicating that collected and uncollected as well as treated and untreated wastewater for urban and rural areas has been accounted for in the state emission estimates. Limited availability of published and updated data on the distribution of domestic treatment facilities which can be correlated with the IPCC treatment/discharge pathway classification is a challenge in the source specific QA/QC for this category.

3.4.3 4D2 Industrial Wastewater Treatment and Discharge

Inputs were also received from experts from NEERI and CPCB on prevalent wastewater treatment technologies for industry sectors such as Iron & Steel, Rubber, Petroleum, Dairy, Coffee, Meat that are considered in this assessment. Discussions were also held with representatives from industrial departments and associations including the Ministry of Statistics and Programme Implementation, Central Board of Excise and Customs - Central Excise, the Central Pulp & Paper Research Institute, the Indian Paper Manufacturers Association, the Coffee Board of India, and the Rubber Board on industrial production datasets. Inputs received helped to ascertain the status of available state-level industrial production data and gaps therein for Beer, Soft drinks, Pulp &

---

[19] This is observed for all states and union territories, except for Andaman and Nicobar wherein the solid waste generation is higher by a factor of 2.3 times for year 2005. However, in the absence of alternate data on waste generation for Andaman and Nicobar and to maintain consistency with other states, the per capita waste generation value of 0.76 kg/capita/year (i.e.0.27 tonnes/capita/year) for year 2005 has been used as a basis for Andaman and Nicobar.

Paper, Coffee and Rubber sectors in particular. Specific considerations for the industrial wastewater treatment and discharge category, in view of the emission estimation approach, are indicated below.

The emission estimates for industrial wastewater are based on a tier 1 approach and cover 11 industry sectors. Activity data on industrial production and correlated proxy data has been sourced from official publications from government departments, nodal agencies, and industry associations. In cases where information on industrial production for a sector has been reported in multiple datasets, the datasets have been compared and data has been sourced to minimize reliability related issues such as consistency in time-series trends, errors in conversion and reporting of units, etc. Country specific wastewater generation rates have been used for all 11 sectors. Country specific values of Degradable organic concentration in the wastewater (kg COD/m^3) have been used for all 11 industry sectors. Limited availability of published data on facility-specific industrial wastewater generation and characteristics technology is a challenge in the source specific QA/QC for this category.

3.5 4A2 Unmanaged Waste Disposal Sites

3.5.1 Category description

When solid waste is disposed in landfills or in dumpsites and in the presence of anaerobic conditions, methanogenic bacteria break-down the degradable organic component in the waste, releasing CH_4 emissions. Decomposition of the organic content occurs slowly and the CH_4 emissions from a given mass of solid waste deposited continue to be released over a time period spanning a few decades.

This assessment covers the disposal of municipal solid waste in the Indian states. Municipal solid waste is generally defined as waste collected by local municipal governments or other local authorities, typically including residential, commercial and institutional waste, street sweepings, and garden and park waste in either solid or semi-solid form (excluding industrial, hazardous, bio-medical and e-waste). Industrial waste and other waste such as clinical waste and hazardous waste are not considered in the emission estimation, given the lack of reliable information for these waste streams and in accordance with India's Second National Communication, BUR 1 and BUR 2 reports. Furthermore, as indicated previously, disposal of municipal solid waste in rural areas is not included in the estimation since decomposition of rural waste occurs largely in the absence of anaerobic conditions and thereby does not lead to significant CH_4 emission generation.

Systematic and scientific disposal of waste is lacking in most of the Indian cities. The landfill sites are not properly constructed, and operation and maintenance of the landfill is inadequate as well. Most of the disposal sites are thereby unmanaged and are generally observed to be shallow[4]. Therefore, the source category '4A2: Unmanaged waste disposal sites' is considered for emission estimation from solid waste disposal in India.

Secondary state-level activity data obtained from key governmental organizations and research institutes including the CPCB, SPCB, CPHEEO, and NEERI has been primarily used in this assessment. The activity data used is of medium quality as data has been extrapolated using specific data sets and appropriate assumptions have been used to address data gaps in the state level datasets. National level data has been used where reliable state level data is not available.

Table 13: Principal Sources and Quality of Data for Solid Waste Disposal Estimates

IPCC ID	GHG source & sink categories	Type	Quality	Source
4	Waste			
4A	Solid Waste Disposal			
4A2	Unmanaged Waste Disposal Sites	Secondary	Medium	CPCB, SPCB, NEERI, CPHEEO

A combination of country specific emission factors and default values for coefficients as per the 2006 IPCC Guidelines have been used in the estimation across the reporting period. The emission factors and assumptions have largely been sourced from India's Second National Communication, BUR 1 and BUR 2 reports, relevant publications from NEERI[20], and the 2006 IPCC Guidelines for national GHG inventories, in this order of preference, to prioritize the use of country specific emission factors and parameters (see the section 3.4.2 on methodology for further details on assumptions and emission factors used).

An assessment of the quality of activity data and emission factors used in the estimation is indicated in the Table 14 below. The quality has been assessed based on the source of the data and its availability. Published data sourced from government institutions and agencies is deemed to be of 'high' quality for the years where such published data is available. For years wherein no data has been published for the parameter, the quality is assigned as 'low', with suitable assumptions used to address data gaps in such cases. Emission factors and default values sourced from the 2006 IPCC Guidelines have been assessed to be of 'high' quality.

- Data and trends from Census of India, 2001 and Census of India, 2011 has been used for state population estimates and therefore, the quality of data is considered as 'high' across all years.
- Published data relating to mass of waste deposited (i.e. waste generation, processing and disposal) is available from NEERI, CPCB and India's Second National Communication for the years 2005, 2007, 2011, 2013, 2014 and 2015. Therefore, the quality for the activity data on mass of waste deposited[21] is assessed to be 'High' for these years and 'low' for the rest of the years wherein information is not available
- The degradable organic carbon (DOC) content is a key parameter for emission estimation using the FOD model and its value depends on the waste composition. To factor in the differences in waste composition across the states, the DOC content has been estimated using available secondary data from NEERI and CPCB on waste composition in each state for year 2005 and the data quality is deemed to be 'high'. Since reliable data on waste composition is not available for the rest of the years, the data is assessed to be of 'low' quality.
- Values for the following emission factors and related parameters are sourced from the 2006 IPCC Guidelines. Therefore, the quality is assessed to be 'high' across the emission estimation period.
    - Fraction of Degradable Organic Carbon which Decomposes (DOC_f)
    - Methane Correction Factor (MCF)
    - Fraction of CH_4 in generated landfill gas (F)

[20] Data sources for all parameters for solid waste disposal are indicated further in section 3.5.2 of this note.
[21] Time series data on mass of waste going to disposal sites for the 50 years before 2005 is not available at the state-level. Therefore, it becomes necessary to estimate the total waste generated using data on urban population and the per capita waste generation and subsequently work out the extent of generated waste that is dumped in disposal sites based on information on waste processing.

- Oxidation factor (OX)
- Methane Recovery (R)
- Reaction constant (k)

Table 14: Qualitative Assessment of Year-wise Activity and Emission Factor Data used in the Solid Waste Disposal Estimates

S. No.	Data/Emission Factor	Quality										
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	Activity Data											
(a)	Population	H	H	H	H	H	H	H	H	H	H	H
(b)	Mass of Waste deposited (W)	H	L	H	L	L	L	H	L	H	H	H
2	Emission Factors											
(a)	Degradable Organic Carbon (DOC)	H	L	L	L	L	L	L	L	L	L	L
(b)	Fraction of Degradable Organic Carbon which Decomposes (DOC_f)	H	H	H	H	H	H	H	H	H	H	H
(c)	Methane Correction Factor (MCF)	H	H	H	H	H	H	H	H	H	H	H
(d)	Fraction of CH_4 in generated landfill gas (F)	H	H	H	H	H	H	H	H	H	H	H
(e)	Oxidation factor (OX)	H	H	H	H	H	H	H	H	H	H	H
(f)	Methane Recovery (R)	H	H	H	H	H	H	H	H	H	H	H
(g)	Reaction constant (k)	H	H	H	H	H	H	H	H	H	H	H

Notes: H- high, L-low
Source: Author's analysis

3.5.2 Methodology

The overall methodology followed for state-level solid waste disposal emission estimates is a mix of Tier 1 and Tier 2 approach. A top-down approach is followed in the collection of secondary activity data and estimation of CH_4 emissions from solid waste disposal for the states.

Table 15: Type of Emission Factor and Level of Methodological Tiers adopted for Solid Waste Disposal Estimates

IPCC ID	GHG source & sink categories	CH_4	
		Method Applied	Emission Factor
4A2	Unmanaged Waste Disposal Sites	T1, T2	D, CS

Notes: T1: Tier 1; T2: Tier 2; CS: Country-specific; D: IPCC default

The FOD model outlined in the 2006 IPCC Guidelines to estimate emissions from decomposition of solid waste in disposal sites over a period of time is used in this assessment. The FOD model considers that waste deposited in a disposal site at a point in time decomposes gradually and the residual waste (material that remains after the partial decomposition of waste during anaerobic digestion process) continues to undergo anaerobic digestion again and generate CH_4 over a subsequent period of time (around 50 years). CH_4 emission will be generated until the waste deposited in the disposal site decomposes completely and reaches its full methane generation potential. The FOD model estimates the actual methane generation at a given point of time, accounting for the total methane generation over a preceding time period. The CH_4 generation potential of the waste that is disposed in a certain year will decrease gradually throughout the following decades. In this process, the release of CH_4 from this specific amount of waste decreases gradually.

As per the IPCC methodology (IPCC, 2006)[22], the following equations are used to estimate CH_4 emission from Solid waste disposal.

CH_4 EMISSION FROM SOLID WASTE DISPOSAL SITES

$$CH4\ Emissions = [\sum CH_4\ generatedT - R_T] * (1 - OXT)$$

$CH_{4\ Emissions}$	= CH_4 emitted in year T, Gg
T	= inventory year
x	= waste category or type/material
R_T	= recovered CH_4 in year T, Gg (default value of 0) (IPCC, 2006)[23]
OX_T	= oxidation factor in year T, (fraction) (default value of 0) (IPCC, 2006)[24]

The amount of CH_4 formed from decomposable material is found by multiplying the CH_4 fraction in generated landfill gas and the CH_4 /C molecular weight ratio (16/12).

CH_4 GENERATED FROM DECAYED DDOCm

$$CH4\ generatedT = DDOC_{m decompT} * F * 16/12$$

Where,

$CH_{4generatedT}$	= amount of CH_4 generated from decomposable material
$DDOC_{m,decompT}$	= Decomposable Degradable Organic Carbon ($DDOC_m$) decomposed in year T, Gg
F	= fraction of CH_4, by volume, in generated landfill gas (fraction) (default value of 0.5) (IPCC, 2006)
16/12	= molecular weight ratio CH_4/C (ratio)

The basis for the calculation is the amount of $DDOC_m$. $DDOC_m$ is the part of the organic carbon that will degrade under the anaerobic conditions in the solid waste disposal site.

It equals the product of the mass of waste deposited (W) for each state, the fraction of degradable organic carbon in the waste (DOC), the fraction of the degradable organic carbon that decomposes under anaerobic conditions (DOC_f), and the part of the waste that will decompose

---

[22] As per IPCC 2006 Guidelines, Vol. 5. Chapter 3: Solid Waste disposal, Equation 3.1.
Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf
[23] As per IPCC 2006 Guidelines, Vol. 5. Chapter 3: Solid Waste disposal, Section 3.2.3.
Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf
[24] As per IPCC 2006 Guidelines, Vol. 5. Chapter 3: Solid Waste disposal, Table 3.2.
Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

under aerobic conditions (prior to the conditions becoming anaerobic) in the solid waste disposal site, which is interpreted with the methane correction factor (MCF).

DECOMPOSABLE DOC FROM WASTE DISPOSAL DATA[25]

$$DDOC_m = W * DOC * DOCf * MCF$$

Where,

$DDOC_m$	= mass of decomposable DOC deposited, Gg
W	= mass of waste deposited for the state, Gg
DOC	= degradable organic carbon for the respective state in the year of deposition, fraction, Gg C/Gg waste
DOC_f	= fraction of DOC that can decompose (fraction) (Default value of 0.5) (IPCC, 2006)
MCF	= CH_4 correction factor for aerobic decomposition in the year of deposition (fraction) (default value of 0.4) (IPCC, 2006)[26]

The DOC in bulk waste is estimated based on the composition of waste and can be calculated from a weighted average of the degradable carbon content of various components (waste types/material) of the waste stream. The following equation estimates DOC using default carbon content values:

ESTIMATED DOC USING DEFAULT CARBON CONTENT VALUES[27]

$$DOC = \sum_i (\mathrm{DOCi} * \mathrm{Wi})$$

Where,

DOC	= fraction of degradable organic carbon in bulk waste, Gg C/Gg waste
DOC_i	= fraction of degradable organic carbon in waste type i
W_i	= fraction of waste type i by waste category

The default DOC values for various fractions in MSW are given in Table 16. Since plastics, glass and metals do not contain degradable organic carbon they have DOC value as zero.

Table 16: Default DOC content of different MSW components

MSW component	DOC content in % of wet waste	DOC content in % of dry waste
Paper/cardboard	40	44
Textiles	24	30
Food waste	15	38
Wood	43	50
Garden and Park waste	20	49
Nappies	24	60

[25] As per IPCC 2006 Guidelines, Vol. 5, Chapter 3: Solid Waste disposal, Equation 3.2. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

[26] As per IPCC 2006 Guidelines, Vol. 5. Chapter 3: Solid Waste disposal, Table 3.1. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

[27] As per IPCC 2006 Guidelines, Vol. 5, Chapter 3: Solid Waste disposal, Equation 3.7. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

Source: 2006 IPCC Guidelines, Vol. 5, Chapter 2, Table 2.5

With a first order reaction, the amount of product is always proportional to the amount of reactive material. This means that the year in which the waste material was deposited in the disposal site is irrelevant to the amount of CH_4 generated each year. It is only the total mass of decomposing material currently in the site that matters.

$DDOC_m$ ACCUMULATED IN THE SWDS AT THE END OF YEAR T[28]

$$DDOCmaT = DDOCmdT + (DDOCmaT - 1 \times e^{-k})$$

$DDOC_m$ DECOMPOSED AT THE END OF YEAR T[29]

$$DDOCmdecompT = DDOCmaT - 1 \times (1 - e^{-k})$$

Where,

T	= inventory year
$DDOC_{maT}$	= DDOCm accumulated in the SWDS at the end of year T, Gg
$DDOC_{maT-1}$	= DDOCm accumulated in the SWDS at the end of year (T-1), Gg
$DDOC_{mdT}$	= DDOCm deposited into the SWDS in year T, Gg
$DDOC_{m,decompT}$	= DDOCm decomposed in the SWDS in year T, Gg
k	= reaction constant,
k	= ln(2)/t1/2 (y-1) = 0.17 (IPCC, 2006)[30]
t1/2	= half-life time (y) (IPCC, 2006)[31]

A sample calculation with the detailed computation of emissions is provided in Appendix 6.9.

Data Sources and Assumptions

1. Population

The urban population of each state for the estimation period from 2005-2015 and for the preceding 50-year time period between the years 1954-2004 is estimated on the basis of population data and decadal population growth trends as per the Census of India data reported for the years 1951, 1961, 1971, 1981, 1991, 2001[32] and 2011 (Planning Commission, 2014). Formation and re-organization of states and union territories of Arunachal Pradesh, Chandigarh, Chhattisgarh, Daman & Dui, Dadra & Nagar Haveli, Goa, Jharkhand, Lakshadweep, Puducherry, Telangana, Uttarakhand has been considered since the emission estimation extends from year 1954 onwards. The decadal population data reported in Census and used in the estimates has been given in Appendix 6.1.

---

[28] As per IPCC 2006 Guidelines, Vol. 5, Chapter 3: Solid Waste disposal, Equation 3.4. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

[29] As per IPCC 2006 Guidelines, Vol. 5, Chapter 3: Solid Waste disposal, Equation 3.5. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

[30] As per IPCC 2006 Guidelines, Vol. 5. Chapter 3: Solid Waste disposal, Table 3.3. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

[31] As per IPCC 2006 Guidelines, Vol. 5. Chapter 3: Solid Waste disposal, Table 3.4. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

[32] The Census information from 1951 to 2001 has been acquired by visiting the Census office

The state of Telangana was bifurcated from Andhra Pradesh in year 2014 and therefore, the population of Andhra Pradesh from year 2014 is estimated by aggregating population of corresponding districts falling under the new Andhra Pradesh state post bifurcation. The population of these districts has been projected based on population and growth rate as per the census of India 2011. The detailed population figures and growth rate for urban and rural Telangana state have been referred from statistical publication of the government of Telangana[33].

2. Mass of Waste deposited (W)

The FOD method assumes that carbon in waste decays gradually for decades to produce CH_4 emission. As per India's Second National Communication, it takes about 50 years for CH_4 emissions to come down to insignificant levels. Hence, it is necessary to estimate or collect 50-year data on waste disposal prior to the base year 2005 i.e. from 1954-2004. Time series data on mass of waste going to disposal sites for the 50 years before 2005 is not available at the state-level. Therefore, it becomes necessary to estimate the total waste generated using data on urban population and the per capita waste generation and subsequently work out the extent of generated waste that is dumped in disposal sites.

Reported data on per capita waste generation for the states is available for the years 1999, 2005, 2011, 2013, 2014 and 2015 (see Table 17). However, the waste generation datasets show high variation for each state across the years and are inconsistent. The per capita waste generation values reported by the CPCB in 1999 seem too low, even compared to the national-level average per capita waste generation given for year 1991 in Table 17. Further, data is not available for all the states in the year 1999. Data reported by CPCB for the years 2011, 2013, 2014 and 2015 shows inconsistent trends, with decreasing per capita waste generation reported for several states across the years 2011 to 2015. This is in contrast with available national-level information which shows that per capita waste generation is increasing at 1.2% annually (see Table 18). Therefore, the state-level waste generation data reported in 2005 is assessed to be more appropriate and in order to maintain consistency across the states, this single dataset is selected as a basis to estimate waste generation.

The 2005 data is based on a CPCB and NEERI study[34] that reports per capita waste generation data for selected cities within each state. Given that data on waste generation is not available for all the cities in a particular state, data reported for select cities is considered to be applicable across the state. Further since reliable time-series data on waste generation is not available in order to assess the waste generation trend specific to each state, the average growth rates available at national-level over the decades are assumed to be applicable for all the states. The state-wise per capita generation data reported for the year 2005 in Table 17 is selected as the basis for emission estimation and the per capita generation rate for the rest of the years from 2006 to 2015 has been calculated using the national-level average growth rates given in Table 18. These annual growth rates are consistent with the growth rate of 1.3% per annum reported in the CPHEEO Manual on Municipal Solid Waste Management-2016[35]. While converting waste generation from daily basis to an annual basis, 365 days have been assumed across all years, including leap years.

[33] As per Statistical Year Book 2017, Government of Telangana, Table 1.4, 1.5 & 1.6
Available at https://www.telangana.gov.in/PDFDocuments/Statistical-Year-Book-2017.pdf

[34] Available at http://cpcb.nic.in/waste-generation-composition/

[35] Available at http://cpheeo.gov.in/upload/uploadfiles/files/Part2.pdf

Table 17: State-wise estimated per capita waste generation based on data reported by NEERI and CPCB

State/Union Territory	Per Capita Waste Generation (kg/day)					
	1999[36]	2005[37]	2011[38]	2013[39]	2014[40]	2015[41]
Andaman & Nicobar	-	0.760	0.348	0.466	0.456	0.446
Andhra Pradesh	0.216	0.533	0.408	0.380	0.294	0.384
Arunachal Pradesh	-	0.340	0.296	0.321	0.327	0.035
Assam	0.088	0.200	0.261	0.140	0.136	1.620
Bihar	0.130	0.310	0.142	0.133	0.128	0.124
Chandigarh	0.262	0.400	0.370	0.324	0.333	0.325
Chhattisgarh	-	0.300	0.197	0.295	0.284	0.324
Dadra & Nagar Haveli	-	0.320	0.119	0.172	0.149	0.283
Daman & Diu	-	0.420	0.119	0.172	0.149	0.283
Delhi	0.333	0.570	0.451	0.485	0.473	0.531
Goa	-	0.540	0.213	0.199	0.449	0.435
Gujarat	-	0.296	0.287	0.334	0.35	0.356
Haryana	0.742	0.420	0.061	0.362	0.31	0.464
Himachal Pradesh	1.28	0.270	0.442	0.423	0.383	0.377
Jammu & Kashmir	0.015	0.530	0.522	0.487	0.471	0.415
Jharkhand	-	0.350	0.216	0.423	0.41	0.398
Karnataka	0.191	0.390	0.275	0.35	0.336	0.332
Kerala	0.159	0.450	0.523	0.083	0.066	0.061
Lakshadweep	-	0.300	0.417	0.356	0.331	0.310
Madhya Pradesh	0.140	0.337	0.224	0.241	0.309	0.302
Maharashtra	0.233	0.338	0.378	0.504	0.415	0.393
Manipur	0.071	0.190	0.135	0.194	0.186	0.179
Meghalaya	0.082	0.340	0.478	0.424	0.319	0.279

[36] Estimated based on corresponding state population in 1999 interpolated from Census of India datasets and reported state-wise total municipal solid waste generation in Annexure- B of CPCB (n.d.): Status Report on Municipal Solid Waste Management. Available at http://www.indiaenvironmentportal.org.in/files/file/MSW_Report.pdf

[37] Reported data from CPCB: Waste Generation and Composition, Table 1. State-wise per capita waste generation is based on reported per capita waste generation for cities in the state. Where data has been reported for multiple cities in a single state, per generation for the particular state has been estimated by taking simple mathematical average of per capita generation for cities in the state. Available at http://cpcb.nic.in/waste-generation-composition/

[38] Estimated based on corresponding state population in 2011 from Census of India datasets and reported state-wise total municipal solid waste generation in Annexure- C of CPCB (n.d.): Status Report on Municipal Solid Waste Management. The data is stated to be updated up to 2012 but most of the data pertains to information forwarded to CPCB by SPCBs in 2011 and is thereby assumed to be applicable for 2011 across all states for consistency. Available at http://cpcb.nic.in/displaypdf.php?id=aHdtZC9NU1dfQW5udWFsUmVwb3J0XzIwMTEtMTIucGRm

[39] Estimated based on corresponding state population in 2013 projected from Census of India datasets and reported state-wise total municipal solid waste generation in Annexure- VI of CPCB (2015): Annual Review Report: 2013-14. The data is stated to be updated up to 2015 but refers to data reported by SPCBs for 2013-14 as indicated in Annexure-VII and is thus is considered for year 2013 in Table 16 in this note. Available at http://cpcb.nic.in/uploads/hwmd/MSW_AnnualReport_2013-14.pdf

[40] Estimated based on corresponding state population in 2014 projected from Census of India datasets and reported state-wise total municipal solid waste generation in Annexure- VIII of CPCB (2016): Annual Review Report: 2014-15. The data is stated to be updated up to 2016 but refers to data reported by SPCBs for 2014-15 as indicated in Annexure-IX and is thus is considered for year 2014 in Table 16 in this note. Available at http://cpcb.nic.in/uploads/hwmd/MSW_AnnualReport_2014-15.pdf

[41] Estimated based on corresponding state population in 2015 projected from Census of India datasets and reported state-wise total municipal solid waste generation in Annexure- V of CPCB (2017): Annual Review Report: 2015-16. The data is stated to be updated up to 2017 but refers to data reported by SPCBs for 2015-16 as indicated in Annexure-V and is thus is considered for year 2015 in Table 16 in this note. Available at http://cpcb.nic.in/uploads/hwmd/MSW_AnnualReport_2015-16.pdf

State/Union Territory	Per Capita Waste Generation (kg/day)					
	1999[36]	2005[37]	2011[38]	2013[39]	2014[40]	2015[41]
Mizoram	0.110	0.250	0.829	0.911	0.887	0.863
Nagaland	-	0.170	0.329	0.417	0.502	0.476
Odisha	0.125	0.360	0.320	0.333	0.314	0.332
Puducherry	0.111	0.590	0.446	0.546	0.530	0.534
Punjab	0.162	0.490	0.269	0.357	0.366	0.388
Rajasthan	0.156	0.390	0.295	0.279	0.272	0.265
Sikkim	-	0.440	0.260	0.243	0.217	0.196
Tamil Nadu	0.209	0.497	0.358	0.395	0.384	0.006
Telangana	-	-	-	-	0.444	0.423
Tripura	0.063	0.400	0.374	0.367	0.351	0.330
Uttar Pradesh	0.171	0.422	0.260	0.408	0.397	0.306
Uttarakhand	-	0.310	0.247	0.308	0.269	0.259
West Bengal	0.213	0.510	0.432	0.281	0.300	0.292

Source: Author's compilation based on CPCB reports

Table 18: Decadal daily Per capita Waste generation and Annual growth rates at national-level for India

Year	Daily Per capita Waste generation (kg/day)[42]	Estimated Annual Per capita Waste generation based on Daily per capita waste generation (kg/annum)	Annual Growth rate[43]
1951	0.305	111.33	1.1%
1961	0.340	124.10	1.0%
1971	0.375	136.88	1.5%
1981	0.430	156.95	0.7%
1991	0.460	167.90	1.2%
2005	0.540	197.1	1.2%[44]

Source: Author's analysis and compilation based on TERI and CPCB data

Data on the proportion of solid waste going to landfill has been estimated based on the available state-wise data on the amount of waste that undergoes treatment. The quantum of solid waste that is treated through processes such as composting, anaerobic digestion, refuse derived-fuel, recycling etc. is diverted from being dumped in disposal sites. Reliable information at the state level on the quantity or proportion of waste going to landfill is not available for the time period 1954-2010. Therefore, it is assumed that 70% of the generated waste decomposes under anaerobic conditions in disposal sites during this period, in consonance with assumptions in India's Second National Communication[45].

The states and the SPCBs report state-level data on solid waste treatment/processing to the CPCB. State-level data available in CPCB annual reports on quantum of waste treated for the

---

[42] Values for 1951 to 1991 sourced from TERI (1998): Looking Back to Think Ahead: Green India 2047'

[43] Annual Growth rates have been estimated based on per capita generation rates reported for certain years as given in the Table 17 and have been used in the emission estimation to calculate per capita generation rates for the intervening years.

[44] The annual growth rate of 1.2% estimated based on data for 1991 and 2007 has been used to calculate per capita generation rates from 2005-2014.

[45] This information is not reported in the BUR 1 and BUR 2 reports and hence referred from the Second National Communication. Available at https://unfccc.int/sites/default/files/resource/indnc2.pdf

years 2011, 2013, 2014 and 2015 for each state is subtracted from the estimated waste generation data (extrapolated from state-wise 2005 data on waste generation), to get the corresponding proportion of solid waste going to disposal sites in the respective years. It is assumed that all waste that is generated and not treated gets dumped at the disposal site. It is observed that the initial estimate of the proportion of waste going to disposal sites for the years 2011, 2013, 2014 and 2015 exceeds 70% for some states (see Table 19).

This estimate, however, becomes inconsistent with the assumed condition for the period 1954-2010 that 70% of the waste generated in all states (and nationally) decomposes under anaerobic conditions in disposal sites, since the extent of waste treatment should increase over the years and thereby the proportion of solid waste going to disposal sites should decrease from 2011-2015 as compared to that up to 2010 (i.e. 70%). To maintain consistency across the estimation period, the proportion of waste being disposed should be 70% or lower for the years 2011, 2013, 2014 and 2015; not higher than 70%. Thus, the estimated value of proportion of waste to disposal site has been adjusted and a value of 70% is considered in the case of states wherein the initial estimate of proportion of waste going to landfill is obtained as higher than 70%. This is a reasonable assumption given that conditions for anaerobic decomposition (which lead to CH_4 generation) are not necessarily available for all waste that is dumped in disposal sites in India due to lack of systematic waste management and disposal.

In the case of states wherein the proportion of waste being disposed is calculated to be lower than 70%, this initial estimate value has been retained for the years 2011-2015 (see Table 20). For instance, in the case of Andhra Pradesh, the initial estimate of proportion going to landfill based on reported data is 77% for 2011, 47% for 2013, 23% for 2014 and 94% for 2015 (see Table 19). Since the estimated proportion of waste going to disposal site for 2011 is higher than 70%, this value is adjusted to 70% for 2011. Since the proportion of waste going to disposal site for the years 2013 (i.e. 47%) and 2014 (i.e. 23%) is lower than 70%, this value is retained, again since the waste going to disposal site is high for the year 2018 (i.e. 94%) the value is adjusted to 70% for the year 2015 and used in the emission estimation (see Table 20). As data is not available for year 2012, proportion of waste going to disposal sites estimated for 2011 is used for 2012 for all the states.

Table 19: Initial Estimate of state-wise waste to disposal site based on treatment reported by CPCB

State/Union Territory	Proportion of waste going to disposal site			
	2011[46]	2013[47]	2014[48]	2015[49]
Andaman & Nicobar	100%	96%	96%	96%
Andhra Pradesh	77%	47%	23%	94%
Arunachal Pradesh	100%	42%	100%	100%
Assam	92%	90%	100%	82%
Bihar	100%	100%	100%	100%
Chandigarh	32%	47%	49%	51%
Chhattisgarh	87%	92%	92%	65%
Dadra & Nagar Haveli	100%	100%	100%	100%
Daman & Diu	100%	100%	100%	100%
Delhi	81%	62%	71%	72%
Goa	100%	68%	70%	71%
Gujarat	89%	85%	72%	74%
Haryana	100%	87%	96%	96%
Himachal Pradesh	23%	29%	42%	44%
Jammu & Kashmir	84%	85%	86%	100%
Jharkhand	98%	98%	98%	98%
Karnataka	79%	81%	73%	69%
Kerala	77%	95%	96%	96%
Lakshadweep	74%	100%	100%	100%
Madhya Pradesh	87%	90%	100%	100%
Maharashtra	89%	76%	71%	67%
Manipur	99%	100%	100%	100%
Meghalaya	54%	59%	78%	86%
Mizoram	100%	100%	100%	100%
Nagaland	100%	85%	100%	100%
Odisha	99%	99%	100%	99%
Puducherry	100%	100%	100%	98%
Punjab	100%	99%	94%	100%
Rajasthan	100%	94%	94%	94%
Sikkim	56%	100%	100%	100%
Tamil Nadu	97%	92%	92%	93%
Telangana	-	-	60%	60%
Tripura	90%	100%	52%	56%
Uttar Pradesh	100%	76%	77%	92%
Uttarakhand	100%	100%	100%	100%

[46] Estimated based on extrapolated quantity of waste generation in this assessment (using reported per capita generation data of 2005) and reported quantity of waste treated in the states for year 2011 in Annexure- C of CPCB (n.d.): Status Report on Municipal Solid Waste Management. Available at http://cpcb.nic.in/displaypdf.php?id=aHdtZC9NU1dfQW5udWFsUmVwb3J0XzIwMTAtMTEucGRm

[47] Estimated based on extrapolated quantity of waste generation in this assessment (using reported per capita generation data of 2005) and reported quantity of waste treated in the states for year 2013 in Annexure- VI of CPCB (2015): Annual Review Report: 2013-14. Available at http://cpcb.nic.in/uploads/hwmd/MSW_AnnualReport_2013-14.pdf

[48] Estimated based on extrapolated quantity of waste generation in this assessment (using reported per capita generation data of 2005) and reported quantity of waste treated in the states for year 2014 in Annexure- VIII of CPCB (2016): Annual Review Report: 2014-15. Available at http://cpcb.nic.in/uploads/hwmd/MSW_AnnualReport_2014-15.pdf

[49] Estimated based on extrapolated quantity of waste generation in this assessment (using reported per capita generation data of 2005) and reported quantity of waste treated in the states for year 2015 in Annexure- V of CPCB (2017): Annual Review Report: 2015-16. Available at http://cpcb.nic.in/uploads/hwmd/MSW_AnnualReport_2015-16.pdf

State/Union Territory	Proportion of waste going to disposal site			
	2011[46]	2013[47]	2014[48]	2015[49]
West Bengal	96%	92%	95%	95%

Source: Author's analysis based on CPCB reports

Table 20: Adjusted Estimate of State-wise Proportion of waste going to Disposal Site and corresponding time periods considered in the estimates

State/Union Territory	Proportion of waste going to disposal site				
	1954 – 2010	2011 & 2012	2013	2014	2015
Andaman & Nicobar	70%	70%	70%	70%	70%
Andhra Pradesh	70%	70%	47%	23%	70%
Arunachal Pradesh	70%	70%	42%	70%	70%
Assam	70%	70%	70%	70%	70%
Bihar	70%	70%	70%	70%	70%
Chandigarh	70%	32%	47%	49%	51%
Chhattisgarh	70%	70%	70%	70%	65%
Dadra & Nagar Haveli	70%	70%	70%	70%	70%
Daman & Diu	70%	70%	70%	70%	70%
Delhi	70%	70%	62%	70%	70%
Goa	70%	70%	68%	70%	70%
Gujarat	70%	70%	70%	70%	70%
Haryana	70%	70%	70%	70%	70%
Himachal Pradesh	70%	23%	29%	42%	44%
Jammu & Kashmir	70%	70%	70%	70%	70%
Jharkhand	70%	70%	70%	70%	70%
Karnataka	70%	70%	70%	70%	69%
Kerala	70%	70%	70%	70%	70%
Lakshadweep	70%	70%	70%	70%	70%
Madhya Pradesh	70%	70%	70%	70%	70%
Maharashtra	70%	70%	70%	70%	67%
Manipur	70%	70%	70%	70%	70%
Meghalaya	70%	54%	59%	70%	70%
Mizoram	70%	70%	70%	70%	70%
Nagaland	70%	70%	70%	70%	70%
Odisha	70%	70%	70%	70%	70%
Puducherry	70%	70%	70%	70%	70%
Punjab	70%	70%	70%	70%	70%
Rajasthan	70%	70%	70%	70%	70%
Sikkim	70%	56%	70%	70%	70%
Tamil Nadu	70%	70%	70%	70%	70%
Telangana	-	-	-	60%	60%
Tripura	70%	70%	70%	52%	56%
Uttar Pradesh	70%	70%	70%	70%	70%
Uttarakhand	70%	70%	70%	70%	70%
West Bengal	70%	70%	70%	70%	70%

Source: Author's analysis

3. Degradable Organic carbon (DOC)

The DOC value depends on the prevalent composition of solid waste. The national-level value for DOC as indicated in India's BUR 2 report is 0.11[50]. This aggregate DOC value is based on an assumed composition of solid waste in India. However, the composition of waste is changing over time as seen from waste composition data available for three different years (1971, 1995 and 2005) from studies conducted by the CPCB and NEERI (see Table 21). Since DOC is dependent on waste composition, the DOC value will also change over the years and should be factored into the estimation.

It is seen that reliable state-wise waste composition data is available only for year 2005 (refer Table 22). Since reliable historical waste composition data for the states is not available for the years before 2005, national-level data on waste composition for years 1971 and 1995 (refer Table 21) has been assumed to be applicable for the states. Further, as year-on-year data on waste composition is not available for the 50-year period before 2005, the available waste composition across the years of 1971 and 1995 is assumed to be applicable for time periods of 1954-1994 and 1995-2004 respectively. Using the default values for DOC content for the degradable fractions in waste, the DOC values for the organic portion of the waste are calculated based on national-level solid waste composition for the time periods 1954-1994 and 1995-2004 and used in the emission estimation for the same time periods. State-level waste composition data for year 2005 is used to estimate state-specific DOC value which is subsequently used in the emission estimates for the time period 2005-2015.

Table 21: Estimated Degradable Organic Content using Waste Composition

Component	Waste Composition[51]		Default DOC Content values (Wet waste) in percent from Table 16 as per 2006 IPCC Guidelines[52]
	1971	1995	
Paper	4.14%	5.78%	40%
Rags	3.83%	3.5%	24%
Compostable Matter	41.24%	41.8%	15%
DOC Estimated for overall waste (in fraction)	**0.088**	**0.094**	**-**
Applicable time period considered for estimated DOC value	**1954-1994**	**1995-2004**	**-**

Source: Author's analysis and compilation based on CREED and CPCB data and 2006 IPCC Guidelines

Table 22: Estimated State-wise DOC Value applicable for the time period 2005-2014

[50] As per India - Second Biennial Update Report to the UNFCCC, Table 2.15. Available at https://unfccc.int/sites/default/files/resource/INDIA%20SECOND%20BUR%20High%20Res.pdf

[51] As per Integrated Modeling of Solid Waste in India (March,1999) CREED Working Paper Series no 26 and CPCB, 1999

[52] As per 2006 IPCC Guidelines for National GHG Inventories, Vol. 5, Chapter 2: Waste Generation, Composition and Management Data, Table 2.5.
Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_2_Ch2_Waste_Data.pdf

State/Union Territory	Reported State-wise Waste Composition (2005)[53]				Estimated State-wise DOC content assumed to be applicable for time period 2005-2015
	Compostable	Total Recyclables	Paper	Rags	
Andaman & Nicobar	48.25%	27.66%	9.63%	5.32%	0.124
Andhra Pradesh	53.19%	21.06%	7.33%	4.05%	0.119
Arunachal Pradesh	52.02%	20.57%	7.16%	3.96%	0.116
Assam	53.69%	23.28%	8.11%	4.48%	0.124
Bihar	51.72%	11.21%	3.90%	2.16%	0.098
Chandigarh	57.18%	10.91%	3.80%	2.10%	0.106
Chhattisgarh	51.4%	16.31%	5.68%	3.14%	0.107
Dadra & Nagar Haveli	71.67%	13.97%	4.86%	2.69%	0.133
Daman & Diu	29.6%	22.02%	7.67%	4.23%	0.085
Delhi	54.42%	15.52%	5.40%	2.98%	0.110
Goa	61.75%	17.44%	6.07%	3.35%	0.125
Gujarat	44.18%	12.35%	4.30%	2.37%	0.089
Haryana	42.06%	23.31%	8.12%	4.48%	0.106
Himachal Pradesh	43.02%	36.64%	12.76%	7.05%	0.132
Jammu & Kashmir	56.64%	19.42%	6.76%	3.73%	0.121
Jharkhand	45.15%	15.92%	5.54%	3.06%	0.097
Karnataka	51.84%	22.43%	7.81%	4.31%	0.119
Kerala	65.15%	16.86%	5.87%	3.24%	0.129
Lakshadweep	46.01%	27.2%	9.47%	5.23%	0.119
Madhya Pradesh	53.16%	17.17%	5.98%	3.30%	0.112
Maharashtra	52.95%	18.49%	6.44%	3.56%	0.114
Manipur	60.00%	18.51%	6.44%	3.56%	0.124
Meghalaya	62.54%	17.27%	6.01%	3.32%	0.126
Mizoram	54.24%	20.97%	7.30%	4.03%	0.120
Nagaland	57.485	22.67%	7.89%	4.36%	0.128
Odisha	49.81%	12.69%	4.42%	2.44%	0.098
Puducherry	49.96%	24.29%	8.46%	4.67%	0.120
Punjab	57.41%	16.63%	5.79%	3.20%	0.117
Rajasthan	45.5%	12.1%	4.21%	2.33%	0.091
Sikkim	46.01%	27.2%	9.47%	5.23%	0.119
Tamil Nadu	48.9%	16.37%	5.70%	3.15%	0.104
Telangana	53.19%	21.06%	7.33%	4.05%	0.119
Tripura	58.57%	13.68%	4.76%	2.63%	0.113
Uttar Pradesh	46.08%	15.11%	5.26%	2.91%	0.097
Uttarakhand	51.37%	19.58%	6.82%	3.77%	0.113
West Bengal	50.44%	12.84%	4.47%	2.47%	0.099

Source: Author's analysis based on CPCB and NEERI data and 2006 IPCC Guidelines

4. $DDOC_m$ decomposed in year T ($DDOC_{m,decompT}$)

[53] State-wise average values estimated for compostable and total recyclables estimated based on information reported for cities in NEERI and CPCB study in 2005. Composition for paper and rags from total recyclable material based on national-level data reported for 2005 in CPHEEO Manual on Municipal Solid Waste Management-2016, Table 1.6, Available at http://cpheeo.gov.in/upload/uploadfiles/files/Part2.pdf

The DDOCm (i.e. the Decomposable Degradable Organic Carbon) decomposed in the year T ($DDOC_{m,decompT}$) depends on the $DDOC_m$ deposited in the year T ($DDOC_{mdT}$), the $DDOC_m$ accumulated at the end of year T ($DDOC_{maT}$), and the $DDOC_m$ accumulated at the end of the previous year (T-1) ($DDOC_{maT-1}$). It is assumed the $DDOC_m$ accumulated in the initial year of the 50-year time period considered under the FOD model (i.e. 1954) is zero for all the states.

Using the values estimated for $DDOC_m$ deposited and $DDOC_m$ accumulated, the $DDOC_m$ decomposed is calculated for all the 50-year period from 1954-2004 and subsequently is used to estimate CH_4 emissions from 2005-2014.

3.5.3 Recalculation

The methodological approach for the present estimation (version 3.0) has remained consistent as in the previous estimates. In line with other sectors wherein emissions are reported under by the GHG Platform India consortium, recalculation of emissions is envisaged to be undertaken and reported if there is a deviation of more than 5% in the estimates as compared to previous versions.

For solid waste disposal, no recalculation has been carried out in the previously reported estimates from year 2005 to 2013 since activity data and emission factors have remained the same.

3.6 4D1 Domestic Wastewater Treatment and Discharge

3.6.1 Category description

Domestic wastewater includes human sewage mixed with other household wastewater, which can include effluent from shower drains, sink drains, washing machines, etc. This source category refers to CH_4 and N_2O emissions generated due to the treatment and discharge of domestic wastewater. CH_4 emissions are generated from domestic wastewater on its treatment (on site through septic tanks, connected by sewer network to a centralized treatment plant) or untreated disposal via an outfall under anaerobic conditions (IPCC, 2006). The extent of CH_4 emission from wastewater depends primarily on the quantity of degradable organic material in the wastewater, the volume of wastewater generated, and the type of treatment system used.

The characteristics of domestic wastewater and consequently the associated GHG emissions vary from place to place depending on factors such as economic status, community food intake, water supply status, treatment systems and climatic conditions of the area. To account for these factors in the CH_4 emission estimation for the Waste Sector, the 2006 IPCC Guidelines on National GHG Inventories[54] categorizes the population in the following groups

- Urban high income
- Urban low income
- Rural

N_2O emission occurs from the degradation of the nitrogen present in domestic wastewater, which mainly results from human protein consumption. The degradation of nitrogen occurs on the disposal of domestic wastewater into waterways, lakes or sea.

Secondary sources including published reports and studies of key governmental and research institutions such as the CPCB, SPCB, the National Sample Survey Organization (NSSO), the Census of India, and the NEERI have been used to source state specific activity data in this assessment. Either national-level data (where available) or IPCC defined default values have been used where state-level data is not available. The data is gauged to be of medium quality overall since data is available intermittently and the same has been applied across the reporting period.

Table 23: Principal Sources and Quality of Data for Domestic Wastewater Treatment and Discharge Estimates

IPCC ID	GHG source & sink categories	Type	Quality	Source
4	**Waste**			
4D	**Wastewater treatment and discharge**			
4D1	Domestic wastewater treatment and discharge	Secondary	Medium	CPCB; SPCB; Census of India; NSSO, NEERI

[54] As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

For the CH_4 emission estimates, the Census of India data for 2001 and 2011 has been used to estimate the distribution of state-wise population into urban and rural residents across the reporting period. Data from the Census of India surveys has been used to work out the distribution of different wastewater discharge/treatment systems for the urban and rural population in the states. For CH_4 emission estimates relating to urban domestic wastewater, this has been supplemented with state-level data from CPCB studies to further estimate the extent of wastewater collected through the sewerage network and its treatment downstream. With regards to the estimates for N_2O emission from domestic wastewater, state specific values of per capita protein intake have been used from NSSO surveys (see the section 3.6.2 on methodology for further details on assumptions, data sources and emission factors used).

An assessment of the quality of activity data and emission factors used in the estimation is indicated in the Table 24 below. The quality has been assessed based on the source of the data[55] and its availability. Published data sourced from government institutions and agencies is deemed to be of 'high' quality for the years where such published data is available. For years wherein no data has been published for the parameter, the quality is assigned as 'low', with suitable assumptions used to address data gaps in such cases. Emission factors and default values sourced from the 2006 IPCC Guidelines have been assessed to be of 'high' quality.

- Population data is available for 2001 and 2011. Population estimates for the intermediate years' have been found using decadal growth rate trends and therefore the quality of data is considered as 'high' across all years.
- The state specific per capita BOD values are sourced from NEERI data available for year 2007 and data quality for this parameter is thus assessed to be of 'high' quality for year 2007[56]. For the rest of the years where data is not available, quality is assessed to be 'low'.
- The degree of utilization of treatment/discharge pathway or system is based on the Latrine facility dataset, Census of India. The data is available for 2001 and 2011 and is considered to be of 'high' quality for year 2011 within the emission estimation period and of 'low' quality for the rest of the years where data is unavailable.
- The values of fraction of population in the income group (i.e. fraction of urban and rural population) have been sourced from Census of India data for 2001 and 2011. Thus, the data quality is considered as 'high' for year 2011 within the reporting period and 'low' for rest of the years wherein data is unavailable.
- The annual per capita protein consumption value is available from NSSO surveys. The data is available for the years 2005, 2009 and 2011 for which data quality is considered 'high'. For the rest of the years', since data is unavailable the quality is assigned as 'low'.
- Values for the following parameters and emission factors are sourced from the 2006 IPCC Guidelines. Therefore, the quality is assessed to be 'high' across the emission estimation period.
    - Organic Component removed as Sludge in inventory year (S)

[55] Data sources for all parameters for domestic wastewater are indicated further in section 3.6.2 of this note.
[56] The values are available for Bihar, Chandigarh, Delhi, Gujarat, Haryana, Himachal Pradesh, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Punjab, Uttar Pradesh, Uttarakhand and West Bengal. For rest of the States, the national average BOD values are used.

- Correction factor for additional industrial BOD discharged into sewers (I)
- Amount of CH_4 recovered in inventory year (R)
- Maximum CH_4 producing capacity (B_o)
- Methane correction factor (MCF_j)
- Fraction of Nitrogen in Protein (F_{NPR})
- Factor for Non-consumed protein added to the wastewater ($F_{NON-CON}$)
- Factor for Industrial and commercial co-discharged protein into the sewer system ($F_{IND-COM}$)
- Nitrogen removed with sludge (N_{SLUDGE})

Table 24: Qualitative Assessment of Year-wise Activity Data used in the State Domestic Wastewater Treatment and Discharge Estimates

Sr. No.	Activity Data/ Emission Factor	Quality										
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	**Activity data**											
(a)	State population (P)	H	H	H	H	H	H	H	H	H	H	H
(b)	Per capita BOD in inventory year, g/person/day	L	L	H	L	L	L	L	L	L	L	L
(c)	Degree of utilisation of treatment/discharge pathway or system, j, for each income group fraction i (Ti,j)	L	L	L	L	L	L	H	L	L	L	L
(d)	Fraction of population in income group i (Ui)	L	L	L	L	L	L	H	L	L	L	L
(e)	Organic Component removed as Sludge, kg BOD/year (BOD)	H	H	H	H	H	H	H	H	H	H	H
(f)	Correction factor for additional industrial BOD discharged into sewers (I)	H	H	H	H	H	H	H	H	H	H	H
(g)	Amount of CH_4 recovered in inventory year (R)	H	H	H	H	H	H	H	H	H	H	H
(h)	Annual per capita protein consumption, kg/person/yr	H	L	L	L	H	L	H	L	L	L	L
2	**Emission factors**											
(a)	Maximum CH_4 producing capacity, kg CH_4/kg BOD (Bo)	H	H	H	H	H	H	H	H	H	H	H
(b)	Methane correction factor (MCF_j)	H	H	H	H	H	H	H	H	H	H	H
(c)	Fraction of Nitrogen in Protein (F_{NPR})	H	H	H	H	H	H	H	H	H	H	H

Sr. No.	Activity Data/ Emission Factor	Quality										
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
(d)	Factor for Non-consumed protein added to the wastewater ($F_{NON-CON}$)	H	H	H	H	H	H	H	H	H	H	H
(e)	Factor for Industrial and commercial co-discharged protein into the sewer system ($F_{IND-COM}$)	H	H	H	H	H	H	H	H	H	H	H
(f)	Nitrogen removed with sludge (N_{SLUDGE})	H	H	H	H	H	H	H	H	H	H	H

Notes: H- high, L-low
Source: Author's analysis

3.6.2 Methodology

The overall methodology followed for domestic wastewater related state-level CH_4 emission estimates is consistent with the IPCC Tier 1 approach. For N_2O emission estimates, a Tier 1 approach has been largely followed with state-wise average protein consumption values over the years used to estimate emissions. As indicated earlier, while a majority of the activity data used is state/country specific, default values of the emission factors as per the 2006 IPCC Guidelines have been used in the estimates for CH_4 and N_2O emission. A top-down approach is largely followed to estimate CH_4 and N_2O emission from domestic wastewater, with bottom up data on STPs used to some extent in the estimates for urban areas.

Table 25: Type of Emission Factor and Level of Methodological Tier adopted for Domestic Wastewater Treatment and Discharge State-level Estimates

IPCC ID	GHG source & sink categories	CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor
4D1	**Domestic wastewater treatment and discharge**	**T1**	**D**	**T1**	**D**

Notes: T1: Tier 1; CS: Country-specific; D: IPCC default

CH_4 Emissions from Domestic Wastewater Treatment and Discharge

Calculation of CH_4 emission from treatment of domestic wastewater is largely based on the State population and the degree of utilization of treatment system or discharge pathways relevant to urban and rural residents respectively. The total organics in wastewater determine the quantum of CH_4 emissions.

As per the 2006 IPCC Guidelines, the following equation is used to estimate CH_4 emissions from domestic wastewater treatment and discharge

$$CH4\ Emissions = \sum_{i,j}[(U_i * Ti_{,j} * EFj)](TOW - S) - R$$

Where,

CH_4 Emissions	= Methane emissions in inventory year, kg CH_4/yr
TOW	= total organics in wastewater in inventory year, kg BOD/yr
S	= organic component removed as sludge in inventory year, kg BOD/yr (default value of 0) (IPCC, 2006)[57]
Ui	= fraction of population in income group i in inventory year
Ti,j	= degree of utilization of treatment/discharge pathway or system, j, for each income group Fraction i in inventory year
i	= income group: rural, urban residents for the respective state
j	= each treatment/discharge pathway or system
EFj	= emission factor, kg CH_4 / kg BOD
R	= amount of CH_4 recovered in inventory year, kg CH_4/yr (default value of 0) ((IPCC, 2006)[58]

The emission factor EF_j is applicable for the various type treatment system or discharge pathways based on the corresponding MCF values as listed in Table 25. It is a function of the maximum CH_4 producing potential (Bo) and the methane correction factor (MCF) for the wastewater treatment and discharge system (IPCC, 2006)[59]. The MCF indicates the extent to which the CH_4 producing capacity (Bo) is realized in each type of treatment and discharge pathway and system.

$$CH4\ Emission\ Factor\ EF_j = B_o * MCFj$$

Where,

EFj	= emission factor, kg CH_4/kg BOD
j	= each treatment/discharge pathway or system
Bo	= maximum CH_4 producing capacity, kg CH4/kg BOD (Default value 0.6) (IPCC, 2006)[60]
MCFj	= methane correction factor (fraction)

The default MCF values for different types of domestic wastewater treatment and discharge pathways as available in the 2006 IPCC guidelines are given in Table 26.

Table 26: Default MCF values by treatment type and discharge pathway

[57] As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Section 6.2.1. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

[58] As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Section 6.2.1 and NEERI document on Inventorization of Methane Emissions from Domestic & Key Industries Wastewater – Indian Network for Climate Change Assessment, 2010. Available at: http://www.moef.nic.in/sites/default/files/M%20Karthik.pdf

[59] As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Equation 6.2. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

[60] As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Table 6.2. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

Type of treatment and discharge pathway or system	Description	MCF
Untreated system		
Sea, river and lake discharge	Rivers with high organic loadings can turn anaerobic	0.1
Stagnant sewer	Open and warm	0.5
Flowing sewer (open or closed)	Fast moving, clean. (Insignificant amounts of CH_4 from pump stations, etc.)	0
Treated system		
Centralized, aerobic treatment plant	Must be well managed. Some CH_4 can be emitted from settling basins and other pockets.	0
Centralized, aerobic treatment plant	Not well managed. Overloaded.	0.3
Anaerobic digester for sludge	CH_4 recovery is not considered here.	0.8
Anaerobic reactor	CH_4 recovery is not considered here.	0.8
Anaerobic shallow lagoon	Depth less than 2 metres, use expert judgment	0.2
Anaerobic deep lagoon	Depth more than 2 metres	0.8
Septic system	Half of BOD settles in anaerobic tank	0.5
Latrine	Dry climate, ground water table lower than latrine, small family (3-5 persons)	0.1
Latrine	Dry climate, ground water table lower than latrine, communal (many users)	0.5
Latrine	Wet climate/flush water use, ground water table higher than latrine	0.7
Latrine	Regular sediment removal for fertilizer	0.1

Source: 2006 IPCC Guidelines, Vol. 5, Chapter 6; Table 6.3

A key parameter for this source category is the total amount of organically degradable material in the wastewater (TOW). This parameter is a function of human population and Biochemical Oxygen Demand (BOD)[61] content of wastewater generated per person. It is expressed in terms of biochemical oxygen demand (kg BOD/year).

The equation for TOW in domestic wastewater is[62]:

$$\boldsymbol{TOW = P * BOD * 0.001 * I * 365}$$

Where,

TOW = total organics in wastewater in inventory year, kg BOD/yr
P = population in inventory year, (person)
BOD = state-specific per capita BOD in inventory year, g/person/day,
0.001 = conversion from grams BOD to kg BOD
I = correction factor for additional industrial BOD discharged into sewers

A sample calculation with the detailed computation of emissions is provided in Appendix 6.10.

[61] The principal factor in determining the CH_4 generation potential of domestic wastewater is the amount of degradable organic material in the wastewater i.e. BOD content. Wastewater with higher BOD concentrations will generally yield more CH_4 than wastewater with lower BOD concentrations. Both the type of wastewater and the type of bacteria present in the wastewater influence the BOD concentration of the wastewater.
[62] As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Equation 6.3. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

Data Sources and Assumptions

1. Population

The urban and rural population for the Indian states for the emission estimation period of 2005-2015 is based on the population data and decadal population growth trends as per the Census of India, 2001 and Census of India, 2011. The state of Telangana was separated from Andhra Pradesh in year 2014 and therefore, the population of Andhra Pradesh from the year 2014 is based on the population of districts belonging to Andhra Pradesh after the separation (population and growth rate as per the Census of India 2011). The detailed population and population growth of urban and rural Telangana has been referred from the statistical publication of the Government of Telangana[63].

2. Fraction of Population in income group i (U_i)

The 2006 IPCC Guidelines do not include information on sub-national or state-level data on distribution of India's population in urban and rural areas. State-wise data on the proportion of urban and rural population for India is available from the population estimates of Census of India for 2001 and 2011 and has been used in the emission estimates for 2005-2015 (see Appendix 6.5). However, the Census data does not provide information to help estimate the distribution of urban population into two income groups- urban low income and urban high income - as classified in the 2006 IPCC Guidelines. Therefore, urban and rural are the only two population categories considered in the state emission estimation.

Assumption: Since only decadal information on the share of urban and rural population is available from the Census of India, the proportion of urban and rural population as per Census of India 2001 and Census of India 2011 is assumed to be applicable for the two time-periods 2005-2010 and 2011-2015 respectively which cover the reporting period in the emission estimates. For the state of Telangana, the rural and urban population values available for 2014 and 2015 have been estimated based on the 2011 census data (based on the population growth rate of districts that constitute Telangana).

3. Degree of Utilization of treatment/discharge pathway or system j, for each income group fraction i ($T_{i,j}$)

The degree of utilization expresses the contribution or share (in terms of a fraction) of each discharge system in the treatment of all the wastewater generated by each income group viz., Rural and Urban. This is a key parameter since this relates to the proportion of the resident population using different wastewater treatment/discharge pathways or systems. For example, the IPCC default degree of utilization rates listed for Urban High-Income group in Table 27 implies that of the total urban high-income population, 18% use on-site septic tanks, 8% use on-site latrines, 67% are served by sewer systems and 7% use systems other than these to discharge and treat their domestic wastewater.

[63] As per Statistical Year Book 2017, Government of Talangana, Table 1.4, 1.5 & 1.6
Available at https://www.telangana.gov.in/PDFDocuments/Statistical-Year-Book-2017.pdf

Each of treatment/discharge pathways or systems will have different CH_4 emission factors (based on IPCC defined MCF values as listed in Table 26); thereby having a varying contribution to the GHG emissions. The default national-level values of degree of utilization rates specified in the 2006 IPCC Guidelines for Urban high income, urban low income, and rural population in India are given in Table 27. The treatment/discharge pathways or systems are broadly classified by the 2006 IPCC Guidelines into collected systems (i.e. wherein wastewater is conveyed using a sewer network) and uncollected systems (wastewater not conveyed using a sewer network).

The 2006 IPCC Guidelines, however, do not include activity data on state-level values for degree of utilization of different treatment/discharge pathway or system across India. Therefore, country-specific state-level data available on connectivity to wastewater treatment/discharge systems from Census of India 2001 and 2011 has been used to estimate the corresponding degree of utilization rates for the urban and rural population. Information recorded in the Census surveys on household connectivity to different treatment/discharge system types has been reclassified into the corresponding IPCC defined categories. For the urban population, this has been further disaggregated using state specific data available on the extent and type of treatment for wastewater collected through sewerage network. The following sections further describe the approach for degree of utilization for urban wastewater and rural wastewater.

Table 27: Default India specific Degree of Utilization Rates for Domestic Wastewater Treatment/Discharge Pathways or Systems

Income Group	Treatment/discharge type used as per 2006 IPCC Guidelines	Classification of the system as per 2006 IPCC Guidelines (Collected/Uncollected and Treatment)	Degree of utilization of treatment/ Discharge pathway or system j, for each income group fraction i ($T_{i,j}$)
Urban High Income	Septic Tank	Uncollected (Treatment on-site)	0.18
	Latrine	Uncollected (Treatment on-site)	0.08
	Other	Uncollected (No Treatment)	0.07
	Sewer	Collected (Treatment/No Treatment)	0.67
	None	Uncollected (No Treatment)	0
Urban Low Income	Septic Tank	Uncollected (Treatment on-site)	0.14
	Latrine	Uncollected (Treatment on-site)	0.10
	Other	Uncollected (No Treatment)	0.03
	Sewer	Collected (Treatment/No Treatment)	0.53
	None	Uncollected (No Treatment)	0.20
Rural	Septic Tank	Uncollected (Treatment on-site)	0
	Latrine	Uncollected (Treatment on-site)	0.47
	Other	Uncollected (No Treatment)	0.1
	Sewer	Collected (Treatment/No Treatment)	0.1
	None	Uncollected (No Treatment)	0.33

Source: Based on 2006 IPCC Guidelines, Vol. 5, Chapter 6 Figure 6.1, Table 6.1 and Table 6.5

Urban Domestic Wastewater:

The Census household survey through its dataset on the ‘availability of several types of latrine facilities’ (Ministry of Home Affairs, 2012) provides state-wise information on the use of different wastewater treatment/discharge systems by urban households (see Table 28 for sample data for the state of Andhra Pradesh). This ‘Latrine facility’ related dataset captures the portion of domestic wastewater that is collected through the sewer network in urban areas as well as the portion of wastewater that is not collected through the sewer network (either treated on-site through systems such septic tanks/latrines or discharged without any kind of treatment). For instance, the ‘piped sewer system’ category in Table 28 refers to sewer network to collect faecal sludge and wastewater and thus, it is inferred that 33.7% of the urban households in Andhra Pradesh were connected to sewer network in 2011.

It is possible to utilize this state-wise data available from the ‘Latrine facility’ dataset and classify it as per the IPCC defined wastewater treatment/discharge pathways i.e. septic tank, sewer, latrine, others and none. The ‘Latrine facility’ dataset covers the collected and uncollected as well as the treated and untreated portions of domestic wastewater. The derived degree of utilization rates (which indicate the distribution of wastewater flows through different treatment/discharge pathways) using this dataset sum up to 100 percent, as recommended by the 2006 IPCC Guidelines.

Other datasets are available from the Census of India surveys (independent of ‘latrine facility’ dataset) that provide information on ‘type of drainage connectivity in households’[64]. However, the classification of wastewater discharge pathways reported in these datasets is limited and therefore it is difficult to align this information with the IPCC defined classification of wastewater treatment/discharge pathways. Therefore, the ‘Latrine facility’ dataset from the Census 2011 and 2001 has been used a single data source for the state-level activity data on degree of utilization. The approach adopted is explained further using the case of Andhra Pradesh state below.

The Census of India 2001 in its household survey classified ‘latrine facilities’ into four types namely Water closet, pit latrine, other latrine and no latrine (see Table 27). In the Census of India 2011 survey on household amenities and assets, these ‘latrine facilities’ are further sub divided into additional categories as follows-

- 'Water closet is further categorized into ‘Piped sewer system’, ‘Septic tank’, and ‘Other system’
- Other latrine: ‘Night soil disposed into open drain’, ‘Service latrine’ (Night soil removed by human, Night soil serviced by animals)
- Pit latrine: With slab/ventilated improved pit, without slab/open pit
- No latrine within premises

Table 28: Latrine facility types as reported in Census of India for Urban Households in Andhra Pradesh

[64] Available at http://www.censusindia.gov.in/2011census/Hlo-series/HH09.html

Census of India – 2001		Census of India – 2011		Remarks on CH_4 emission generation
Classification of latrine facility	**Percent of Urban Households connected**	**Classification of latrine facility**	**Percent of Urban Households connected**	
Water Closet	47.0%	Water Closet	79.4%	
		- Piped sewer system	33.7%	Generates CH_4 emission, Emission is dependent on what proportion undergoes treatment downstream & the type of treatment (aerobic or anaerobic) and the proportion of collected wastewater that is discharged without any treatment
		- Septic tank	44.4%	Generates CH_4 emission
		- Other system	1.3%	Does not generate CH_4 emissions as Census of India defines these as latrine systems which discharge wastewater to open areas such as streets, yards, drainage ditch, which will therefore lead to wastewater decomposition in aerobic condition
Pit Latrine	15.1%	**Pit Latrine**	4.1%	
		- With slab/ ventilated improved pit	3.9%	Generates CH_4 emission
		- Without Slab/ Open pit	0.2%	Generates CH_4 emission
Other Latrine	16.0%	Other Latrine	2.6%	
		- Night soil disposed into open drain	2.1%	Does not generate CH_4 emission as the wastewater is disposed into open drain, which will therefore lead to wastewater or septage decomposition under aerobic conditions
		- Night soil removed by humans	0.1%	Does not generate CH_4 emissions as Census of India indicates that these systems will discharge wastewater/ septage into open areas which will therefore lead to wastewater decomposition in aerobic condition
		-Night soil serviced by animals	0.4%	Does not generate CH_4 emissions as Census of India indicates that these systems will discharge wastewater/ septage into open areas which will therefore lead to wastewater

Census of India – 2001		Census of India – 2011		Remarks on CH_4 emission generation
Classification of latrine facility	**Percent of Urban Households connected**	**Classification of latrine facility**	**Percent of Urban Households connected**	
				decomposition in aerobic condition
No latrine within premises	21.9%	No latrine within premises	13.9%	
		- Public latrine	2.0%	Generates CH_4 emission
		- Open Defecation	11.9%	Does not generate CH_4 emission as decomposition under aerobic conditions

Source: Author's analysis and compilation based on Census of India data

<u>Note:</u> Discharge or treatment systems which generate CH_4 emission in rural areas indicated in bold in the table

For 2011, the degree of utilization for septic tank and latrine systems (including public, other latrine system) for Andhra Pradesh can be estimated directly based on the Census of India 2011 data (see Table 29 and Figure 17). However, the classification of septic tank and latrine systems in the Census of India 2001 is not as detailed as that in Census 2011, thereby presenting challenges in estimating corresponding degree of utilization. For instance, based on the Census 2001 data it is not possible to infer how many of the 47% urban households connected to 'Water closet' facility in Andhra Pradesh are using septic tanks.

In such cases, corresponding proportions of these systems which are available in the Census 2011 data have been used to estimate the percentage distribution of these systems in year 2001. For example, from the Census 2011 data, the percentage contribution of Septic tank in 'Water closet' latrine facility works out to 55.92% (i.e.44.4% ÷ 79.4%) (see Table 28 and Table 29). This proportion has been applied to the total percentage of households connected to 'Water closet' in 2001 to further estimate the percentage of households connected to septic tanks in 2001 as 26.28% i.e. 55.92% of 47% (see Table 30). The proportion of 'piped sewer systems' in 2001 under the 'Water closet' category has been estimated similarly. Public latrines in the 'No latrine within premises' category in 2011 (i.e. 2% ÷ 13.9% = 14.39%) has been used to estimate the proportion of public latrines in 2001 as 2.14% (i.e. 14.39% of 21.9%). Schematic in Appendix 6.3 depicts the classification of wastewater discharge/treatment systems and corresponding degree of utilization rates estimated for the urban population in 2001.

Assumption for Overall Degree of Utilization Rates: Since only decadal information on the use of different wastewater treatment/discharge pathways by the Urban population is available from the Census of India, the corresponding degree of utilization estimated for the Urban population as per Census of India 2001 and Census of India 2011 data is assumed to be applicable for the two-time periods- 2005-2010 and 2011-2015 respectively across the reporting years in the emission estimates.

Further Assessment of Degree of Utilization for 'Sewer' to account for Untreated Wastewater and Type of Treatment (Aerobic/Anaerobic):
Regarding the urban households that are served by 'piped sewer system' category (i.e. 33.7% as per Census 2011 in case of Andhra Pradesh), it is necessary to further assess what proportion of the wastewater discharged by this subset undergoes either aerobic treatment or anaerobic treatment or is discharged without any treatment. This is because the quantum of CH_4 emission

generated will vary for each of these discharge pathways, given that the corresponding MCF value is different for each pathway (see Table 26). Therefore, reported data on wastewater generation, installed capacity of sewage treatment, the treatment technologies used in STPs has been analyzed for each state and subsequently the fractions for degree of utilization for 'sewer systems' have been further split up in to three pathways –

- 'Sewer - collected and not treated'
- 'Sewer - collected and anaerobic treatment' and
- 'Sewer - collected and aerobic treatment'

State-wise information related to STPs is not available for all the years from 2005-2015. Therefore, reported state-wise information on sewage generation and STPs that is available for the three years of 1999[65], 2008[66], and 2014[67] has been used in the assessment. Further, the data reported in these three years is not available for all the states consistently. For some states, the data is not available either for any of the years or is available for one year or two years. Therefore, in the case of unavailability of STP related information for a particular state and a particular year, datasets available in previous/subsequent point of time have been used accordingly.

The assumptions used to further estimate the state-wise degree of utilization for the three sewer pathways – sewer (collected and not treated), sewer (collected and anaerobic treatment), and sewer (collected and aerobic treatment) – based on different cases of state-level data availability are as follows:

State-level STP data available for years	Assumptions	States/union territories where this case applies
1999, 2008 and 2014	• STP data reported in 1999 is assumed to be applicable for the time period 2005-2007 • STP data reported in 2008 is assumed to be applicable for the time period	• Andhra Pradesh • Delhi • Goa • Gujarat • Haryana • Karnataka

[65] Estimated based on reported information referred from CPHEEO (2005): Status of Water Supply, Sanitation and Solid Waste Management in Urban Areas. Appendix 2: Table B-2 and Table B-3. Available at https://www.indiawaterportal.org/sites/indiawaterportal.org/files/Status%20Study_Water%20Supply_Sanitation_Solid%20Waste%20Management_CPHEEO_2005.pdf
[66] Estimated for 2008 based:
i) CPCB (2010): Annual report 2009-10. Information referred from Table 6.2, Table 6.3, Chapter XiV. Available at http://cpcb.nic.in/openpdffile.php?id=UmVwb3J0RmlsZXMvQW5udWFsUmVwb3J0XzQwX0FubnVhbF9SZXBvcnRfMDktMTAucGRm
ii) CPCB (2008): Evaluation of Operation and Maintenance of Sewage Treatment Plants in India-2007. Information referred from Table 2.1, Table 2.2 and Chapter 3. Available at http://cpcb.nic.in/openpdffile.php?id=UmVwb3J0RmlsZXMvTmV3SXRlbV85OV9OZXdJdGVtXzk5XzUucGRm
iii) CPCB (2013): Performance Evaluation of STPs under NCRD. Information referred from Table 2, Table 3, Table 4, Table 5, Table 8, Table 14, Annexure – IV. Available at http://cpcb.nic.in/openpdffile.php?id=UmVwb3J0RmlsZXMvMjlfMTQ1ODExMDk5Ml9OZXdJdGVtXzE5NV9TVFBfUkVQT1JULnBkZg==
iv) CPCB (2009): Status of Water Supply, Wastewater Generation and Treatment in Class-I Cities & Class-II Towns Of India. Information referred from Table 3.4, Table 3.5, Table 3.6, Table 3.11, Table 3.12, Table 3.18, Table 3.19. Available at http://cpcb.nic.in/openpdffile.php?id=UmVwb3J0RmlsZXMvTmV3SXRlbV8xNTNfRm9yZXdvcmQucGRm
[67] CPCB (2015): Inventorization of STPs. Information referred from Table 3 and Chapter 4. Available at http://www.cpcb.nic.in/upload/NewItems/NewItem_210_Inventorization_of_Sewage-Treatment_Plant.pdf

State-level STP data available for years	Assumptions	States/union territories where this case applies
	2008-2010 (since a number of STPs sanctioned after the commencement of the Jawaharlal Nehru National Urban Renewal Mission (2005-2012) were completed post 2007 and therefore this point in time is assumed to represent a significant change in the status of sewage treatment) • STP data reported in 2014 is assumed to be applicable for the time period 2011-2015 (to be consistent with the time period considered in using Census 2011 dataset for the degree of utilization rates)	• Kerala • Maharashtra • Tamil Nadu • Uttar Pradesh • West Bengal
1999 and 2014	• STP data reported in 1999 is assumed to be applicable for the time period 2005-2007 • STP data reported in 2014 is assumed to be applicable for the time period 2008-2015	• Chandigarh • Madhya Pradesh • Odisha • Puducherry • Punjab • Rajasthan
2008 and 2014	• STP data reported in 2008 is assumed to be applicable for the time period 2005-2010 • STP data reported in 2014 is assumed to be applicable for the time period 2011-2015	• Assam • Bihar • Uttarakhand
2014 only	• All the wastewater collected through the 'piped sewer system' is assumed to not undergo any treatment until the year 2010. Therefore, the corresponding degree of utilization value of 'piped sewer system' based on Census 2001 data is allocated solely to 'sewer -collected and not treated' category for the period 2005-2010. • STP data reported in 2014 is assumed to be applicable for the time period 2011-2015	• Jammu and Kashmir • Jharkhand • Sikkim • Tripura • Himachal Pradesh • Telangana state was formed in the year 2014 and therefore the STP data reported in 2014 is used for 2014 and 2015
STP data is not available for any year	All the wastewater collected through the 'piped sewer system' is assumed to not undergo any treatment across all the	• Andaman and Nicobar Islands • Arunachal Pradesh

State-level STP data available for years	Assumptions	States/union territories where this case applies
	years. Therefore, the corresponding degree of utilization value of 'piped sewer system' based on Census 2001 data is allocated solely to 'sewer -collected and not treated' category for the period 2005-2010.	• Chhattisgarh • Dadra and Nagar Haveli Daman and Diu • Lakshadweep • Manipur • Meghalaya • Mizoram • Nagaland

The classification of wastewater discharge/treatment systems and corresponding estimated values of degree of utilization for urban population for the state of Andhra Pradesh, based on Census 2011 data and state-level STP data reported for 2014, are given in Figure 17 and Table 29. These estimated values are assumed to be applicable for the time period 2011-2015.

The classification of wastewater discharge/treatment systems and corresponding estimated values of degree of utilization for the urban population in Andhra Pradesh, based on Census 2001 data and state-level STP data reported for 1999 and 2008, are given in Table 30 in this section and in Appendix 6.3. These estimated values are assumed to be applicable for the two time-periods of 2005-2007 and 2008-2010 as indicated.

The state-wise degree of utilization values considered for urban domestic wastewater in this assessment, based on Census 2011 and 2001 data are listed in Table 31 and Table 32.

Figure 16: Classification of Wastewater Treatment Systems and Estimated Degree of Utilization for Urban population, Andhra Pradesh, 2011

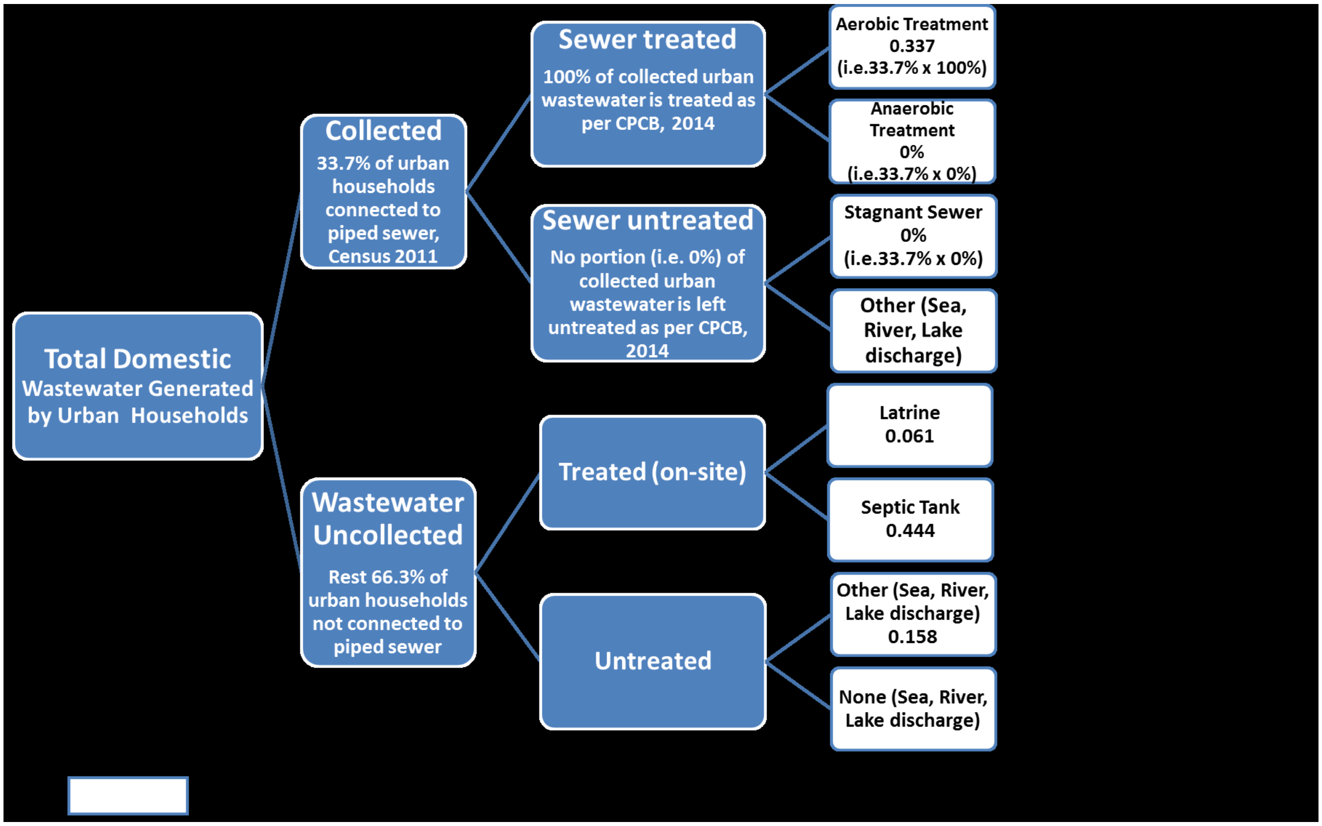


Table 29: Estimated degree of utilization of treatment/ Discharge pathway or system j, for Andhra Pradesh State Urban group fraction i (Ti,j), 2011 based on Census of India data

Classification of wastewater treatment/discharge system based on Census data[68]	Applicable Treatment/Discharge pathway or system (j) selected from Table 26 as per 2006 IPCC Guidelines[69]	Estimated degree of utilization of treatment/ Discharge pathway or system j, for Urban group fraction i (Ti,j) - 2011	Remarks
Piped sewer systems	-	0.337	33.7% of urban households connected to sewer network as per Census 2011. This cumulative degree of utilization value for 'piped sewer system' is split further based on STP data reported for the state.
	Stagnant Sewer (collected and not treated)	0.337x0%= 0	0% of collected domestic wastewater for Andhra Pradesh is not treated as per STP data reported for year 2014 (see Appendix 6.6).

[68] As per http://censusindia.gov.in/2011census/hlo/Data_sheet/India/Latrine.pdf
[69] Selected from Table 25 of this note and based on the 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Figure 6.1, Table 6.1 and Table 6.3.
Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

Classification of wastewater treatment/discharge system based on Census data[68]	Applicable Treatment/Discharge pathway or system (j) selected from Table 26 as per 2006 IPCC Guidelines[69]	Estimated degree of utilization of treatment/ Discharge pathway or system j, for Urban group fraction i (Ti,j) - 2011	Remarks
	Sewer (collected and aerobic treatment - Centralized, aerobic treatment plant, not well managed)	0.337x100%x 100%=0.337	100% of domestic wastewater is treated for Andhra Pradesh (i.e. 0% of not treated); of which 100% is treated with aerobic technology as per STP data reported for Andhra Pradesh year 2014 (see Appendix 6.6).
	Sewer (collected and anaerobic treatment - Anaerobic Reactor/ Anaerobic digester for sludge)	0.337x100%x0%=0	100% of domestic wastewater is treated for Andhra Pradesh (i.e. 0% of not treated); of which 0% is treated with anerobic technology as per STP data reported for Andhra Pradesh year 2014 (see Appendix 6.6).
Septic tank (under Water Closet)	Septic tank (Uncollected and Treatment on-site)	0.444	44.4% of urban households connected to septic tanks as per Census 2011
Pit Latrine	Latrine (Uncollected and Treatment on-site)	0.041	4.1% of urban households connected to pit latrines as per Census 2011
Public Latrine (under No latrine within premises	Latrine (Uncollected and Treatment on-site)	0.020	2.0% of urban households using public latrines as per Census 2011
Pathway for rest of wastewater that is uncollected and untreated	Others and None (Uncollected and No Treatment)	100%-33.7%-44.4%-4.4%-2.0%= 15.8% i.e. 0.158	The remaining proportion of the urban wastewater is estimated by deducting proportions of all the systems listed above in this table. This proportion represents wastewater that is neither collected nor treated. As per 2006 IPCC guidelines, the wastewater discharge/treatment pathways for uncollected and untreated wastewater are categorized as ‘Others’ and ‘None’. The distribution of Urban wastewater handled between these two categories cannot be estimated based on available information for Andhra Pradesh (also for other States and UTs) and hence the ‘Others’ and ‘None’ categories are clubbed together in the degree of utilization estimation.

Source: Author’s analysis and compilation based on Census of India data

Note: *Percentage values given in the Census data have been converted into fractions to express the degree of utilization rates*

Table 30: Estimated Degree of utilization of treatment/ Discharge pathway or system j, for Andhra Pradesh State Urban group fraction i ($T_{i,j}$), 2001 based on Census of India data

Classification of wastewater treatment/discharge system based on Census data[70]	Applicable Treatment/Discharge pathway or system (j) selected from Table 26 as per 2006 IPCC Guidelines[69]	Estimated degree of utilization of treatment/ Discharge pathway or system j, for Urban group fraction i (Ti,j) - 2001	Remarks
Piped sewer system	-	(33.7% ÷ 79.4%) x 47% = 19.95% i.e. 0.199	Piped sewer system accounts for 42.44% (i.e. 33.7% ÷ 79.4%) of 'Water closet' latrine facility as per Census 2011 data. This percentage is applied to the percentage of households connected to 'Water closet' in Andhra Pradesh (i.e. 47%) as per Census 2001 in order to estimate the corresponding proportion of households connected to septic tanks in 2001. This cumulative degree of utilization value for 'piped sewer system' is split further based on STP data reported for the state.
	Stagnant Sewer (collected and not treated)	a) 0.199 x 1.57% = 0.0031 (applicable for year 2008-2010)	1.57% of collected domestic wastewater for Andhra Pradesh is not treated as per STP data reported for year 2008 (see Appendix 6.6). The estimated degree of utilization value of 0.0031 is assumed to be applicable for the period 2008-2010 for Andhra Pradesh.
		b) 0.199 x 55.5% = 0.110 (applicable for year 2005-2007)	55.5% of collected domestic wastewater for Andhra Pradesh is not treated as per STP data reported for year 1999 (see Appendix 6.6). The estimated degree of utilization value of 0.110 is assumed to be applicable for the period 2005-2007 for Andhra Pradesh.
	Sewer (collected and aerobic treatment - Centralized, aerobic treatment plant, not well managed)	a) 0.199 x 98.43% x 100%= 0.1964 (applicable for year 2008-2010)	Remaining 98.43% of domestic wastewater is treated (i.e. 100%-1.57% that is not treated) for Andhra Pradesh; of which 100% is treated with aerobic technology for Andhra Pradesh as per STP data reported

[70] As per http://censusindia.gov.in/2011census/hlo/Data_sheet/India/Latrine.pdf

Classification of wastewater treatment/discharge system based on Census data[70]	Applicable Treatment/Discharge pathway or system (j) selected from Table 26 as per 2006 IPCC Guidelines[69]	Estimated degree of utilization of treatment/ Discharge pathway or system j, for Urban group fraction i (Ti,j) - 2001	Remarks
	Sewer (collected and aerobic treatment - Centralized, aerobic treatment plant, not well managed)		for year 2008. The estimated degree of utilization value of 0.1964 is assumed to be applicable for the period 2008-2010 for Andhra Pradesh.
		b) 0.199 x 44.5% x 100%= 0.0888 (applicable for year 2005-2007)	Remaining 44.5% of domestic wastewater is treated (i.e. 100%-55.5% that is not treated) for Andhra Pradesh; of which 100% is treated with aerobic technology as per STP data reported for Andhra Pradesh for year 1999. The estimated degree of utilization value of 0.0888 is assumed to be applicable for the period 2005-2007 for Andhra Pradesh.
	Sewer (collected and anaerobic treatment - Anaerobic Reactor/ Anaerobic digester for sludge)	a) 0.199 x 98.43% x 0%= 0(applicable for year 2008-2010)	Remaining 98.43% of domestic wastewater is treated (i.e. 100%-1.57% that is not treated) for Andhra Pradesh; of which 0% is treated with anaerobic technology as per STP data reported for Andhra Pradesh year 2008. The estimated degree of utilization value of 0 is assumed to be applicable for the period 2008-2010 for Andhra Pradesh.
		b) 0.199 x 98.43% x 0%=0 (applicable for year 2005-2007)	Remaining 45.5% of domestic wastewater is treated (i.e. 100%-55.5% that is not treated) for Andhra Pradesh; of which 100% is treated with aerobic technology as per STP data reported for Andhra Pradesh for year 1999. The estimated degree of utilization value of 0 is assumed to be applicable for the period 2005-2007 for Andhra Pradesh.
Septic tank (under Water Closet)	Septic tank (Uncollected and Treatment on-site)	(44.4% ÷ 79.4%) x 47% = 26.3% i.e. 0.263	Septic tanks account for 75.77% of 'Water closet' latrine facility as per Census 2011. This percentage is applied to the percentage of households connected to 'Water closet' (i.e. 7.1%) as per Census 2001 in order to estimate the corresponding proportion of households connected to septic tanks in 2001.

Classification of wastewater treatment/discharge system based on Census data[70]	Applicable Treatment/Discharge pathway or system (j) selected from Table 26 as per 2006 IPCC Guidelines[69]	Estimated degree of utilization of treatment/ Discharge pathway or system j, for Urban group fraction i (Ti,j) - 2001	Remarks
Pit Latrine	Latrine (Uncollected and Treatment on-site)	0.15	10.3% of urban households connected to pit latrines as per Census 2001
Public Latrine (under No latrine within premises)	Latrine (Uncollected and Treatment on-site)	(2% ÷ 13.9%) x 21.9% = 3.15% i.e. 0.032	Census 2001 does not include information for public latrines separately. Public latrines account for 14.39% of 'No latrine within premises' category as per Census 2011. This percentage is applied to the percentage of households having 'No latrine within premises' (i.e. 21.9%) as per Census 2001 to estimate the corresponding proportion of households using public latrines in 2001.
Pathway for rest of wastewater that is uncollected and untreated	Others and None (Uncollected and No Treatment)	100%-19.95%-26.28%-0.15%-3.15%= 35.52% i.e. 0.3552	The remaining proportion of the urban wastewater is estimated by deducting proportions of all the systems listed above in this table. This proportion represents wastewater that is neither collected nor treated. As per 2006 IPCC guidelines, the wastewater discharge/treatment pathways for uncollected and untreated wastewater are categorized as 'Others' and 'None'. The distribution of Urban wastewater handled between these two categories cannot be estimated based on available information for Andhra Pradesh and hence the 'Others' and 'None' categories are clubbed together in the degree of utilization estimation.

Source: Author's analysis and compilation based on Census of India data

Table 31: State-wise Degree of utilization considered in the estimates- Urban, 2011

State/Union Territory	Piped sewer system	Septic tank	Pit Latrine	Public Latrine	Others/None
Andaman and Nicobar Islands	3.00%	83.20%	0.20%	5.10%	8.50%
Andhra Pradesh	33.70%	44.40%	4.10%	2.00%	15.80%
Arunachal Pradesh	13.80%	53.60%	13.90%	3.80%	14.90%
Assam	15.00%	50.30%	21.00%	1.30%	12.40%
Bihar	7.20%	52.70%	4.50%	2.20%	33.40%
Chandigarh	85.90%	0.90%	0.50%	9.20%	3.50%
Chhattisgarh	9.10%	48.60%	1.10%	5.40%	35.80%
Dadra and Nagar Haveli	8.00%	71.70%	0.70%	7.60%	12.00%
Daman and Diu	6.30%	77.60%	1.10%	10.50%	4.50%
Delhi	60.50%	24.70%	1.70%	7.10%	6.00%
Goa	18.60%	59.30%	3.50%	5.20%	13.40%
Gujarat	60.40%	24.20%	2.10%	3.60%	9.70%
Haryana	54.80%	23.80%	7.70%	1.30%	12.40%
Himachal Pradesh	40.70%	45.30%	0.80%	4.00%	9.20%
Jammu and Kashmir	25.30%	37.90%	4.30%	1.80%	30.70%
Jharkhand	14.00%	49.20%	1.80%	1.80%	33.20%
Karnataka	53.30%	17.00%	11.90%	4.40%	13.40%
Kerala	14.30%	56.70%	21.80%	0.90%	6.30%
Lakshadweep	2.90%	93.80%	0.50%	0.40%	2.40%
Madhya Pradesh	20.20%	50.10%	1.60%	3.30%	24.80%
Maharashtra	37.80%	28.60%	2.40%	21.00%	10.20%
Manipur	7.40%	43.10%	23.30%	1.90%	24.30%
Meghalaya	9.70%	68.70%	12.30%	1.90%	7.40%
Mizoram	5.10%	71.30%	17.20%	0.60%	5.80%
Nagaland	4.50%	67.30%	15.00%	3.20%	10.00%
Odisha	11.50%	45.00%	4.20%	2.00%	37.30%
Puducherry	19.90%	60.90%	0.60%	5.80%	12.80%
Punjab	63.70%	19.90%	6.80%	0.80%	8.80%
Rajasthan	25.60%	45.60%	5.50%	1.30%	22.00%
Sikkim	34.40%	55.70%	3.30%	2.60%	4.00%
Tamil Nadu	27.40%	37.90%	6.90%	8.60%	19.20%
Telangana	0.00%	0.00%	0.00%	0.00%	100.00%
Tripura	6.70%	37.60%	47.00%	0.80%	7.90%
Uttar Pradesh	28.30%	46.90%	2.90%	2.10%	19.80%
Uttarakhand	31.70%	53.10%	6.60%	1.70%	6.90%
West Bengal	13.60%	45.40%	22.60%	3.70%	14.70%

Source: Author's compilation

Table 32: State-wise Degree of utilization considered in the estimates- Urban, 2001

State/Union Territory	Piped sewer system	Septic tank	Pit Latrine	Public Latrine	Others/None
Andaman and Nicobar Islands	2.03%	56.27%	6.70%	9.29%	25.72%
Andhra Pradesh	19.95%	26.28%	15.10%	3.15%	35.52%
Arunachal Pradesh	5.18%	20.11%	32.10%	4.70%	37.91%
Assam	12.43%	41.67%	26.40%	1.11%	18.39%
Bihar	4.93%	36.08%	11.40%	2.14%	45.45%
Chandigarh	69.90%	0.73%	1.00%	14.76%	13.60%
Chhattisgarh	6.01%	32.12%	5.20%	6.43%	50.23%
Dadra and Nagar Haveli	7.14%	64.01%	3.50%	9.27%	16.08%
Daman and Diu	4.53%	55.85%	3.40%	24.88%	11.33%
Delhi	33.31%	13.60%	15.20%	14.76%	23.13%
Goa	8.98%	28.62%	18.70%	10.90%	32.81%
Gujarat	44.08%	17.66%	9.80%	5.71%	22.76%
Haryana	21.08%	9.15%	26.50%	2.48%	40.79%
Himachal Pradesh	23.28%	25.91%	12.00%	8.37%	30.45%
Jammu and Kashmir	9.79%	14.66%	20.20%	1.89%	53.46%
Jharkhand	8.91%	31.33%	7.40%	1.83%	50.53%
Karnataka	33.47%	10.68%	20.70%	7.23%	27.93%
Kerala	14.21%	56.32%	11.10%	2.77%	15.60%
Lakshadweep	2.09%	67.74%	0.80%	2.82%	26.54%
Madhya Pradesh	11.61%	28.80%	11.90%	4.13%	43.56%
Maharashtra	24.94%	18.87%	7.10%	30.66%	18.44%
Manipur	2.38%	13.87%	67.00%	2.13%	14.62%
Meghalaya	5.09%	36.05%	33.10%	3.71%	22.05%
Mizoram	2.18%	30.44%	54.50%	0.80%	12.08%
Nagaland	1.13%	16.91%	40.50%	3.50%	37.96%
Odisha	8.43%	32.98%	9.50%	2.29%	46.80%
Puducherry	14.58%	44.60%	2.20%	11.28%	27.34%
Punjab	34.64%	10.82%	20.50%	1.64%	32.40%
Rajasthan	14.12%	25.15%	18.20%	1.73%	40.80%
Sikkim	32.57%	52.73%	1.90%	4.44%	8.36%
Tamil Nadu	18.78%	25.97%	11.20%	12.38%	31.67%
Telangana	-	-		-	-
Tripura	5.78%	32.41%	44.80%	1.14%	15.87%
Uttar Pradesh	11.73%	19.44%	18.10%	2.49%	48.24%
Uttarakhand	15.04%	25.19%	26.70%	3.48%	29.59%
West Bengal	12.21%	40.75%	22.90%	3.75%	20.39%

Source: Author’s compilation

Rural Domestic Wastewater:

As in the case of urban domestic wastewater, information reported by the Census of India 2011 and 2001 has been used to arrive at the degree of utilization rates for rural domestic wastewater. The Census household survey through its dataset on the ‘availability of diverse types of latrine facilities’ (Ministry of Home Affairs, 2012) provides state-wise information on the use of different wastewater treatment/discharge systems by rural households (see Table 33 for sample data for Andhra Pradesh).

In Andhra Pradesh, the ‘piped sewer system’ category in the Census survey dataset refers to sewerage network to collect faecal sludge and wastewater. Thus, it is inferred that 2.3% of rural households were connected to sewer network in 2011 and represent the collected portion of rural domestic wastewater. However, given that wastewater treatment facilities are largely absent in rural areas, the rural wastewater that is collected through the sewer network largely does not undergo any treatment downstream of the sewer network. Therefore, the portion of rural domestic wastewater that is collected and conveyed through the sewer network is assumed to not undergo any treatment and decomposes under aerobic conditions, thereby not leading to CH_4 emission – unlike the urban domestic wastewater wherein wastewater discharged through sewer network is a source of emission. The remaining portion of rural domestic wastewater (that is not collected through the sewer network) is either treated on-site through systems such septic tanks and latrines or discharged without any kind of treatment (see Figure 18).

Table 33: Latrine facility types as reported in Census of India for Rural Households in Andhra Pradesh

Census of India – 2001		Census of India – 2011		Remarks on CH_4 emission generation
Classification of latrine facility	**Percent of Rural Households connected**	**Classification of latrine facility**	**Percent of Rural Households connected**	
Water Closet	8.6%	Water Closet	25.7%	
		- Piped sewer system	2.3%	Does not generates CH_4 emission as there is no treatment downstream and decomposes under aerobic condition
		- Septic tank	22.6%	Generates CH_4 emission
		- Other system	0.80%	Does not generate CH_4 emissions as Census of India defines these as latrine systems which discharge wastewater to open areas such as streets, yards, drainage ditch, which will therefore lead to wastewater decomposition in aerobic condition
Pit Latrine	6.4%	**Pit Latrine**	6%	
		- With slab/ ventilated improved pit	5.4%	Generates CH_4 emission

Census of India – 2001		Census of India – 2011		Remarks on CH_4 emission generation
Classification of latrine facility	**Percent of Rural Households connected**	**Classification of latrine facility**	**Percent of Rural Households connected**	
		- Without Slab/ Open pit	0.6%	Generates CH_4 emission
Other Latrine	3.1%	Other Latrine	0.4%	
		- Night soil disposed into open drain	0.2%	Does not generate CH_4 emission as the wastewater is disposed into open drain, which will therefore lead to wastewater or septage decomposition under aerobic conditions
		- Night soil removed by humans	0.0%	Does not generate CH_4 emissions as Census of India indicates that these systems will discharge wastewater/ septage into open areas which will therefore lead to wastewater decomposition in aerobic condition
		-Night soil serviced by animals	0.2%	Does not generate CH_4 emissions as Census of India indicates that these systems will discharge wastewater/ septage into open areas which will therefore lead to wastewater decomposition in aerobic condition
No latrine within premises	81.9%	No latrine within premises	67.8%	
		- Public latrine	2.7%	Generates CH_4 emission
		- Open Defecation	65.1%	Does not generate CH_4 emission as decomposition under aerobic conditions

Source: Author's analysis and compilation based on Census of India data

Note: Discharge or treatment systems which generate CH_4 emission in rural areas are indicated in bold in the table

For 2011, the degree of utilization for septic tank and latrine systems (including public, other latrine system) can be estimated directly based on the Census of India 2011 data (see Table 34 and Figure 18). However, the classification of septic tank and latrine systems in the Census of India 2001 is not as detailed as that in Census 2011, thereby presenting challenges in estimating corresponding degree of utilization. For instance, based on the Census 2001 data it is not possible to infer how many of the 8.6% rural households in Andhra Pradesh connected to 'Water closet' facility is using septic tanks. In such cases, corresponding proportions of these systems which are available in the Census 2011 data have been used to estimate the percentage distribution of these systems in year 2001. This approach is similar to that followed in the case of urban domestic wastewater.

For example, from the Census 2011 data, the percentage contribution of Septic tank in 'Water closet' latrine facility works out to 87.94% (i.e.22.6% ÷ (2.3%+22.6%+0.8%)). This proportion has been applied to the total percentage of households connected to 'Water closet' in 2001, to further work out the percentage of households connected to septic tanks in 2001 as 7.56% i.e. 87.94% of 8.6% (see Table 35). The proportion of 'piped sewer systems' in 2001 under the 'Water closet' category has been estimated similarly. Public latrines in the 'No latrine within premises' category in 2011 (i.e. 3.98%) has been used to estimate the proportion of public latrines in 2001 as 3.26% (i.e. 3.98% of 81.90%). Schematic in Appendix 6.4 depicts the classification of wastewater discharge/treatment systems and corresponding degree of utilization rates estimated for the rural population in 2001.

The state-wise degree of utilization values considered for rural domestic wastewater in this assessment, based on Census of India 2011 and 2001 data are listed in Table 36 and Table 37.

Assumption: Since only decadal information on the use of different wastewater treatment/discharge pathways by the rural population is available from the Census of India, the corresponding degree of utilization estimated for the rural population as per Census of India 2001 and Census of India 2011 data is assumed to be applicable for the two time-periods 2005-2010 and 2011-2015 respectively across the reporting years in the emission estimates.

Figure 17: Classification of Wastewater Treatment Systems and Estimated Degree of Utilization for Rural Andhra Pradesh, 2011

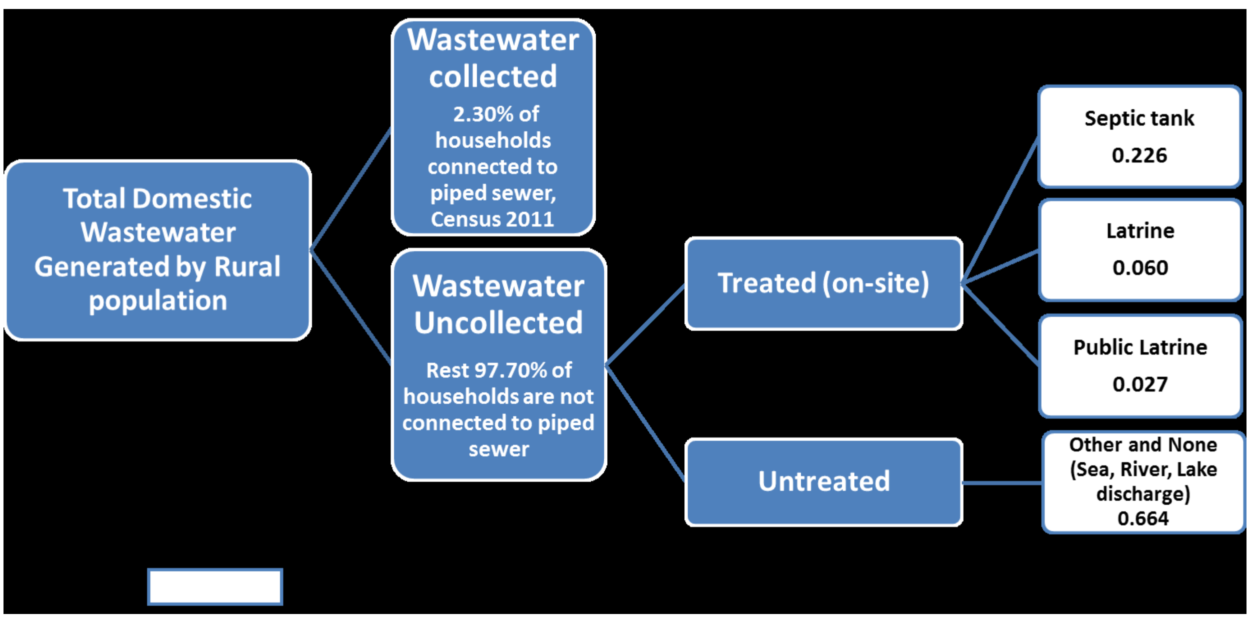


Table 34: Estimated degree of utilization of treatment/ Discharge pathway or system j, for Andhra Pradesh State Rural group fraction i (Ti,j), 2011 based on Census of India data

Classification of wastewater treatment/discharge system based on Census data[68]	Applicable Treatment/Discharge pathway or system (j) selected from Table 25 as per 2006 IPCC Guidelines[69]	Estimated degree of utilization of treatment/ Discharge pathway or system j, for Rural group fraction i (Ti,j) - 2011	Remarks
Piped sewer systems	Sewer (Collected and No Treatment)	0.023	2.3% of rural households connected to sewer network as per Census 2011
Septic tank (under Water Closet)	Septic tank (Uncollected and Treatment on-site)	0.226	22.6% of rural households connected to septic tanks as per Census 2011
Pit Latrine	Latrine (Uncollected and Treatment on-site)	0.06	6% of rural households connected to pit latrines as per Census 2011
Public Latrine (under No latrine within premises	Latrine (Uncollected and Treatment on-site)	0.027	2.7% of rural households using public latrines as per Census 2011
Pathway for rest of wastewater that is uncollected and untreated	Others and None (Uncollected and No Treatment)	100% - 2.30% - 22.6% - 6% - 2.7% = 66.4% i.e. 0.664	The remaining proportion of the rural wastewater is estimated by deducting proportions of the 4 systems listed above in this table. This proportion represents wastewater that is neither collected nor treated. As per 2006 IPCC guidelines, the wastewater discharge/treatment pathways for uncollected and untreated wastewater are categorized as 'Others' and 'None'. The distribution of rural wastewater handled between these two categories cannot be estimated based on available information for India and hence the 'Others' and 'None' categories are clubbed together in the degree of utilization estimation.

Source: Author's compilation and analysis based on Census of India data

Note: Percentage values given in the Census data have been converted into fractions to express the degree of utilization rates

Table 35: Estimated Degree of utilization of treatment/ Discharge pathway or system j, for Andhra Pradesh Rural group fraction i (Ti,j), 2001 based on Census of India data

Classification of wastewater treatment/discharge system based on Census data[68]	Applicable Treatment/Discharge pathway or system (j) selected from Table 25 as per 2006 IPCC Guidelines[69]	Estimated degree of utilization of treatment/ Discharge pathway or system j, for Rural group fraction i (Ti,j) - 2001	Remarks
Piped sewer system	Sewer (Collected and No Treatment)	(2.3% ÷ 25.7%)x 8.6% = 0.77% i.e. 0.077	Piped sewer system accounts for 8.95% (i.e. 2.3% ÷ 25.7%) of 'Water closet' latrine facility as per Census 2011. This percentage is applied to the percentage of households connected to 'Water closet' (i.e. 8.6%) as per Census 2001 in order to estimate the corresponding proportion of households connected to septic tanks in 2001.
Septic tank (under Water Closet)	Septic tank (Uncollected and Treatment on-site)	(22.6 ÷ 25.7%) x 8.6% = 7.56% i.e. 0.0756	Septic tanks account for 87.94% (i.e. 22.6 ÷25.7%) of 'Water closet' latrine facility as per Census 2011. This percentage is applied to the percentage of households connected to 'Water closet' (i.e. 8.6%) as per Census 2001 in order to estimate the corresponding proportion of households connected to septic tanks in 2001.
Pit Latrine	Latrine (Uncollected and Treatment on-site)	0.064	6.4% of rural households connected to pit latrines as per Census 2001
Public Latrine (under No latrine within premises)	Latrine (Uncollected and Treatment on-site)	(2.70% ÷ 67.8%) x 81.9% = 3.26% i.e. 0.0326	Census 2001 does not include information for public latrines separately. Public latrines account for 3.98% (i.e. 2.70% ÷ 67.8%) of 'No latrine within premises' category as per Census 2011. This percentage is applied to the percentage of households having 'No latrine within premises' (i.e. 81.9%) as per Census 2001 to estimate the corresponding proportion of households using public latrines in 2001.
Pathway for rest of wastewater that is uncollected and untreated	Others and None (Uncollected and No Treatment)	100%-0.77%-7.56%-6.40%-3.26% = 82.01% i.e. 0.820	The remaining proportion of the rural wastewater is estimated by deducting proportions of the 4 systems listed above in this table. This proportion represents wastewater that is neither collected nor treated. As per 2006 IPCC guidelines, the wastewater discharge/treatment pathways for uncollected and untreated wastewater are categorized as

Classification of wastewater treatment/discharge system based on Census data[68]	Applicable Treatment/Discharge pathway or system (j) selected from Table 25 as per 2006 IPCC Guidelines[69]	Estimated degree of utilization of treatment/ Discharge pathway or system j, for Rural group fraction i (Ti,j) - 2001	Remarks
			'Others' and 'None'. The distribution of rural wastewater handled between these two categories cannot be estimated based on available information for Andhra Pradesh and Other States of India and hence the 'Others' and 'None' categories are clubbed together in the degree of utilization estimation.

Source: Author's compilation and analysis based on Census of India data

Table 36: State-wise Degree of utilization considered in the estimates- Rural, 2011

State/Union Territory	Piped sewer system	Septic tank	Pit Latrine	Public Latrine	Others/None
Andaman and Nicobar Islands	2.30%	50.40%	4.50%	0.90%	41.90%
Andhra Pradesh	2.30%	22.60%	6.00%	2.70%	66.40%
Arunachal Pradesh	3.30%	11.90%	20.40%	3.00%	61.40%
Assam	3.30%	8.30%	37.20%	2.00%	49.20%
Bihar	1.20%	11.60%	2.20%	1.00%	84.00%
Chandigarh	83.00%	4.70%	0.10%	6.30%	5.90%
Chhattisgarh	0.60%	7.60%	4.10%	0.30%	87.40%
Dadra and Nagar Haveli	1.60%	23.10%	0.80%	2.80%	71.70%
Daman and Diu	1.70%	48.60%	0.40%	14.40%	34.90%
Delhi	10.40%	58.60%	5.20%	10.20%	15.60%
Goa	7.80%	51.90%	5.80%	1.70%	32.80%
Gujarat	3.90%	21.60%	6.30%	1.20%	67.00%
Haryana	2.50%	26.40%	23.10%	1.60%	46.40%
Himachal Pradesh	3.20%	52.40%	9.00%	0.90%	34.50%
Jammu and Kashmir	4.70%	10.80%	5.80%	3.10%	75.60%
Jharkhand	0.40%	5.00%	1.20%	0.70%	92.70%
Karnataka	2.00%	10.20%	14.60%	3.50%	69.70%
Kerala	9.90%	44.60%	34.00%	1.20%	10.30%
Lakshadweep	0.70%	97.10%	0.00%	0.30%	1.90%
Madhya Pradesh	0.80%	8.30%	2.60%	0.50%	87.80%
Maharashtra	2.20%	19.20%	14.10%	6.20%	58.30%
Manipur	5.40%	15.40%	40.50%	1.70%	37.00%
Meghalaya	4.70%	11.40%	26.40%	3.10%	54.40%

State/Union Territory	Piped sewer system	Septic tank	Pit Latrine	Public Latrine	Others/None
Mizoram	6.40%	23.00%	45.40%	2.50%	22.70%
Nagaland	2.80%	21.10%	32.80%	8.50%	34.80%
Odisha	0.90%	7.80%	3.30%	1.20%	86.80%
Puducherry	1.30%	36.20%	1.00%	1.40%	60.10%
Punjab	5.90%	32.60%	27.10%	1.50%	32.90%
Rajasthan	1.20%	9.80%	6.80%	0.50%	81.70%
Sikkim	3.00%	61.40%	15.40%	1.00%	19.20%
Tamil Nadu	2.20%	14.40%	5.10%	3.50%	74.80%
Tripura	2.30%	5.10%	65.30%	3.10%	24.20%
Uttar Pradesh	2.20%	12.00%	4.50%	1.10%	80.20%
Uttarakhand	3.40%	34.50%	14.20%	0.90%	47.00%
West Bengal	1.80%	9.30%	26.90%	2.00%	60.00%

Source: Author's compilation

Table 37: State-wise Degree of utilization considered in the estimates- Rural, 2001

State/Union Territory	Piped sewer system	Septic tank	Pit Latrine	Public Latrine	Others/None
Andaman and Nicobar Islands	0.76%	16.74%	12.40%	1.30%	68.79%
Andhra Pradesh	0.77%	7.56%	6.40%	3.26%	82.01%
Arunachal Pradesh	0.76%	2.74%	24.00%	3.34%	69.16%
Assam	1.38%	3.48%	46.90%	2.00%	46.24%
Bihar	0.34%	3.25%	6.00%	1.04%	89.37%
Chandigarh	44.90%	2.54%	6.40%	16.54%	29.62%
Chhattisgarh	0.10%	1.33%	1.80%	0.33%	96.43%
Dadra and Nagar Haveli	1.06%	15.37%	0.20%	3.15%	80.22%
Daman and Diu	0.67%	19.29%	9.40%	20.15%	50.49%
Delhi	2.82%	15.91%	32.90%	15.97%	32.40%
Goa	2.54%	16.89%	18.90%	3.03%	58.64%
Gujarat	1.66%	9.21%	8.10%	1.40%	79.62%
Haryana	0.16%	1.70%	20.50%	2.60%	75.04%
Himachal Pradesh	0.36%	5.84%	15.00%	1.95%	76.85%
Jammu and Kashmir	0.66%	1.51%	16.40%	2.94%	78.50%
Jharkhand	0.14%	1.77%	2.10%	0.71%	95.28%
Karnataka	0.70%	3.58%	9.50%	4.04%	82.18%
Kerala	10.39%	46.79%	12.80%	3.30%	26.73%
Lakshadweep	0.65%	90.36%	0.40%	1.04%	7.55%
Madhya Pradesh	0.20%	2.08%	3.90%	0.52%	93.30%
Maharashtra	0.49%	4.29%	10.20%	8.18%	76.83%
Manipur	0.65%	1.86%	66.80%	2.73%	27.95%
Meghalaya	0.67%	1.63%	29.80%	4.02%	63.88%
Mizoram	0.68%	2.45%	70.20%	3.30%	23.37%

State/Union Territory	Piped sewer system	Septic tank	Pit Latrine	Public Latrine	Others/None
Nagaland	0.47%	3.56%	47.30%	9.77%	38.90%
Odisha	0.29%	2.55%	3.10%	1.29%	92.77%
Puducherry	0.68%	18.96%	1.00%	1.80%	77.55%
Punjab	0.88%	4.89%	26.40%	2.99%	64.83%
Rajasthan	0.30%	2.47%	8.10%	0.53%	88.60%
Sikkim	1.07%	21.81%	29.80%	2.55%	44.77%
Tamil Nadu	0.92%	6.02%	4.60%	3.90%	84.56%
Tripura	0.70%	1.55%	66.00%	3.70%	28.04%
Uttar Pradesh	0.26%	1.43%	8.30%	1.14%	88.87%
Uttarakhand	0.62%	6.30%	16.10%	1.34%	75.63%
West Bengal	0.69%	3.58%	15.30%	2.74%	77.69%

Source: Author's compilation

4. Methane Correction Factor (MCF_j)

Methane Correction Factor (MCF) is an indication of the degree to which the wastewater treatment system is anaerobic (and thereby generates GHG emission) and this parameter varies with the type of treatment or discharge pathway. The emission factor EF_j for a given type of treatment system or discharge pathway is a product of the maximum CH_4 producing potential (Bo) (default value of 0.6 kg of CH_4/kg BOD as per 2006 IPCC Guidelines[71]) and the respective MCF value for that particular wastewater treatment and discharge system. In the emission estimates, corresponding default MCF values as per the 2006 IPCC Guidelines[72] (given in Table 26) have been used based on the applicable treatment/discharge pathways or systems for urban and rural population.

Table 38: MCF values considered for various treatment types for Urban and Rural Population

Treatment/ discharge pathway or system (j)	Classification of the system (Collected/ Uncollected and Treatment)	Specific Treatment/Discharge pathway or system (j) selected from Table 25	MCF_j
Urban Population			
Sewer	Collected (Anaerobic treatment)	Anaerobic reactor/Anaerobic digester for sludge	0.80
	Collected (Aerobic treatment)	Centralized, aerobic treatment plant (not well managed, overloaded)	0.30
	Collected (No Treatment)	Stagnant Sewer	0.50
Other	Uncollected (No Treatment)	Sea Lake or river discharge	0.10

[71] The 2006 IPCC Guidelines define BOD and COD based default values for Bo. Since the data point for organic content of domestic wastewater is measured in BOD terms, the BOD based default value of 0.6 kg of CH4/kg BOD is used in the assessment. As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Table 6.2.
Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf
[72] Based on 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater treatment and discharge, Table 6.3
Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

Treatment/ discharge pathway or system (j)	Classification of the system (Collected/ Uncollected and Treatment)	Specific Treatment/Discharge pathway or system (j) selected from Table 25	MCF_j
None	Uncollected (No Treatment)	Sea Lake or river discharge	0.10
Septic Tank	Uncollected (Treatment on-site)	Septic system	0.50
Latrine	Uncollected (Treatment on-site)	Latrine (Dry climate, ground water table lower than latrine, small family (3-5 members))	0.10
Rural Population			
Sewer	Collected (treated/untreated)	Flowing sewer (Open/Closed)	0
Other	Uncollected (No Treatment)	Sea Lake or river discharge	0.10
None	Uncollected (No Treatment)	Sea Lake or river discharge	0.10
Septic Tank	Uncollected (Treatment on-site)	Septic system	0.50
Latrine	Uncollected (Treatment on-site)	Latrine (Dry climate, ground water table lower than latrine, small family (3-5 members))	0.10
Latrine (Public)	Uncollected (Treatment on-site)	Latrine - Dry climate, ground water table lower than latrine, communal (many users)	0.50

Source: Author’s compilation based on 2006 IPCC Guidelines

Assumptions:

- The portion of urban wastewater that is collected in sewers but is untreated can be handled through ‘stagnant sewers’ or be discharged into water bodies such as ‘sea, lake or river’. The corresponding value of MCF of ‘sea, lake or river discharge’ is 0.1 and the MCF value of ‘stagnant sewer’ is 0.5. The quantity of this untreated wastewater that is discharged into water bodies is unknown and therefore the entire portion of collected and untreated urban wastewater is accounted under ‘stagnant sewer’ (MCF of 0.5). This assumption is based on the largely prevalent condition of untreated wastewater being discharged through sewers in urban areas.
- As reported in India’s Second National Communication[73], wastewater generated in rural areas is not handled or treated in any way and decomposes under aerobic conditions. Using this basis, the proportion of rural wastewater that is collected and conveyed through sewer systems is also assumed to not undergo any treatment downstream and decomposes under aerobic conditions, thereby not leading to CH_4 emissions. Thus, the ‘flowing sewer’ system having a MCF value of ‘0’ and leading to no GHG emissions is selected as the corresponding treatment system for the proportion of rural wastewater collected through sewer.
- Rural wastewater that is uncollected and untreated can be either discharged into ‘sea, lake or river’ or ‘to ground’. However, the quantity of wastewater that is discharged ‘to ground’ is unknown and therefore the entire portion of uncollected and untreated rural wastewater is accounted under ‘sea, lake or river discharge’ which has a MCF of 0.1.

5. Biochemical oxygen demand (BOD)

[73] This information is not available in the BUR 1 and BUR 2 reports

The primary factor in determining the CH_4 generation potential of wastewater is the amount of degradable organic material in the wastewater. BOD is a common parameter used to measure the organic component of domestic wastewater. Under the same ambient conditions, wastewater with higher BOD concentration will generally yield more CH_4 than wastewater with lower BOD concentration. The BOD concentration indicates only the amount of carbon that is aerobically biodegradable.

The 2006 IPCC Guidelines gives the default value of BOD generated per person for India which is about 34 gm/person/day[74]. An average national value for BOD of 40.5 gm/person/day is used for India in emission estimation for Second National Communication (NEERI, 2010). State-specific BOD values available for some of the states have been used (see Table 39). For states, wherein state-level BOD value is not available, the average national value of 40.5 gm/person/day is used.

Table 39: State level average per capita BOD

State/Union Territory	Average per capita BOD (gm BOD/day)[75]
Bihar	27.00
Chandigarh	61.86
Delhi	46.80
Gujarat	38.90
Haryana	38.00
Himachal Pradesh	19.60
Jharkhand	27.00
Karnataka	38.00
Madhya Pradesh	34.00
Maharashtra	38.00
Punjab	46.90
Uttar Pradesh	39.00
Uttarakhand	39.00
West Bengal	38.90

Source: NEERI

Assumption: Given that updated year-wise values of BOD generated per person are not available for the states, constant values as reported above are used across the reporting period. While converting BOD values from daily basis to an annual basis, 365 days have been assumed across all years, including for leap years, in line with the equation for TOW calculation in the 2006 IPCC Guidelines[76].

6. Correction factor for additional Industrial BOD discharged into sewers (I)

Effluent from industries and commercial establishments is often co-discharged in sewers and mixes with domestic wastewater.

---

[74] As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Table 6.4. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

[75] As per Inventorization of Methane Emissions from Domestic & Key Industries Wastewater – Indian Network for Climate Change Assessment, NEERI, 2010.

[76] As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Equation 6.3. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

This correction factor I accounts for additional BOD from mixing of such industrial and commercial effluent with domestic wastewater. Based on the Second National Communication for India and the 2006 IPCC Guidelines, the default values of 1.25 for 'I' for collected wastewater and 1 for uncollected wastewater respectively are used in this assessment[77].

N_2O Emissions from Domestic Wastewater

N_2O emissions can occur as direct emissions from treatment plants or from indirect emissions from wastewater after disposal of effluent into waterways, lakes or the sea.

As per the 2006 IPCC Guidelines the following equation is used to estimate N_2O emissions from domestic wastewater treatment and discharge[78]

$$N_2O\ Emissions = N_{EFFLUENT} * EF_{EFFLUENT} * 44/28$$

Where,

N_2O emissions	= N_2O emissions in inventory year, kg N_2O/yr
$N_{EFFLUENT}$	= nitrogen in the effluent discharged to aquatic environments, kg N/yr
$EF_{EFFLUENT}$	= emission factor for N_2O emissions from discharged to wastewater, kg N_2O-N/kg N The factor 44/28 is used for conversion of kg N_2O-N into kg N_2O.

The activity data that is needed for estimating N_2O emissions is nitrogen content in the wastewater effluent, state population, and the average annual per capita protein consumption (kg/person/yr).

The total nitrogen in the effluent is estimated as follows[79]:

$$N_{EFFLUENT} = (P * Protein * F_{NPR} * F_{NON-CON} * F_{IND-COM}) - N_{SLUDGE}$$

Where,

$N_{EFFLUENT}$	= total annual amount of nitrogen in the wastewater effluent, kg N/yr
P	= human population
Protein	= annual per capita protein consumption, kg/person/yr
F_{NPR}	= fraction of nitrogen in protein, kg N/kg protein (default value of 1.1) (IPCC, 2006)[80]
$F_{NON-CON}$	= factor for non-consumed protein added to the wastewater (default value of 1.1) (IPCC, 2006)[80]
$F_{IND-COM}$	= factor for industrial and commercial co-discharged protein into the sewer system, (default value of 1.25) (IPCC, 2006)[80]
N_{SLUDGE}	= nitrogen removed with sludge, kg N/yr (default value of 0) (IPCC, 2006)[80]

---

[77] Based on 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Equation 6.3. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf
[78] As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Equation 6.7. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf
[79] As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Equation 6.8. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf
[80] As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Section 6.3.1.3. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

Data Sources and Assumptions

1. Human Population

The urban and rural population for the Indian states for the emission estimation period of 2005-2015 is based on the population data and decadal population growth trends as per the Census of India, 2001 and Census of India, 2011. The state of Telangana was separated from Andhra Pradesh in year 2014 and therefore, the population of Andhra Pradesh from the year 2014 is based on the population of districts belonging to Andhra Pradesh after the separation (population and growth rate as per the census of India 2011). The detailed population and population growth of urban and rural Telangana has been referred from statistical publication of the government of Telangana[81].

2. Annual per capita protein consumption (Protein)

State-wise protein consumption values are available from the NSSO reports. As per data available in NSSO report on Nutritional Intake 2004-05, the state-wise protein consumption is considered for the period 2005 to 2008. Based on NSSO surveys conducted subsequently, the updated per capita protein consumption values for urban and rural population have been used in this assessment as shown in the Table 40. Based on the daily protein consumption, annual protein consumption values have been calculated for urban and rural population and used in the equation to estimate N_2O emissions.

Assumption: Updated year-wise values of per capita protein consumption are not available for urban and population. Therefore, the available values based on NSSO surveys in 2004-05, 2009-10 and 2011-12 are used across the emission reporting period for 2005 to 2008, 2009 to 2010, and 2011 to 2015 respectively as indicated in Table 40. While converting protein consumption values from daily basis to an annual basis, 365 days have been assumed across all years, including for leap years.

[81] As per Statistical Year Book 2017, Government of Talangana, Table 1.4, 1.5 & 1.6
Available at https://www.telangana.gov.in/PDFDocuments/Statistical-Year-Book-2017.pdf

Table 40: State-wise Daily Per Capita Protein Consumption considered for Urban and Rural Population

State/Union Territory	Protein Intake (kg/capita/day) 2004-05, NSSO Report [82]		Protein Intake (kg/capita/day) 2009-10, NSSO Report [83]		Protein Intake (kg/capita/DAY) 2011-12, NSSO Report [84]	
	Urban	Rural	Urban	Rural	Urban	Rural
Andaman and Nicobar Islands	57.7	53.4	60	60.75	67.65	63.6
Andhra Pradesh	50.9	49.8	54.8	53.8	56.75	56.75
Arunachal Pradesh	93.3	67.7	57.3	59.1	57.25	51.65
Assam	55.9	52.7	55.7	51.55	53.5	52.2
Bihar	62.2	57.8	59.45	55.6	59.65	60.1
Chandigarh	65.5	60.3	64.5	62.8	60.1	61.55
Chhatisgarh	53.9	47.4	52.05	46.75	53.45	49.65
Dadra and Nagar Haveli	51.9	41.3	52.1	44.95	51.95	41.05
Daman and Diu	47.6	49.6	53.35	52.6	52.05	55.3
Delhi	61.3	56.9	53.5	57	59.35	59.8
Goa	47	47.5	58.35	54.1	60.15	54.15
Gujarat	57.3	53.3	54.85	55	55.2	52.25
Haryana	60.5	69.6	61.05	68.85	65.1	70.35
Himachal Pradesh	67.5	68.4	66.4	70.2	72.35	73.45
Jammu and Kashmir	61.2	63.6	62.65	64.05	64.95	65.7
Jharkhand	69.5	51.2	58.95	51.05	59	53.05
Karnataka	52.2	48.8	54.05	51.2	55.5	53.2
Kerala	56.7	55.4	56.95	55.85	59.75	57.8
Lakshadweep	71.6	71.2	68.65	71.05	69.5	73.3
Madhya Pradesh	58.2	58.8	56.55	60.55	60.55	63.4
Maharashtra	52.1	55.7	55.75	58.2	58.2	58.35
Manipur	52.5	59.6	46.45	48.4	46.85	49.25
Meghalaya	50.6	50.8	42.65	44.4	47.85	43.8
Mizoram	67.6	77.2	56.2	52.5	56.65	52.3
Nagaland	73.9	65.7	58.7	57.65	57	56.4
Odisha	55.2	48.3	55.25	52.1	54.35	51.65
Puducherry	52.1	47.8	61.05	57.75	62.65	57.55
Punjab	63.4	66.7	62.4	66.3	63.45	68.2
Rajasthan	64	69.6	62.1	69.6	64.7	70.15

[82] As per NSSO (2007): Nutritional Intake in India 2004-05, Table 3R for Rural protein intake and Table 3U for Urban protein intake. Available at http://mospi.nic.in/sites/default/files/publication_reports/513_final.pdf

[83] As per NSSO (2012): Nutritional Intake in India 2009-10. The NSSO survey was conducted over two rounds (or schedules). Values used are average values based on findings across the two schedules in the NSSO survey 2009-10 as indicated in Table 3A-R & Table 3C-R for Rural and Table 3A-U & Table 3C-U for Urban. Available at http://www.indiaenvironmentportal.org.in/files/file/nutrition%20intake%20in%20india.pdf

[84] As per NSSO (2014): Nutritional Intake in India 2011-12. The NSSO survey was conducted over two rounds (or schedules). Values used are average values based on findings across the two schedules in the NSSO survey 2011-12 as indicated in Table 3A & Table 3B. Available at http://www.indiaenvironmentportal.org.in/files/file/nutritional%20intake%20in%20India%202011-12.pdf

State/Union Territory	Protein Intake (kg/capita/day) 2004-05, NSSO Report [82]		Protein Intake (kg/capita/day) 2009-10, NSSO Report [83]		Protein Intake (kg/capita/DAY) 2011-12, NSSO Report [84]	
	Urban	Rural	Urban	Rural	Urban	Rural
Sikkim	51.5	49.9	56.75	52.35	51.75	52.5
Tamil Nadu	49.2	44.9	52.85	49.65	53.4	51.05
Telangana	NA	NA	NA	NA	NA	NA
Tripura	56.9	47.1	63	59.75	59.5	57
Uttar Pradesh	65.1	65.9	58.15	61.65	59.15	61.35
Uttarakhand	62.8	61.6	57.4	60.05	66.3	69.6
West Bengal	55.1	52	52.25	50.6	55.85	53.65

Source: Author's compilation based on NSSO data

3.6.3 Recalculation

A consistent methodological approach has been followed for the present estimation (version 3.0) as in the previous estimates. In line with other sectors covered by the GHG Platform India consortium, recalculation of emissions is envisaged to be undertaken and reported if there is a deviation of more than 5% in the estimates as compared to previous versions.

For domestic wastewater, no recalculation has been carried out in the previously reported estimates from year 2005 to 2013 since activity data and emission factors have remained the same.

3.7 4D2 Industrial Wastewater Treatment and Discharge

3.7.1 Category description

CH_4 is emitted from industrial wastewater when it is treated or disposed anaerobically. Wastewater from industrial sources may be treated on-site, transferred through a sewer to a centralized treatment plant or disposed of untreated in nearby areas or via an outfall.

The scope of the GHG emissions estimation is limited to only those industry sectors which have substantial generation of wastewater containing organic matter, thereby leading to release of GHG emissions from treatment and/or discharge of such organic wastewater. 11 industry sectors have been included for estimating CH_4 from industrial wastewater in line with India's National Communications, related documentation from NEERI[85], and the 2006 IPCC guidelines for National GHG inventories. The product categories for the 10 industry sectors included in the estimates are indicated in Table 41.

Table 41: Industrial Sectors and products considered

Iron and Steel	Production of Pig Iron, Sponge Iron and Finished steel (alloy & Non-alloy)
Fertilizer	Production of Nitrogenous and Phosphatic Fertilizers (finished product for sale)
Meat	Finished Meat production from all the registered Slaughterhouses
Sugar	Finished Sugar production from cane
Coffee	Production of all types of coffee (Arabica, Robusta and varieties of these) in Indian states
Pulp & Paper	Production of paper[86] from all pulp and paper industries in Indian states
Petroleum	Refining and production of Petroleum, Oil and Lubricants[87]
Rubber	Production of Finished Natural and Synthetic Rubber
Dairy	Production of milk in the Dairy Sector in Indian states
Tannery	Production of Raw Bovine, Sheep, lamb, Goat and kid skins and hides
Fish Processing	Preservation and processing of different types of fish in processing facilities

The other industrial sectors which consume and discharge chemicals or other inorganic matter that are not sources of significant GHG emission, such as Cement industry, Plastic industry, Pharmaceuticals, Automobile industry etc., are not included in the analysis. This assessment is applicable for all on-site generation and treatment of industrial wastewater for the industrial sectors listed above within all states in India. Assessment of CH_4 generation potential from industrial wastewater streams is based on the concentration of degradable organic matter in the wastewater, the volume of wastewater generated, and the type of prevalent wastewater treatment systems used by the respective industrial sector.

[85] Documents referred include Inventorization of Methane Emissions from Domestic & Key Industries Wastewater – Indian Network for Climate Change Assessment, NEERI, 2010.; Impact of methane emissions from wastewater sector in India through a case study of an effluent treatment plant, NEERI, 2011. Available at: http://www.cseindia.org/userfiles/Karthik.pdf

[86] Paper produced from various raw materials – Wood, Agro and Recycled fiber based raw materials which is used for various purposes – writing, printing, newsprint and packaging are all included

[87] Industrial output/production data is considered from petroleum refining and not from crude oil extraction since water consumption and wastewater generation is significant in the refining process. International Petroleum Industry Environmental Conservation Association (IPIECA) (2010): Petroleum refining water/wastewater use and management-Operations Best Practice series

Due to the lack of documented information on the total volume of wastewater generated from industrial sectors across states, a tier 1 approach in which industrial production is used as a metric to estimate volume of wastewater generation is adopted in this assessment. It is found that reliable activity data on industrial production at the state-level that can be directly used in the emission calculation equation is not available for most of the sectors across the reporting period, either wholly or partly. Given these challenges in the availability of state-level data, apportionment has been used as an approach to address data gaps (to varying degrees) in 8 out of the 10 industry sectors considered in the assessment. Apportionment or approximations based on national level production data have been done based on relevant proxy data such as installed production capacity by state, no. of manufacturers or manufacturing facilities by state, gross economic value added by state, etc. Further details of the sector-wise approach and assumptions used for the activity data on industrial production data are given in the subsequent section 3.7.2 on 'Data sources and Assumptions' in this chapter.

Secondary data on industrial production and industrial activity between the years 2005 – 2015 is sourced from multiple entities such as the Ministry of Steel, Indian Bureau of Mines, Directorate of Sugarcane Development, the Coffee Board, the Fertilizer Association of India, the Rubber Board, Food & Agriculture organization, and the Department of Animal Husbandry, Dairying & Fisheries, to name a few. Where the use of country-specific information is not feasible due to limitations in the data, IPCC defined default values have been used.

Table 42: Principal Sources and Quality of Data for Industrial Wastewater Treatment and Discharge Estimates

IPCC ID	GHG source & sink categories	Type	Quality	Source
4D2	Industrial wastewater treatment and discharge	Secondary	Low-Medium	• Ministry of Steel • Indian Bureau of Mines • Department of Fertilizers, Ministry of Chemicals and Fertilizers • Directorate of Sugarcane Development, Ministry of Agriculture • Department of Agriculture, Cooperation & Farmers Welfare Ministry of Agriculture & Farmers Welfare • Coffee Board, Ministry of Commerce and Industry • Petroleum Planning and Analysis Cell, Ministry of Petroleum & Natural Gas • Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture • Central Pulp & Paper Research Institute • Rubber Board, Ministry of Commerce and Industry • Food and Agriculture Organization (FAO) • Department of Industrial Policy and Promotion, Ministry of Commerce & Industry • NEERI • 2006 IPCC Guidelines on national emission inventories

Country specific wastewater generation rates are used for all 10 sectors based on NATCOM, NEERI and CSE data. Degradable organic concentration in the wastewater (kg COD/m^3) for 7 sectors is based on NATCOM & NEERI data and for 3 sectors is based on IPCC default data (see methodology section 3.6.2). Maximum CH_4 producing capacity, kg CH_4/kg COD (Bo) and MCF values are also based on IPCC default data. Due to lack of country-specific data on the emission factors for CH_4 emissions from industrial wastewater, default values of these emission factors as specified by the 2006 IPCC Guidelines have been used in this assessment.

Industrial production data reported in potential single source datasets such as the ASI and industry associations is found to be in disparate units. The requisite guidance for normalization/conversion of the production data to a single unit (i.e. tonnes as required in the emission calculation) is absent and this has necessitated the use of multiple data sources for each of the industrial sectors under consideration. While data has been sourced from alternate published data sources, these data sources themselves collate data from a number of sources which has impacted quality and reliability of the data. Further, as indicated earlier, the availability of activity data on industrial production at the state-level and for all years of the reporting period is a challenge and therefore national- level activity data has been apportioned for a number of sectors. Due to the lack of updated year-on-year information on the changes in volume of wastewater generated per tonne of product - a parameter that should vary given the improvements in production technologies - constant values have been used for this parameter across the reporting period for all industry sectors, with the exception of the Pulp and Paper sector where such information was available for a few years. State-wise information for this parameter is not available and thereby corresponding national-level value has been used for the industry sectors.

Activity data and related information for the industrial sectors has been largely sourced from official publications from government departments and nodal institutions/associations. However, given the unavailability of data (across the states and for particular years) and the need for apportionment/ approximations to address data gaps, the data is assessed to range from low to medium quality across the industry sectors (see section 3.6.2 on Methodology for further details on assumptions and emission factors used)[88].

An assessment of the quality of activity data and emission factors used in the estimation across industry sectors is indicated in the Table 43 below. The quality has been assessed based on the source of the data[89] and its availability. Published data sourced from government institutions and agencies is deemed to be of 'high' quality for the years where such published data is available. Data from peer reviewed literature and studies undertaken by research and academic institutions with experience of working in the waste sector is deemed to be of 'medium' quality. Data sourced from private organizations, online databases, and individual researchers is deemed to be of 'low' quality. Further, for years wherein no data has been published for the parameter, the quality is assigned as 'low', with suitable assumptions used to address data gaps in such cases. Emission factors and default values sourced from the 2006 IPCC Guidelines have been assessed to be of 'high' quality.

---

[88] It is difficult to assess the quality of activity data by state since industrial activity for a particular sector is non-existent in some states. Therefore, a qualitative assessment has been done for each industry sector, since this is largely applicable across all states for a particular sector.

[89] Data sources for all parameters for industrial wastewater are indicated further in section 3.7.2 of this note.

- Data and trends from Annual Reports, Status Papers, Statistical records of line ministries such as Ministry of Agriculture, Ministry of Commerce and Industry, Ministry of Chemicals and Fertilizers of Government of India, have been used for data on state-wise ‘Industrial production (Pi)’ for the industry sectors considered in estimates. Therefore, the quality of data is considered as ‘high’ for the years wherein published state-level industrial production datasets from such government institutions are available while ‘low’ quality is assigned for years wherein reliable data is not available. Issues were found with quality and availability of state-level industrial production data for the Dairy, Rubber, Tannery, and Petroleum sectors, thereby requiring use of proxy data such as gross value added, production capacity and no. of manufacturers in the emission estimation and therefore ‘low’ quality has been assigned across the estimation period for these sectors.
- Information on ’volume of wastewater generated per tonne of product’ has been sourced from published data from NEERI and India’s Second Biennial Update Report for year 2014 for the sectors of Sugar, Coffee, Petroleum, Dairy, Tannery, and Fish processing and is deemed to be of ‘high’ quality for this year. For the sectors of Iron & Steel, Fertilizer, and Rubber, information is not provided in BUR 2 document and is sourced from published data from NEERI for year 2007 and deemed to be of ‘high’ quality for 2007. For the Pulp and Paper sector, this information is based on technical guidance manual prepared by a private organization in year 2010 and is thus gauged to be of ‘low’ quality.
- The values for ‘Degradable organic component in industrial wastewater (CODi)’ used for Sugar, Coffee, Petroleum, Dairy, Meat, Pulp & Paper, Tannery, and Fish processing sectors are sourced from India’s Second Biennial Update Report for year 2014 and are deemed to be of ‘high’ quality for this year. The COD values for Iron & Steel, Fertilizers and Rubber sectors are based on a NEERI study but pertain to year 2003 which falls outside the emission estimation period and therefore quality is assessed to be ‘low’ for these sectors.
- ‘Methane correction factor (MCF_j)’ value is based on the prevalent wastewater treatment system used in the respective industrial sector. While the MCF values for corresponding treatment technologies has been sourced from the 2006 IPCC Guidelines, information on prevalent treatment system used is based on National Communication documents, 2006 IPCC Guidelines, and sector specific publications and the quality is assessed accordingly. MCF for Coffee and Meat are based on the 2006 IPCC Guidelines and thus assessed to be of ‘high’ quality. Information for this parameter for Fertilizer, Dairy, Sugar, Pulp & Paper, and Tannery is sourced from India’s Second National Communication and is thus assessed to be of ‘high’ quality for year 2007. MCF for Iron & Steel and Petroleum is based on private organization and independent research based publications and is thus assessed to be of ‘low’ quality. Information sourced for the Tannery sector pre-dates the estimation period 2005-2015 and is therefore assessed to be of ‘low’ quality.
- Values for the following parameters and emission factors for all industry sectors are sourced from the 2006 IPCC Guidelines. Therefore, the quality is assessed to be ‘high’ across the emission estimation period.
    - Organic component removed as sludge (Si)
    - Amount of CH_4 recovered (Ri)
    - Maximum CH_4 producing capacity (Bo)

Table 43: Qualitative Assessment of Year-wise Activity and Emission Factor Data used in the Industrial Wastewater Treatment and Discharge Estimates

S. No.	Activity Data/Emission Factor	Quality										
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	**Activity Data**											
(a)	Industrial Production (Pi)											
	Iron & Steel	L	L	L	L	L	L	H	H	H	H	H
	Fertilizers	L	H	H	H	H	H	H	H	H	H	L
	Sugar	H	H	H	H	H	H	H	L	L	H	H
	Coffee	H	H	H	H	H	H	H	H	H	H	H
	Petroleum	L	L	L	L	L	L	L	L	L	L	H
	Dairy	L	L	L	L	L	L	L	L	L	L	L
	Meat	H	H	H	H	H	H	H	H	H	H	H
	Pulp & Paper	L	L	L	L	L	L	H	H	H	H	H
	Rubber	L	L	L	L	L	L	L	L	L	L	L
	Tannery	L	L	L	L	L	L	L	L	L	L	L
	Fish processing	L	L	L	H	H	H	H	H	L	L	L
(b)	Wastewater generated, m3 /t product (Wi)											
	Iron & Steel	L	L	H	L	L	L	L	L	L	L	L
	Fertilizers	L	L	H	L	L	L	L	L	L	L	L
	Sugar	L	L	L	L	L	L	L	L	L	H	L
	Coffee	L	L	L	L	L	L	L	L	L	H	L
	Petroleum	L	L	L	L	L	L	L	L	L	H	L
	Dairy	L	L	L	L	L	L	L	L	L	H	L
	Meat	L	L	H	L	L	L	L	L	L	L	L
	Pulp & Paper	L	L	L	L	L	L	L	L	L	L	L
	Rubber	L	L	H	L	L	L	L	L	L	L	L
	Tannery	L	L	L	L	L	L	L	L	L	H	L
	Fish processing	L	L	L	L	L	L	L	L	L	H	L
(c)	Chemical oxygen demand (CODi)											
	Iron & Steel	L	L	L	L	L	L	L	L	L	L	L
	Fertilizers	L	L	L	L	L	L	L	L	L	L	L
	Sugar	L	L	L	L	L	L	L	L	L	H	L
	Coffee	L	L	L	L	L	L	L	L	L	H	L
	Petroleum	L	L	L	L	L	L	L	L	L	H	L
	Dairy	L	L	L	L	L	L	L	L	L	H	L
	Meat	L	L	L	L	L	L	L	L	L	H	L
	Pulp & Paper	L	L	L	L	L	L	L	L	L	H	L
	Rubber	L	L	L	L	L	L	L	L	L	L	L
	Tannery	L	L	L	L	L	L	L	L	L	H	L
	Fish processing	L	L	L	L	L	L	L	L	L	H	L
(d)	Organic component removed as sludge (Si)	H	H	H	H	H	H	H	H	H	H	H
(e)	Amount of CH_4 recovered (Ri)	H	H	H	H	H	H	H	H	H	H	H
2	**Emission Factors**											
(a)	Methane correction factor (MCFj)											

S. No.	Activity Data/Emission Factor	Quality										
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
	Iron & Steel	L	L	L	L	L	L	L	L	L	L	L
	Fertilizers	L	L	H	L	L	L	L	L	L	L	L
	Sugar	L	L	H	L	L	L	L	L	L	L	L
	Coffee	H	H	H	H	H	H	H	H	H	H	H
	Petroleum	L	L	L	L	L	L	L	L	L	L	L
	Dairy	L	L	H	L	L	L	L	L	L	L	L
	Meat	H	H	H	H	H	H	H	H	H	H	H
	Pulp & Paper	L	L	H	L	L	L	L	L	L	L	L
	Rubber	L	L	L	L	L	L	L	L	L	L	L
	Tannery	L	L	H	L	L	L	L	L	L	L	L
	Fish processing	L	L	L	L	L	L	L	L	L	H	L
(b)	Maximum CH_4 producing capacity(Bo)	H	H	H	H	H	H	H	H	H	H	H

H-high, M-medium, L-low
Source: Author's analysis

3.7.2 Methodology

A Tier 1 approach has been followed to estimate CH_4 emissions from industrial wastewater since neither state-specific nor country-specific data on volumes of industrial wastewater generated is available. 10 industrial sectors with substantial organic wastewater generation are considered in the state-level emission estimation. Emission estimation for each sector is based on the following parameters:

- Industrial production in tonnes
- Wastewater generated per tonne of product
- Organic concentration (i.e. characteristic of wastewater)
- MCF based on broad treatment technology used by sector
- Methane recovery (if any)

A top-down approach has been followed and a combination of country-specific and state specific (where available) activity data has been sourced for most of the industry sectors, with IPCC default values used where such data is unavailable. Default values of the emission factors as per the 2006 IPCC Guidelines have been used in the calculations. In some industries, CH_4 is recovered from industrial wastewater, and in the present calculations, CH_4 recovered for energy purposes in Sugar and Dairy industries has been subtracted from the total CH_4 estimated to be emitted from these industries (recovery rate was 70%, 75% and 75% respectively[90]).

Table 44: Type of Emission Factor and Level of Methodological Tier adopted for Industrial Wastewater Treatment and Discharge Estimates

---

[90] This information is not available in the recent BUR 1 and BUR 2 reports and is thereby sourced from India's Second National Communication, Page 77. Available at https://unfccc.int/sites/default/files/resource/indnc2.pdf

IPCC ID	GHG source & sink categories	CH_4	
		Method Applied	Emission Factor
4D1	Industrial wastewater treatment and discharge	T1	D

Notes: T1: Tier 1; D: IPCC default

As per the 2006 IPCC Guidelines, the following equation is used to estimate CH_4 emissions from industrial wastewater treatment[91].

$$CH_4\ Emissions = \sum_i \left[\left(TOW_i - S_i \right) EF_i - R_i \right]$$

Where:

CH_4 Emissions = CH_4 emissions in inventory year, kg CH_4/yr

TOW_i = state-wise total organically degradable material in wastewater from industry i in inventory year, kg COD/yr

i = industrial sector

S_i = organic component removed as sludge in inventory year, kg COD/yr (Default value 0.35) (IPCC, 2006)[92]

EF_i = emission factor for industry i,kg CH_4/kg COD for treatment/discharge pathway or system(s) used in inventory year

R_i = amount of CH_4 recovered in inventory year, kg CH_4/yr

The activity data for this source category is the amount of organically degradable material in the wastewater (TOW), which is a function of industrial output (product) P (tonnes/year), wastewater generation W (m^3/ton of product), and degradable organics concentration in the wastewater COD (kg COD/m^3) as given in the equation[93]:

$$TOWi = Pi \bullet Wi \bullet CODi$$

Where:

TOWi = total organically degradable material in wastewater for industry i, kg COD/yr

i = industrial sector

P_i = state-wise total industrial product for industrial sector i, t/yr

W_i = wastewater generated, m^3/t product

COD_i = chemical oxygen demand, kg COD/m^3

For each industrial sector, the emission factor is estimated using the maximum methane producing capacity and the average methane correction factor (MCF) based on the type of treatment method used by the industry. The MCF indicates the extent to which the CH_4 producing potential (B_o) is released in each type of treatment method and thereby it is an indication of the degree to which the system is anaerobic.

$$CH_4\ Emission\ Factor\ EFj = B_o \bullet MCFj$$

Where:

[91] As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Equation 6.4. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

[92] As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

[93] As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Equation 6.5. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

EF_j = emission factor for each treatment/discharge pathway or system used by the industry, kg CH_4/kg COD
j = each treatment/discharge pathway or system
B_o = maximum CH_4 producing capacity, kg CH_4/kg COD (Default value 0.25[94])
MCF_j = methane correction factor (fraction)

Table 45: Default MCF values based on treatment type and discharge pathway or system for Industrial Wastewater

Type of treatment and discharge pathway or system	Details	MCF
Untreated		
Sea, river and lake discharge	Rivers with high organics loadings may turn anaerobic, however this is not considered here	0.1
Treated		
Aerobic treatment plant	Well managed	0
Aerobic treatment plant	Not well managed. Overloaded	0.3
Anaerobic digester for sludge	CH4 recovery not considered	0.8
Anaerobic reactor (e.g., UASB, Fixed Film Reactor)	CH4 recovery not considered	0.8
Anaerobic shallow lagoon	Depth less than 2 metres	0.2
Anaerobic deep lagoon	Depth more than 2 metres	0.8

Source: 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Table 6.8

A sample calculation with the detailed computation of emissions is provided in Appendix 6.11.

Data Sources and Assumptions

1. Industrial Production (P_i)

As indicated earlier, the unavailability of reliable data on industrial production is a key challenge encountered in the state-level emission estimates. In some cases, industrial production data is not available at the state-level at all. Data is also found to be partly missing for some years in the reporting period or is not reported in a disaggregated manner for some states. To address these data gaps, national level production data has been apportioned to the state-level for 8 sectors (including Iron & Steel, Fertilizer, Pulp & Paper, Rubber, Tannery, Petroleum, Coffee, Dairy) out of 11 sectors in total, either across all years and all states or partially for some of the years. Information such as installed production capacity by state, no. of manufacturers or manufacturing facilities by state, and gross economic value added by state, which can be correlated with industrial production has been used to scale down national-level data to the state-level.

The following sources have been used to obtain the production data or correlated information on industrial activity for the industry sectors under consideration. The assumptions used to address data gaps for the industry sectors are listed below the Table 46.

Table 46: Data sources for Industrial Production data

[94] As per 2006 IPCC Guidelines, Vol.5, Chapter 6: Wastewater Treatment and Discharge and NEERI document on Inventorization of Methane Emissions from Domestic & Key Industries Wastewater – Indian Network for Climate Change Assessment, 2010. Available at: http://www.moef.nic.in/sites/default/files/M%20Karthik.pdf

Sector	Data Point	Data Source
Iron & Steel	• Installed capacity of Pig Iron production for private sector plants and their location • Production of Pig iron by public sector plants and their location • National-level Pig iron production	Indian Bureau of Mines- The Indian Minerals Yearbook 2012 (Part- II: Metals & Alloys – Iron & Steel and Scrap), Table 8[95] Indian Bureau of Mines- The Indian Minerals Yearbook 2013 (Part- II: Metals & Alloys – Iron & Steel and Scrap), Table 8[96] Indian Bureau of Mines- The Indian Minerals Yearbook 2014 (Part- II: Metals & Alloys – Iron & Steel and Scrap), Table 8[97] The Indian Minerals Yearbook 2015 (Part- II: Metals & Alloys – Iron & Steel and Scrap), Table 8[98] Indian Bureau of Mines- The Indian Minerals Yearbook 2016 (Part- II: Metals & Alloys – Iron & Steel and Scrap), Table 8 and Table for SAIL – Hot Metal, Page 14[99] JSW Steel website, JSW Steel - An Overview[100] Ministry of Steel - Annual Report 2007-08, Annexure VII[101] Ministry of Steel, Government of India- Annual Report 2012-13, Annexure VII[101] Ministry of Steel, Government of India -Annual Report 2014-15, Annexure VII[101] Ministry of Steel, Government of India- Annual Report 2017-18, Annexure VII[101]
	• Installed capacity of Sponge iron plants and their location • National-level Sponge iron production	Ministry of Steel, Government of India- Annual Report 2008-09, Annexure III[101] Indian Bureau of Mines- The Indian Minerals Yearbook 2012 (Part- II: Metals & Alloys – Iron & Steel and Scrap), Table 2[95] Indian Bureau of Mines- The Indian Minerals Yearbook 2014 (Part- II: Metals & Alloys – Iron & Steel and Scrap), Table 9[97] Indian Bureau of Mines- The Indian Minerals Yearbook 2015 (Part- II: Metals & Alloys – Iron & Steel and Scrap), Table 9[98] Indian Bureau of Mines- The Indian Minerals Yearbook 2016 (Part- II: Metals & Alloys – Iron & Steel and Scrap), Table 9[99] Indian Bureau of Mines- The Indian Minerals Yearbook 2016 (Part- II: Metals & Alloys – Iron & Steel and Scrap), Table 2: Production of Iron and Steel, 2011-12 to 2015-16[99]
	• Installed capacity of Steel Production by plants and their location • National-level Steel Production	Report of the Working Group on Steel Industry for 12th FYP (2012-2017), Ministry of Steel 2011, Table 3.7[102] Ministry of Steel, Government of India- Annual Report 2008-09, Annexure VII[101] Indian Bureau of Mines- The Indian Minerals Yearbook 2012 (Part- II: Metals & Alloys – Iron & Steel and Scrap), Table 3[95] Indian Bureau of Mines- The Indian Minerals Yearbook 2015 (Part- II: Metals & Alloys – Iron & Steel and Scrap), Table 3[98] The Indian Minerals Yearbook 2016 (Part- II: Metals & Alloys – Iron & Steel and Scrap), Table 2[99]

[95] Available at https://ibm.gov.in/index.php?c=pages&m=index&id=178
[96] Available at http://ibm.nic.in/writereaddata/files/05282015123104Iron%20&%20Steel%20and%20Scrap_2013.pdf
[97] Available at https://ibm.gov.in/index.php?c=pages&m=index&id=480
[98] Available at https://ibm.gov.in/index.php?c=pages&m=index&id=871
[99] Available at https://ibm.gov.in/index.php?c=pages&m=index&id=881
[100] Available at https://www.jsw.in/jsw-steel-2017/mda.html
[101] Available at https://steel.gov.in/sites/default/files/Annual%20Report%20%282008-09%29.pdf
[102] Available at http://planningcommission.gov.in/aboutus/committee/wrkgrp12/wg_steel2212.pdf

Sector	Data Point	Data Source
Fertilizer	Plant-wise production of nitrogen and phosphate fertilizer and their location	Department of Fertilizers, Ministry of Chemicals and Fertilizers, Government of India, Annual Report 2014-15, Annexure IV[103] Department of Fertilizers, Ministry of Chemicals and Fertilizers, Government of India, Annual Report 2012-13, Annexure IV[104] Department of Fertilizers, Ministry of Chemicals and Fertilizers, Government of India, Annual Report 2010-11, Annexure IV[105] Department of Fertilizers, Ministry of Chemicals and Fertilizers, Government of India, Annual Report 2008-09, Annexure IV[106] Department of Fertilizers, Ministry of Chemicals and Fertilizers, Government of India, Annual Report 2006-07, Annexure IV[107] Department of Fertilizers, Ministry of Chemicals and Fertilizers, Government of India, Annual Report 2004-05, Annexure IV[108]
Sugar	State-wise production of Sugar	National Food Security Mission, Ready Reckoner, Crop Unit-IV, Statistics on Cotton, Jute & Sugar, Page 69[109] Annexure XXIX, Status Paper on Sugarcane, Directorate of Sugarcane Development, Ministry of Agriculture[110]
Coffee	State-wise production of Coffee	Database on Coffee – February 2016, Table 1.6, Coffee Board, Ministry of Commerce and Industry, Government of India[111] Database on Coffee – June/July 2016, Table 1.6, Coffee Board, Ministry of Commerce and Industry, Government of India[112] Quarterly Publications on Database on Coffee - Part I, Table 1.6 Production of Coffee in Major States/Districts of India, Coffee Board, Ministry of Commerce and Industry, Government of India[113] Data for the years 2004-05 to 2007-08 has been received over telephone from Dy. Director (Market Research), Coffee Board
Petroleum	• Volume of Crude Oil processed by refineries and their location • National-level production of Petroleum, Oil and Lubricants	Petroleum Planning and Analysis Cell (PPAC), Ministry of Petroleum & Natural Gas – Crude Processing[114] Petroleum Planning and Analysis Cell (PPAC), Ministry of Petroleum & Natural Gas – Production of Petroleum Products[115]

[103] Available at http://www.fert.nic.in/sites/default/files/fertilizer%20web.pdf
[104] Available at http://fert.nic.in/sites/default/files/Annual_Report2012-13.pdf
[105] Available at http://fert.nic.in/sites/default/files/Annual_Report_English_2011_0.pdf
[106] Available at http://fert.nic.in/sites/default/files/Annual-Report-2008-2009-english.pdf
[107] Available at http://fert.nic.in/sites/default/files/Annual-Report-2006-2007-english.pdf
[108] Available at http://fert.nic.in/sites/default/files/Annual-Report-2004-2005-english.pdf
[109] Available at https://nfsm.gov.in/ReadyReckoner/CU4/CUIV_Statistics.pdf
[110] State-wise information as reported from 2004-05 to 2011-12
[111] Available at https://www.indiacoffee.org/Database/DATABASE_Feb16_I.pdf
[112] Available at https://www.indiacoffee.org/Database/DATABASE_July16_I.pdf
[113] For Year 2013-14: available at https://www.indiacoffee.org/Database/DATABASE_Mar15_I.pdf; Year 2012-13 available at https://www.indiacoffee.org/Database/DATABASEJuly13_I.pdf; year 2011-12 available at https://www.indiacoffee.org/Database/DATABASEJuly12_I.pdf; year 2010-11 available at https://www.indiacoffee.org/Database/DATABASEOct11_I.pdf; year 2009-10 available at https://www.indiacoffee.org/Database/DATABASE_Mar10I.pdf; year 2008-09 available at https://www.indiacoffee.org/Database/SepNovI_09.pdf
[114] Available at http://www.ppac.org.in/WriteReadData/userfiles/file/PT_crude_H.xls
[115] Available at http://www.ppac.org.in/WriteReadData/userfiles/file/PT_production_source_H.xls

Sector	Data Point	Data Source
Dairy	• No. of registered dairy plants and their installed capacity by state • National-level milk production	Basic Animal Husbandry & Fisheries Statistics- 2017, Table 1, Department of Animal Husbandry, Dairying & Fisheries, Ministry of Agriculture[116] National Action Plan for Dairy Development – Vision 2022, 2018, Annex 7, Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture and Farmers Welfare[117] Basic Animal Husbandry Statistics 2012 - PART VIII- Dairying Statistics, Table 74, Department of Animal Husbandry, Dairying & Fisheries, Ministry of Agriculture[118]
Meat	State-wise Meat production	Basic Animal Husbandry & Fisheries Statistics- 2017, Table 29, Department of Animal Husbandry, Dairying & Fisheries, Ministry of Agriculture[119] Basic Animal Husbandry and Fisheries Statistics, 2012, Part III: Meat and Wool, Table 22, Department of Animal Husbandry, Dairying & Fisheries, Ministry of Agriculture[120] Basic Animal Husbandry Statistics, 2010, Table 21, Department of Animal Husbandry, Dairying & Fisheries, Ministry of Agriculture[121]
Pulp and Paper	State-wise Paper production	Compendium of Census Survey of Indian Paper Industry, Central Pulp & Paper Research Institute, 2017 (print version)
Rubber	• No. of licensed rubber manufacturers by state • Rubber cultivation in Meghalaya and Nagaland • National-level production of rubber	Statistics & Planning Department, Rubber Board- Rubber Statistical Monthly News -June 2006, Page 2 – Production and Consumption of NR & SR Statistics & Planning Department, Rubber Board- Rubber Statistical Monthly News -May 2008, Page 2 – Production and Consumption of NR & SR [122] Statistics & Planning Department, Rubber Board- Rubber Statistical Monthly News –June 2010, Page 2 – Production and Consumption of NR & SR[123] Statistics & Planning Department, Rubber Board- Rubber Statistical Monthly News –July 2011, Page 2 – Production and Consumption of NR & SR [124] Statistics & Planning Department, Rubber Board- Rubber Statistical Monthly News –May 2013, Page 2 – Production and Consumption of NR & SR [125]

[116] Available at http://dadf.gov.in/sites/default/filess/Basic Animal Husbandry and Fisheries Statistics 2017 %28English version%29_5.pdf
[117] Available at http://dahd.nic.in/sites/default/filess/Vision%202022-Dairy%20Development%20English_0_0.pdf
[118] Available at http://dadf.gov.in/sites/default/filess/11.%20Part%20VIII%20Dairying%20%20Statistics%20BAHS%202012.pdf
[119] Available at http://dadf.gov.in/sites/default/filess/Basic Animal Husbandry and Fisheries Statistics 2017 %28English version%29_5.pdf
[120] Available at http://dadf.gov.in/sites/default/filess/wool.pdf
[121] As reported for 2004-05 to 2009-10 for all states
[122] Available at: https://web.archive.org/web/20140921184255/http://www.rubberboard.org.in/RSN/RubberStatisticalMay2008.pdf
[123] Available at https://web.archive.org/web/20140922072822/http://www.rubberboard.org.in/RSN/RSN_June2010.pdf
[124] Available at https://web.archive.org/web/20140922081911/http://www.rubberboard.org.in/RSN/RSN_July2011.pdf
[125] Available at https://web.archive.org/web/20150611070250/http://www.rubberboard.org.in/RSN/RS_News_May2013(annual).pdf

Sector	Data Point	Data Source
		Statistics & Planning Department, Rubber Board- Rubber Statistical Monthly News –September 2014, Page 2 – Production and Consumption of NR & SR[126] Rubber Board, Rubber Production in India (n.d.), Table 33: Number of Licensed Manufacturers in Different Indiastat: State-wise Number of Licensed Manufactures of Rubber in India (2010- 2011 to 2015- 2016) Rubber Board, Rubber Production in India (n.d.), Table 2: State-Wise Area under Rubber Statistics & Planning Department, Rubber Board- Rubber Statistical Monthly News –May 2015, Page 2 – Production and Consumption of NR & SR Statistics & Planning Department, Rubber Board- Rubber Statistical Monthly News –June 2017, Page 2 – Production and Consumption of NR & SR[127] Website of Rubber Board- Manufacturer License List -2018[128]
Tannery	• Gross value added for leather and related products • National level production of Bovine, Sheep, lamb, Goat and kid skins and hides	Handbook of Industrial Policy and Statistics 2008-09, Table 14.2-Table 14.36, Department of Industrial Policy and Promotion, Ministry of Commerce & Industry[129] Food and Agriculture Organization (FAO)- World Statistical Compendium for raw hides and skins, leather and leather footwear 1998-2015, Table 5, Table 7, Table 9[130]
Fish processing	• State-wise production of processed fish	Handbook on Fisheries Statistics 2014, Section A: Production and Disposal, Table A – 10.1 to Table A- 10.5, Department of Animal Husbandry, Dairying and Fisheries [131]

Source: Author's compilation

Assumptions:

- To ensure consistency with the INCAA Report, BUR 1 and the BUR 2 reports, the GHG emission estimates is to be prepared on a calendar year basis. For all the industrial sectors included in this assessment except Tannery sector, production data is available on a financial year basis has been apportioned on a calendar year basis. Production datasets available on financial year basis have been converted to calendar year datasets for a given calendar year by considering 3/4th of the value from the previous financial year (corresponding to 9 months from April to December out of 12 months in a year) and 1/4th from the next financial year (corresponding to 3 months from January to March out of 12 months in a year). For example, 3/4th of the production data from the financial year 2004-05 and 1/4th of the production data from the financial year 2005-06 has been considered and added together to estimate the production data for the calendar year 2005, and so

[126] Available at https://web.archive.org/web/20150612061420/http://www.rubberboard.org.in/PDF/rsnewssep2014.pdf
[127] Available at http://www.rubberboard.org.in/rbfilereader?fileid=189
[128] Available at http://rbegp.in/RUBI/LicensingReportsInIndex.do?licensetypepk=1&statepk=0&districtpk=0
[129] Available at http://eaindustry.nic.in/industrial_handbook_200809.pdf
[130] Available at http://www.fao.org/3/a-i5599e.pdf
[131] Available at http://fsi.gov.in/LATEST-WB-SITE/pdf_files/statistics/hofs-2014.pdf

on. Production data for Tannery sector was already reported for the calendar year and thus no further estimation was required to convert this data to calendar year basis.

- Iron & Steel Sector assumption and apportionments:
  (a) State-wise total Pig Iron production is not available directly from the data sources for all years of the emission estimation period. Therefore, state-wise Pig Iron production has been consolidated based on reported data for public and private sector plants. Production data considered for public sector plants has been aggregated for relevant states, based on reported production data and location of the plant. With regard to private sector plants, only aggregated all-India level production of Pig Iron by private sector plants from 2004-05 to 2013-14 is available and state-wise production is not reported. Further, data on 'installed capacities' is only reported for these plants for years 2011-12 to 2015-16 and data on production of Pig Iron by these plants is not reported. Given the lack of time-series data, the state-wise proportion of 'installed capacity' of Pig Iron plants, as reported to be consistent for year 2011-12 to 2013-14, is assumed to be applicable from 2004-05 to 2010-11. The state-wise production has been estimated based on the corresponding share of installed capacity of the private sector plants (as available for year 2011-12 to 2013-14). Breakup of installed capacity of JSW Steel Plants at Vijaynagar, Dolvi, & Salem has been obtained from the JSW Steel website.
  (b) State-wise data on production of Sponge Iron is not available across the emission estimation period. Data on 'installed capacity' for Sponge Iron plants by their location is available for the period 2011-12 to 2015-16 and production data for each of these plants is not available. To address the unavailability of state-level production data, aggregated national-level data available on Sponge Iron production from 2004-05 to 2015-16 has been apportioned to each of the states based on corresponding proportions of 'installed capacity' of Sponge Iron plants by their location. Given the lack of time-series data, the state-wise proportion of 'installed capacity' of Sponge Iron plants, as reported to be consistent for year 2011-12 to 2013-14, is assumed to be applicable from 2004-05 to 2010-11.
  (c) State-wise data on production of Steel is not available across the emission estimation period. Data on 'installed capacity' for Steel plants by their location is available for the period 2010-11 to 2013-14 and production data for each of these plants is not available. To address the unavailability of state-level production data, aggregated national-level data available on Steel production from 2004-05 to 2015-16 has been apportioned to each of the states based on corresponding proportions of 'installed capacity' of Steel plants by their location. Given the lack of time-series data, the state-wise proportion of 'installed capacity' of Steel plants, as available for 2010-11 to 2013-14, is assumed to be applicable across the emission estimation period.
  (d) With regard to Steel, aggregated data reported for Steel Authority of India Limited (SAIL) steel plants producing finished steel[132] has been apportioned among 3 states based on the plant location and their respective 'installed capacities'. Further in the

[132] (a) The three SAIL steel plants include- (1) Alloy Steels Plant, Durgapur, West Bengal with 184,000 tonnes per annum production capacity in 2015 (2) Salem Steel Plant (SSP), Tamil Nadu with 339,000 tonnes per annum production capacity in 2015 (3) Visvesvaraya Iron and Steel Limited (VISL), at Bhadravathi, Karnataka with 216,000 tonnes per annum production capacity

Steel dataset, location of some plants is reported as 'Multi location' and the specific state is not indicated. The ‘Multi location’ category includes the following five states: Maharashtra, West Bengal, Andhra Pradesh, Chattisgarh, and Karnataka. Therefore, in this case the ‘installed capacity’ reported under 'Multi location' has been split equally in these 5 states, given the lack of information.

- <u>Fertilizer Sector data assumption and apportionments:</u>
  (a) Reported data on plant-wise production of Nitrogen and phosphate fertilizer for 2004-05 to 2014-15 has been aggregated to the state-level based on plant location.
  (b) While production data reported separately for Nitrogen and Phosphate fertilizer is available for previous years, such segregated data is not available for year 2015-16. Therefore, the nitrogen and phosphate fertilizer production for year 2015-16 has been estimated based on corresponding annual average growth trend over 5 year period from 2009-10 to 2014-15.
  (c) Nitrogen fertilizer production data for plants located in Andhra Pradesh, Goa, Karnataka, Odisha, Rajasthan, Tamil Nadu and West Bengal is not reported for year 2004-05 and has been estimated based on the corresponding annual growth rate in nitrogen fertilizer production for these states from 2003-04 to 2005-06.
  (d) Phosphate fertilizer production data for plants located in Odisha and West Bengal is not reported for year 2004-05 and has been estimated based on the corresponding annual growth rate in phosphate fertilizer production for these states from 2003-04 to 2005-06.

- <u>Sugar Sector data assumption and apportionments:</u>
  (a) State-wise data on Sugar production for year 2012-13 is not available. National-level Sugar production data available for 2012-13 has been apportioned to each of the states based on corresponding proportions over a 5 year period from 2010-11 to 2015-16, except for former Andhra Pradesh. For Andhra Pradesh, given that the state was divided into two states in 2014 (i.e. post 2012-13), the corresponding proportion to the national-level production for 2010-11 and 2011-12 has been used to estimate figures for 2012-13.

- <u>Coffee Sector data assumption and apportionments:</u>
  (a) Coffee production for the states of Andhra Pradesh and Odisha is clubbed together in the source document and is not reported separately. Similarly, coffee production in North East region is not reported separately for each of the constituent states. Therefore, for these states the following assumptions have been considered to estimate coffee production for these states across the reporting period as per communication with Deputy Director (Market Research), Coffee Board -
    - In the Andhra Pradesh & Odisha cluster, Andhra Pradesh and Odisha has a respective share of 95% and 5% approximately in the coffee production
    - In the North-East region, the states of Assam and Meghalaya have an approximate share of 20% each and the rest of the five states (Arunachal Pradesh, Manipur, Mizoram, Nagaland, Tripura) have a share of approximately 12% each in the North East region's total Coffee Production

- <u>Petroleum Sector data assumption and apportionments:</u>

(a) State-wise data on production of Petroleum products (petroleum, oil and lubricants) is not available. Reported data on the 'volume of crude oil processed' is available for different refineries along with their location for the period 2004-05 to 2015-16. National-level data available on cumulative production of Petroleum products for 2004-05 to 2015-16 has been apportioned to each of the states that house refineries based on corresponding proportion of 'volume of crude oil processed' by each refinery to the 'total volume of Crude Oil processed' by all refineries.

- Milk Sector data assumption and apportionments:
  (a) State-wise data on Milk processed by dairies is not available across the emission estimation period. State-wise data on 'cumulative installed capacity' of registered dairies is available for year 2011. To address the unavailability of state-level production data, aggregated national-level data available on Milk production from 2004-05 to 2015-16 has been apportioned to each of the states based on corresponding proportions of 'installed capacity' of dairies by State. Given the lack of time-series data, the state-wise proportion of 'installed capacity' of dairies, as available for year 2011, is assumed to be applicable across the emission estimation period.
  (b) Given that the aforementioned dataset on installed capacity of dairies is from 2011, data has been reported cumulatively for the states of Andhra Pradesh and Telangana, which were bifurcated later in 2014. Milk processing for Telangana and Andhra Pradesh for 2014-15 and 2015-16, post bifurcation of the two states, has been estimated by applying corresponding proportions of processing capacity for cooperative dairy plants as reported in 2016 for Andhra Pradesh and Telangana respectively.

- Pulp & Paper Sector data assumption and apportionments:
  (a) State-wise paper production is available only for the time period 2010-11 to 2013-14 and is not available for the period from 2004-05 to 2009-10. The total National-level production has been estimated for these years by applying an average annual growth rate of 6% to the available data from 2010-11 to 2013-14 as per inputs received from the Central Pulp & Paper Research Institute (CPPRI). The paper production for relevant states has subsequently been estimated for the period from 2004-05 to 2009-10 based on the corresponding average share of each state in the production as per reported data from 2011-12 to 2013-14. Data reported for paper production by CPPRI for 2014-15 and 2015-16 has been updated subsequently for these two years.

- Rubber sector data assumption and apportionments:
  (a) State-wise data on Natural and Synthetic Rubber processed by states is not available across the emission estimation period. National-level data on cumulative production of Natural and Synthetic Rubber has been apportioned to each of the corresponding states based on the available data on state-wise no. of licensed rubber manufacturers across the period between 2004-05 and 2015-16. Information on the 'installed production capacity' for the licensed rubber manufacturers is not available and thus given the lack of alternate production related data, apportionment has been done solely on the basis of the number of licensed manufacturers.
  (b) Data on no. of rubber manufacturers for the union territories of Chandigarh, Dadra & Nagar Haveli, and Daman & Diu is not reported separately in the data sources.

Reported data on state-wise no. of manufacturers that is available for year 2018 has been used accordingly for these 3 union territories.

(c) Data on no. of rubber manufacturers for the states of Jammu and Kashmir, Meghalaya, Nagaland, Puducherry and Tripura is not reported separately in the data sources and is clubbed under 'Others' across the emission reporting period. Reported data on state-wise no. of manufacturers for year 2018 has been used for Puducherry, Tripura, and Jammu & Kashmir. Segregated data on no. of manufacturers in Meghalaya and Nagaland is not available and therefore information on corresponding share of rubber cultivation in these two states, available for year 2004-05 only, has been used as a basis for apportionment.

(d) Data on no. of rubber manufacturers for Telangana and Andhra Pradesh is reported in the data source collectively under Andhra Pradesh. Data on no. of manufacturers for Telangana reported for year 2018 by the data source has been used for years 2014-15 and 2015-16 due to unavailability of data. This figure/value has further been deducted from cumulative total reported for Andhra Pradesh and Telangana to arrive at the total no. of manufacturers for Andhra Pradesh state (only) for 2014-15 and 2015-16

- Tannery sector data assumption and apportionments:

(a) State-wise data on leather processed by states not available for the emission estimation period. State-wise data on corresponding 'Gross Value Added' by Tannery sector is available for year 2005-06. Data on no. of tannery factories is also available however data on 'production or installed capacities' is not known for the tanneries. Hence, 'Gross Value Added' is gauged to be a more appropriate metric to represent the manufacturing activity in tannery sector for each state and has been used as a basis for apportionment. National-level data available on cumulative production of tannery products (total of Bovine, Sheep, lamb, Goat and kid skins and hides) has been apportioned to each of the states based on the corresponding share of 'Gross Value Added' for each state to total state-aggregate 'Gross Value Added' for the sector. Given the lack of time-series data, the state-wise proportion of 'Gross Value Added' by the Tannery sector, as available for year 2005-06, is assumed to be applicable across the emission estimation period.

- Fish Processing Sector data assumption and apportionments:

(a) Reported data on state-wise fish processing production is available for the time period from 2008 to 2012 only. The total national-level production has been estimated for the rest of the years (i.e. 2005 to 2007 and 2013 to 2015) by applying the average annual growth rate from 2008 to 2012. The fish processing production for each state for the period from 2005 to 2007 and 2013 to 2015 has subsequently been estimated based on the corresponding average percentage share of each state as per reported data from 2008 to 2012.

2. Wastewater generated per tonne of product (W_i)

A combination of country specific and default values available at the national level have been used for this coefficient since state-level values are not available. The following data sources are used, in the order of preference to prioritize the use of country specific values for this coefficient (based on the availability of information)

1. India's BUR 2, 2014 to the UNFCCC
2. India's Second National Communication to the UNFCCC
3. related NEERI[133] documentation (indicated in the following Table)
4. 2006 IPCC Guidelines (Vol. 5, Chapter 6: Wastewater Treatment and Discharge)

The values for wastewater generation per tonne of production and respective data sources are indicated in the Table 47 below.

Table 47: Industry-wise Wastewater generation per tonne of Product

Industry	Wastewater generation (m^3/tonne of product)	Reference
Iron & Steel	60	India's Second National Communication to the UNFCCC, 2012, Box 2.7. Available at: https://unfccc.int/sites/default/files/resource/indnc2.pdf
Fertilizer	8	India's Second National Communication to the UNFCCC, 2012, Box 2.7. Available at: https://unfccc.int/sites/default/files/resource/indnc2.pdf
Sugar	0.4	India's BUR 2 Report 2014, Table 2.17. Available at: https://unfccc.int/sites/default/files/resource/INDIA%20SECOND%20BUR%20High%20Res.pdf
Coffee	15	India's BUR 2 Report 2014, Table 2.17. Available at: https://unfccc.int/sites/default/files/resource/INDIA%20SECOND%20BUR%20High%20Res.pdf
Petroleum	0.6	India's BUR 2 Report 2014, Table 2.17. Available at: https://unfccc.int/sites/default/files/resource/INDIA%20SECOND%20BUR%20High%20Res.pdf
Dairy	6	India's BUR 2 Report 2014, Table 2.17. Available at: https://unfccc.int/sites/default/files/resource/INDIA%20SECOND%20BUR%20High%20Res.pdf
Meat	11.7	India's Second National Communication to the UNFCCC, 2012, Box 2.7. Available at: https://unfccc.int/sites/default/files/resource/indnc2.pdf
Pulp & Paper	127.5	• Technical EIA Guidance Manual for Pulp & Paper Industry prepared by IL&FS Ecosmart Limited for MoEF, 2010. Refer Table 3-10, page 67. Available at: http://environmentclearance.nic.in/writereaddata/form-1a/homelinks/TGM_Pulp%20and%20Paper_010910_NK.pdf • Technical Compendium on Energy Saving opportunities – Pulp & Paper sector published by Confederation of Indian Industry, 2013. Refer Table 3 for production share. Available at http://shaktifoundation.in/wp-content/uploads/2014/02/pulp_paper.pdf
Rubber	26.3	India's Second National Communication to the UNFCCC, 2012, Box 2.7. Available at: https://unfccc.int/sites/default/files/resource/indnc2.pdf

[133] NEERI was the lead institution involved in the estimation of GHG emissions from industrial wastewater for the Waste sector in India's official inventory. NEERI has been contacted for details on the methodology and information for this assessment and in case of data gaps or limited availability of information in the National Communication reports, preference has been given to relevant NEERI documents.

Industry	Wastewater generation (m^3/tonne of product)	Reference
Tannery	35	India's BUR 2 Report 2014, Table 2.17. Available at: https://unfccc.int/sites/default/files/resource/INDIA%20SECOND%20BUR%20High%20Res.pdf
Fish processing	13	India's BUR 2 Report 2014, Table 2.17. Available at: https://unfccc.int/sites/default/files/resource/INDIA%20SECOND%20BUR%20High%20Res.pdf

Source: Author's compilation

Assumptions:

- Wastewater generation per tonne of product would likely vary over the years, with improvements in production processes and technologies leading to reduction in wastewater generation. However, due to the lack of such updated information in the 2006 IPCC Guidelines**Error! Bookmark not defined.** and India's BUR 2 document, and in the a bsence of other published literature, constant values of wastewater generated per tonne of product have been used for all the years (2005-2015) in this assessment for the industry sectors.
- For the Pulp & Paper sector, a value of 127.5 m^3/tonne has been used in the estimates. The weighted average value of wastewater generation per tonne (127.5 m^3/tonne) has been estimated by multiplying wastewater generation per tonne values reported for three types of paper mills (viz. large integrated paper mills, agro-based mills, and waste-paper based mills) with corresponding share of production for each mill type (see Table 48). The wastewater generation values have been sourced from a Pulp & paper industry technical EIA guidance manual prepared for the MoEF in 2010. Information on share of Pulp & Paper sector's production for the three mill types is reported for year 2008 in another sector publication by CII. Based on sectoral studies by Centre for Science and Environment[134] and by the National Productivity Council and CPCB[135], wastewater generation per unit product is expected to have reduced in the Pulp and Paper sector over the years. When comparing values reported in NATCOM-II (i.e. 230 m^3/tonne for 2007) and BUR 2 (i.e. 250 m^3/tonne for 2014) reflects an increasing trend and both wastewater generation values reported look to be quite high and are therefore not used in the estimates.

Table 48: Estimated wastewater generation value for Pulp and paper sector

Paper Mill Type	Wastewater generation per tonne (m^3/tonne)	Percent share in total production
Large integrated mills	175	36%

[134] A CSE study in 2012-13 for the sector indicates that wastewater generation has reduced to 60 m^3 per tonne in 2011-12 and 57 m^3 per tonne in 2012-13 due to improvements in technology, with an average annual reduction of 7.4% since 1995-96.

[135] Field studies conducted by the National Productivity Council in 10 pulp and paper mills in 2005-06, in consultation with the CPCB, indicate that the wastewater discharge per tonne of product ranges from 65-100 m^3. National Productivity Council and CPCB (2006): Final Report on Development of Guidelines for Water Conservation in Pulp and Paper Sector. Available at http://cpcb.nic.in/newitems/45.pdf

Agro-based mills	150	29%
Waste-paper based mills	60	35%
Estimated average wastewater generation per tonne for Pulp & Paper Sector	(175 × 36%) + (150 × 29%) + (60 × 35%) = 127.5 m^3/tonne	

Source: Author's analysis based on MoEF and CII data

3. Degradable organic component in industrial wastewater (COD_i)

The following data sources are used, in the order of preference to prioritize the use of country specific values for this coefficient (based on the availability of information)

1. India's BUR 2, 2014 to the UNFCCC
2. NEERI documentation on Methane Emissions from wastewater in India (indicated in the following Table)
3. 2006 IPCC Guidelines (Vol. 5, Chapter 6: Wastewater Treatment and Discharge)

Specific values of degradable organic concentration in the wastewater (kg COD/m^3) used in the India's BUR 2 estimate for 2014 are indicated for the Sugar, Coffee, Petroleum, Dairy, Meat, Pulp & Paper, Tannery, and Fish processing sectors in the BUR 2 document. State-wise values for this coefficient are not available. Therefore, default and country specific national level values are used for this coefficient in this assessment are indicated in the Table 49 below.

Table 49: Industry-wise degradable organic concentration in the Wastewater

Industry	COD (kg COD/m^3)	Reference
Iron & Steel	0.55	NEERI (2010): Status of Methane Emissions from Wastewater and Role of Clean Development Mechanisms in India. Published in the TERI Information Digest on Energy and Environment, [S.l.], p. 155-166, June. 2010. ISSN 0972-6721. Available at: http://www.i-scholar.in/index.php/tidee/article/view/89982
Fertilizer	3.0	NEERI (2010): Status of Methane Emissions from Wastewater and Role of Clean Development Mechanisms in India. TERI Information Digest on Energy and Environment, [S.l.], p. 155-166, June 2010. ISSN 0972-6721. Available at: http://www.i-scholar.in/index.php/tidee/article/view/89982
Sugar	5	India's BUR 2 Report 2014, Table 2.17. Available at: https://unfccc.int/sites/default/files/resource/INDIA%20SECOND%20BUR%20High%20Res.pdf
Coffee	9	India's BUR 2 Report 2014, Table 2.17. Available at: https://unfccc.int/sites/default/files/resource/INDIA%20SECOND%20BUR%20High%20Res.pdf
Petroleum Refineries	1	India's BUR 2 Report 2014, Table 2.17. Available at: https://unfccc.int/sites/default/files/resource/INDIA%20SECOND%20BUR%20High%20Res.pdf
Dairy	3	India's BUR 2 Report 2014, Table 2.17. Available at: https://unfccc.int/sites/default/files/resource/INDIA%20SECOND%20BUR%20High%20Res.pdf
Meat	5	India's BUR 2 Report 2014, Table 2.17. Available at: https://unfccc.int/sites/default/files/resource/INDIA%20SECOND%20BUR%20High%20Res.pdf
Pulp & Paper	2	India's BUR 2 Report 2014, Table 2.17. Available at: https://unfccc.int/sites/default/files/resource/INDIA%20SECOND%20BUR%20High%20Res.pdf

Industry	COD (kg COD/m³)	Reference
Rubber	6.12	NEERI (2010): Status of Methane Emissions from Wastewater and Role of Clean Development Mechanisms in India. Published in TERI Information Digest on Energy and Environment, [S.l.], p. 155-166, jun. 2010. ISSN 0972-6721. Available at: http://www.i-scholar.in/index.php/tidee/article/view/89982
Tannery	4.5	India's BUR 2 Report 2014, Table 2.17. Available at: https://unfccc.int/sites/default/files/resource/INDIA%20SECOND%20BUR%20High%20Res.pdf
Fish processing	2.5	India's BUR 2 Report 2014, Table 2.17. Available at: https://unfccc.int/sites/default/files/resource/INDIA%20SECOND%20BUR%20High%20Res.pdf

Source: Author's compilation

4. Methane Correction Factor and Emission Factor (EF_i) for the industry

The value of the MCF is based on the prevalent wastewater treatment system used in the respective industrial sector (see Table 45). The following data sources are used, in the order of preference (based on the availability of information) for consistency with India's National Communication and the IPCC guidelines

1. India's Second National Communication to the UNFCCC
2. 2006 IPCC Guidelines (Vol. 5, Chapter 6: Wastewater Treatment and Discharge)
3. India's BUR 2 report, 2014
4. Sector-specific documents and studies (used where information is not available from NEERI and IPCC guidelines)

The data sources to identify the prevalent wastewater treatment technologies for the industrial sectors and the corresponding emission factor used are indicated in Table 50. State-level information for the emission factor related parameters is not available. The 2006 IPCC Guidelines and other reference documents define values for the emission factors and coefficients at the national level only. Therefore, the national level values listed for each industry sector are used in the emission estimation across all states.

Table 50: Industry-wise Methane Correction Factor based on the prevalent treatment system

Industry	Bo (kg CH4/kg COD)[136]	MCF [137]	EF= B_o x MCF (kg CH4/kg COD)	Reference for Prevalent Treatment Technology
Iron & Steel	0.25	0	0	Sirajuddin, Ahmed, Umesh Chandra, R. K. Rathi, (2010) "Waste water treatment technologies Commonly practiced in Major Steel Industries of India" In 16th Annual International Sustainable Development Research Conference 2010, 30 May – 1 June, 2010 The University of Hong Kong, Hong Kong.
Fertilizer	0.25	0.2	0.05	India's Second National Communication to the UNFCCC, 2012. Available at: https://unfccc.int/sites/default/files/resource/indnc2.pdf
Sugar	0.25	0.8	0.2	• India's Second National Communication to the UNFCCC, 2012. Available at: https://unfccc.int/sites/default/files/resource/indnc2.pdf • Methane extraction from Organic wastewater, at Mandya District, Karnataka< India by M/s Sri Chamundeswari Sugars Ltd. Available at: https://cdm.unfccc.int/Projects/DB/DNV-CUK1176804855.99/view
Coffee	0.25	0.8	0.2	2006 IPCC guidelines for National Greenhouse Gas Inventories, Vol. 5, Chapter 6: Wastewater Treatment and Discharge. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf
Petroleum Refineries	0.25	0	0	Technical EIA Guidance Manual for Petroleum Refining Industry prepared by IL&FS Ecosmart Limited for MoEF, 2010. Available at: http://envfor.nic.in/sites/default/files/TGM_Petroleum_Refineries_010910.pdf
Dairy	0.25	0.8	0.2	India's Second National Communication to the UNFCCC, 2012. Available at: https://unfccc.int/sites/default/files/resource/indnc2.pdf
Meat	0.25	0.8	0.2	2006 IPCC guidelines for National Greenhouse Gas Inventories, Vol. 5, Chapter 6: Wastewater Treatment and Discharge. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf
Pulp & Paper	0.25	0.8	0.2	• India's Second National Communication to the UNFCCC, 2012. Available at: https://unfccc.int/sites/default/files/resource/indnc2.pdf

[136] Bo value is taken as default value as per 2006 IPCC Guidelines, Vol. 5, Chapter 6. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

[137] MCF value is taken based on treatment systems listed in 2006 IPCC Guidelines, Vol. 5, Chapter 6, Table 6.8 (see Table 63 in this document). Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

Industry	Bo (kg CH4/kg COD)[136]	MCF [137]	EF= B_o x MCF (kg CH4/kg COD)	Reference for Prevalent Treatment Technology
				• Methane recovery from wastewater generated at Paper manufacturing unit of Sree Sakthi Paper Mills Ltd., Kerala, India. Available at https://cdm.unfccc.int/Projects/DB/SGS-UKL1236761076.31
Rubber	0.25	0	0	• Central Pollution Control Board (CPCB), Pollution Control Implementation Division – III report on 'Pollution Control in Natural Rubber Processing Industry'. Available at: http://cpcb.nic.in/divisionsofheadoffice/pci3/pciiiidivrubber.pdf • Woodard, F. (2001). Industrial waste treatment handbook. Available at: http://neerienvis.nic.in/pdf/publications/e-book/Industrial%20Waste%20Treatment%20Handbook.pdf
Tannery	0.25	0.2	0.05	India's Second National Communication to UNFCCC, 2012. Available at: https://unfccc.int/sites/default/files/resource/indnc2.pdf
Fish processing	0.25	0	0	India's BUR 2 Report 2014, Table 2.17. Available at: https://unfccc.int/sites/default/files/resource/INDIA%20SECOND%20BUR%20High%20Res.pdf

Source: Author's compilation

5. Methane Recovery Rates

CH_4 is recovered in some of the industries such as sugar and dairy for energy purposes. In such cases, the methane recovered is to be subtracted from the total CH_4 estimated to be emitted from wastewater treatment in these industries. Since, state-level information on methane recovery rates is not available, national-level values as per GHG estimates prepared for year 2007 for India's Second National Communication[138] have been used across the states:

- Sugar: 70% methane recovery rate
- Dairy: 75% methane recovery rate

3.7.3 Recalculation

Emission estimates from industrial wastewater are directly proportional to following two activity data parameters:

- Wastewater generation per tonne of product (m^3/tonne) (specific to each industry type)
- COD values for the wastewater (kg COD/m^3) (specific to each industry type)

Based on information published in India's recent BUR 2 document, updated values of either one or both of these activity parameters have been used in the current emission estimates (version

[138] This information is not available in the recent BUR 1 and BUR 2 and hence NATCOM II is referred.

3.0) for the industry sectors of Sugar, Coffee, Petroleum, Dairy, Meat, Pulp & paper, and Tannery. A comparison of the updated activity data across these sectors is presented in Table 51.

A recalculation of GHG emissions has been undertaken and reported since the deviation in emissions as compared to previous estimates (version 2.0) exceeds the threshold of 5%. The use of the latest published information on wastewater generation per unit product and COD values from the national communication document will help to improve accuracy of estimates and its comparability with the official inventory. The corresponding emission recalculations have resulted in a decrease in the overall GHG emissions from industrial wastewater as seen in Table 52.

Table 51: Changes in Activity Data for Industry sectors

Industry Sector	Wastewater generation (m3/tonne of product) (2005-2013)			COD (kg COD/m3) (2005-2013)			Source of updated activity data
	Phase 3	Phase 2	Difference w.r.t Phase 2	Phase 3	Phase 2	Difference w.r.t Phase 2	
Sugar	0.4	1	-60.0%	5	2.5	100.0%	Wastewater generation and COD values from India's BUR 2 document
Coffee	15	5	200.0%	9	9	0.0%	- Wastewater generation value from India's BUR 2 Report 2014 - No change in COD value
Petroleum	0.6	0.7	-14.3%	1	1	0.0%	- Wastewater generation value from India's BUR 2 document - No change in COD value
Dairy	6	3	100.0%	3	2.24	33.9%	Wastewater generation and COD values from India's BUR 2 document
Meat	11.7	11.7	0.0%	5	4.1	22.0%	- COD value from India's BUR 2 document - No change in wastewater generation value
Pulp & Paper	127.5	92.04; (in 2005) decreasing to 60 (in 2013) at rate of 7.4% per year	80.6%	2	5.9	-66.1%	- COD value from India's BUR 2 document - Wastewater generation updated from sectoral publications
Tannery	35	32	9.4%	4.5	3.1	45.2%	Wastewater generation and COD values from India's BUR 2 document

Source: Author's analysis

Table 52: Recalculation of CH_4 emission estimates for Industrial Wastewater Treatment and Discharge

Year	CH_4 estimates from Industrial wastewater treatment and discharge (Mil. tonnes of CO_2e)		Percent difference w.r.t. Phase 2
	Phase 3	Phase 2	
2005	13.39	23.75	-43.6%
2006	14.22	23.64	-39.9%
2007	15.30	23.71	-35.4%
2008	16.26	23.62	-31.1%
2009	17.25	23.54	-26.7%
2010	18.30	23.47	-22.0%
2011	19.38	23.31	-16.9%
2012	20.95	24.20	-13.4%
2013	22.17	23.99	-7.6%

Source: Author's analysis

Table 53: Comparison of GHG emission estimates in phase 3 and phase 2 for Industry Sectors with recalculation

Industry Sector [139]	CH_4 Estimates (mil. tonnes of CO2e)	2005	2006	2007	2008	2009	2010	2011	2012	2013
Sugar	Phase 3	0.044	0.066	0.068	0.044	0.045	0.058	0.065	0.064	0.062
	Phase 2	0.055	0.082	0.085	0.055	0.056	0.073	0.081	0.080	0.076
	Percent difference wrt Phase 2	-20.0%	-20.0%	-20.0%	-20.0%	-20.0%	-20.0%	-20.0%	-20.4%	-19.6%
Coffee	Phase 3	0.156	0.161	0.152	0.162	0.172	0.172	0.176	0.180	0.175
	Phase 2	0.052	0.054	0.051	0.054	0.057	0.057	0.059	0.060	0.058
	Percent difference wrt Phase 2	200.0 %	200.0 %	200.0 %	200.0 %	200.0 %	200.0 %	200.0 %	200.0 %	200.0 %
Dairy	Phase 3	1.81	1.91	2.01	2.10	2.18	2.28	2.39	2.48	2.58
	Phase 2	0.68	0.71	0.75	0.78	0.81	0.85	0.89	0.93	0.96
	Percent difference wrt Phase 2	167.9 %	167.9 %	167.9 %	167.9 %	167.9 %	167.9 %	167.9 %	167.9 %	167.9 %
Meat	Phase 3	0.57	0.57	0.88	1.04	1.10	1.18	1.32	1.43	1.51
	Phase 2	0.47	0.47	0.72	0.85	0.91	0.97	1.08	1.18	1.24
	Percent difference wrt Phase 2	22.0%	22.0%	22.0%	22.0%	22.0%	22.0%	22.0%	22.0%	22.0%
Pulp & Paper	Phase 3	10.37	11.03	11.73	12.48	13.28	14.13	14.94	16.30	17.35
	Phase 2	22.09	21.88	21.67	21.47	21.27	21.06	20.74	21.50	21.18
	Percent difference wrt Phase 2	-53.1%	-49.6%	-45.9%	-41.9%	-37.6%	-32.9%	-28.0%	-24.2%	-18.1%

[139] While the figure for wastewater generation per tonne product has been updated for Petroleum refining industry based on BUR 2, there is no change in GHG estimates for this industry sector. This is since the prevalent wastewater treatment system mapped to this sector is aerobic treatment type, which is assumed to be 'well managed' and thereby has emission factor of zero and zero corresponding GHG emissions. Thereby since it has zero corresponding emissions and no emission changes result from recalculation, Petroleum refining industry is not included in the Table 52.

Industry Sector[139]	CH_4 Estimates (mil. tonnes of CO2e)	2005	2006	2007	2008	2009	2010	2011	2012	2013
Tannery	Phase 3	0.081	0.083	0.084	0.086	0.088	0.090	0.090	0.092	0.098
	Phase 2	0.051	0.052	0.053	0.054	0.055	0.057	0.057	0.058	0.062
	Percent difference wrt Phase 2	58.8%	58.8%	58.8%	58.8%	58.8%	58.8%	58.8%	58.8%	58.8%

Source: Author's analysis

It should further be noted that the scope of assessment has been expanded to include emissions from fish processing industry in this source category. However, given that the prevalent wastewater treatment system for fish processing is well-managed aerobic treatment type, which has emission factor of '0' and thereby results in zero emissions.

3.8 Uncertainty

A qualitative description of uncertainty, addressing activity data and emission factors, for each of the 3 source categories included in the GHG estimates is provided below.

1) 4A2 Unmanaged Waste Disposal Sites

Uncertainties in the emission estimates from solid waste disposal result due to the following factors

- **Limited reliable information on waste generation and disposal:** The FOD method used in the emission estimation, assumes that carbon in waste decays gradually for decades to generate CH_4 emission long after it is disposed and therefore, it is necessary to estimate or collect 50-year data on waste disposal prior to the base year of 2005 i.e. from 1954-2004. Reliable state-level data on municipal solid waste generation and disposal rates is not available for the said period. The Municipal Solid Waste (Management and Handling) Rules, 2000[140] (amended recently in 2016[141]) and the Manual on Municipal Solid Waste Management Systems[142] that lays down guidelines for urban local bodies to collect and treat solid waste first came into existence in the year 2000. As per the guidelines in the Rules, urban local bodies are mandated to report to the respective SPCB's and CPCB on the status of their waste generation and treatment rates. Given that a reporting mandate and mechanism was only established in the year 2000 under the ambit of the Municipal Solid Waste (Management and Handling) Rules, 2000, official datasets relating to solid waste generation and its management before this time are not available. Therefore, in absence of an official source of data before the year 2000, data from other sources has been used and interpolated. Even in the post-2000 period, reliable year-on-year state-level data on solid waste generation and disposal is not available. Data that is being reported by states is observed to be inconsistent.

[140] Available at http://www.moef.nic.in/legis/hsm/mswmhr.html
[141] Available at http://www.moef.nic.in/content/so-1357e-08-04-2016-solid-waste-management-rules-2016?theme=moef_blue
[142] Available at http://mohua.gov.in/publication/manual-on-solid-waste-management-systems-cpheeo-2000.php

Given the lack of information, it is assumed that 70% of the waste generated goes to the landfill across the period from 1954-2010, contributing to uncertainty in the estimates.

- **Functionality of treatment systems:** The available state-level datasets on the treatment rates are presently based on the capacity of the processing plants existing in cities across the states. It does not take into account the functionality of the plants. A number of treatment plants across states are either non-operational or not working to their full potential which is resulting in additional amount of waste going to disposal sites than the recorded values. Due to lack of consolidated datasets on the functionality of the waste treatment plants at the state level, it is difficult to factor this in the estimations.
- **Limited data for DOC estimation:** The DOC estimation is a function of waste composition, which has changed over time and varies from state to state based on consumption patterns. Since regularly updated data on state-level waste composition is not available across the period from 1954-2004, nationally available average waste composition data available for the two years of 1971 and 1995 is assumed to be applicable for the time periods 1954-1994 and 1995-2004 respectively. Reliable state-level waste composition data is available for year 2005 only and has been assumed to be applicable across the period 2005-2015. The corresponding DOC values have been estimated based on this intermittently available waste composition data and applied across the three time periods of 1954-1994, 1995-2004, and 2005-2015 to calculate state emissions. While waste composition may not change drastically, this approximation due to unavailability of reliable data contributes to a certain level of uncertainty in the estimates.

As per 2006 IPCC Guidelines[143], uncertainty of GHG emissions from the disposal of solid waste based on activity data and emission factors are as follows:

- Total municipal solid waste generated: 30% is a typical value for countries which collect waste generation data on a regular basis; for countries with poor quality data: more than a factor of two.
- Fraction of municipal solid waste sent to solid waste disposal site: $\underline{+}$ 30% for countries collecting data on disposal at SWDS
- Total uncertainty of waste Composition: $\underline{+}$ 30% for countries with country-specific data based on studies including periodic sampling
- Degradable Organic Carbon (DOC): $\underline{+}$10% for country-specific value and based on the experimental data over longer time periods
- Methane Correction Factor (MCF): $\underline{+}$ 30% for IPCC default value of 0.4
- Fraction of CH_4 in generated landfill gas: $\underline{+}$ 5% for IPCC default value of 0.5
- Methane Recovery: $\underline{+}$ 50% if metering is not in place.

2) 4D1 Domestic Wastewater Treatment and Discharge

Uncertainties in the emission estimates for this source category result from the following factors

---

[143] As per IPCC 2006 Guidelines, Vol. 5, Chapter 3: Solid Waste disposal, Table 3.5.
Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

- **Distribution of wastewater discharge pathways and treatment systems:** Updated year-on-year data on wastewater generation and the distribution of different treatment systems is lacking for the urban and rural areas across the states. Given this data constraint, constant values for the distribution of discharge/treatment systems, based on the Census of India 2011 and 2001 survey on household amenities and assets) have been used for the urban and rural populations in the states across the period from 2005-2015. The degree of utilization rates based on Census 2001 and 2011 data available for the states have been applied for the two-time periods of 2005-2010 and 2011-2015 respectively. Given the lack of updated information, on-ground developments in the states with regards to deployment wastewater treatment systems and any ensuing impacts on emissions may not be accurately captured in the state-level estimates.
- **MCF based on discharge pathway or treatment system classification:** The MCF represents the degree to which the wastewater treatment system is anaerobic and thereby generates GHG emission. IPCC defined MCF values[72] depending on the type of discharge pathway or treatment systems are used in the assessment. Due to lack of relevant information, the following assumptions have been made in the emission estimates which contribute to uncertainty.
  - The portion of urban wastewater that is collected in sewers but is untreated can be handled either through 'stagnant sewers' or be discharged into water bodies such as 'sea, lake or river'. The corresponding MCF value of 'sea, lake or river discharge' is 0.1 and the MCF value of 'stagnant sewer' is 0.5. The quantity of this untreated wastewater that is discharged into water bodies is unknown and therefore the entire portion of collected and untreated urban wastewater is accounted under 'stagnant sewer' for all the states.
  - Considering the relative lack of infrastructure for wastewater treatment in rural areas, it is assumed that the proportion of rural wastewater that is collected and conveyed through sewer systems does not undergo any treatment downstream and decomposes under aerobic conditions, thereby not leading to CH_4 emissions. Thus, the 'flowing sewer' system having a MCF value of '0' and leading to no GHG emissions is selected as the corresponding treatment system for the proportion of rural wastewater collected through sewer in all the states.
  - Rural wastewater that is uncollected and untreated can be either discharged into 'sea, lake or river' or 'to ground'. However, the quantity of wastewater that is discharged 'to ground' is unknown and therefore the entire portion of uncollected and untreated rural wastewater for all states is accounted under 'sea, lake or river discharge' which has a MCF value of 0.1.
- **Availability of state-wise data on sewage treatment plants:** The performance of existing STPs that handle collected wastewater is observed to unsatisfactory across the states. Several these plants are not operating to their full capacities and do not conform to the CPCB'/SPCB's environmental standards for discharge of treated wastewater into streams. Hence domestic and industrial wastewater going to the treatment plants is discharged without treatment in some cases. Untreated discharge and mixing of industrial and domestic wastewater will impact the emission generation potential from such wastewater streams. State-level data on STPs is reported intermittently (reported in the

years 1999, 2008 and 2014 as indicated in section 3.7.2). Furthermore, data is reported inconsistently across the states and is not available for some states at all. Given the data gaps, suitable assumptions have been used to assess how wastewater is handled in STPs in the states across the emission estimation period. Due to the lack of reliable and regularly reported data on the status of wastewater treatment plants, it is difficult to factor in these considerations in the state emission estimates.

- **Urban-Rural population and its distribution:** Decadal information on the urban and rural population available from the Census of India 2001 and Census of India 2011 has been used and population for the intermediate years has been estimated for the states based on corresponding decadal growth rate. Decadal information on the proportion of urban and rural population from the Census of India 2001 and 2011 has been applied across the emission estimation years. These estimates on urban and rural population may vary from the actual distribution existing in the states over the emission estimation period.
- **Biological Oxygen Demand values**: State specific BOD values are available only for 14 states. For the remaining states, national level average per capita BOD values are used in the CH_4 emission estimation. Since updated BOD values are not available on yearly basis, constant BOD values that are available are used across all the years.

As per 2006 IPCC Guidelines[144], the following conclusions may be drawn regarding uncertainty of GHG emissions from the treatment and disposal of domestic wastewater:
Activity data:

- Uncertainty resulting from values considered for Degree of utilization of treatment/discharge pathway or system for each income group (Ti,j): ±50% for each individual pathway/system
- Uncertainty resulting from values considered for Fraction of population income group (U), particularly for urban high income and low-income group: ±15%
- Uncertainty resulting from values of Human population (P): ±5%
- Uncertainty related to BOD per person: ±30%
- Uncertainty resulting from Correction factor for additional industrial BOD discharged into sewers (I): ±20% for the collected portion of wastewater

Emission factor:

- Uncertainty related to the values of the Fraction treated anaerobically (MCF), depending on the type of technology: Untreated systems and latrines, ± 50%; Lagoons, poorly managed treatment plants± 30%; Centralized well managed plant, digester, reactor, ± 10%
- Uncertainty related to the Maximum CH_4 producing capacity (Bo): ±30%

3) 4D2 Industrial Wastewater Treatment and Discharge

Emission estimate uncertainties are considerable in the case of industrial wastewater. Key factors that result in such significant uncertainties include:

---

[144] As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Table 6.7. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

- **Unavailability of reliable state-level production data across the years for each industry type**: Since data on industrial wastewater generation is unavailable, industrial production is a crucial starting point in the activity dataset to estimate the total wastewater generation for each industrial sector as per the tier 1 approach adopted. Reliable state-level data on industrial production is not available for most of the industry sectors across the emission estimation period. In some cases, industrial production data is not available at the state-level at all. Data is also found to be partly missing for some years in the reporting period or is not reported in disaggregated manner for some states. To address these data gaps, apportionment has been done for 8 out of 10 sectors based on national level production data and relevant proxy data such as installed production capacity, no. of manufacturers, etc. at the state level. Given that the activity data estimated using such approximations may not accurately reflect the prevalent industry environment in the reporting period and therefore this unavailability of activity data has impacted reliability. Further, the data is sourced from multiple data sources, which in turn report data that is collated from numerous sources, leading to the errors in reporting from the universe of respondents being carried over into the emission estimates.
- **The operational status of industrial wastewater treatment:** The type of wastewater treatment considered in the estimates is based primarily on information from NATCOM reports, IPCC guidelines and, NEERI publications. However, the status of the treatment plants that exist in the states, in terms of whether these are fully functional or not, is not recorded for any of the considered years. The amount of total degradable organic carbon (TOW) in industrial wastewater that is discharged into open or closed domestic sewers is very difficult to quantify, since information regarding the functional status of on-site treatment plants is not available.
- **Wastewater generation per unit product:** In the case of industrial wastewater, it is likely that wastewater generation per tonne of product and therefore wastewater generation may vary over the years with changes in production processes and technologies. However, due to the lack of such updated information, constant values of wastewater generated per tonne of product have been used for all the years (2005-2015) in the state-level emission estimates, except for Pulp & Paper sector.

As per 2006 IPCC Guidelines[145], the following conclusions may be drawn regarding uncertainty of GHG emissions from the treatment and disposal of industrial wastewater:

- Uncertainty resulting from values considered for Maximum CH_4 producing capacity (Bo): ±30%
- Uncertainty resulting from values considered for Industrial Production: ±25%
- Uncertainty resulting from kg COD per unit of produced product: -50%, +100% (a factor of 2)

3.9 Recommended Improvements

The unavailability of published state-specific and regularly updated information on the activity data, emission factors and related coefficients has been a challenge in the state emission estimation process for all 3 source-categories in the Waste sector. The specific challenges encountered for each source-category and possible mitigation ways are further described below.

---

[145] As per 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Table 6.10. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

1) 4A2 Unmanaged Waste Disposal Sites

Historical data on state-wise municipal solid waste generation and disposal is not available. Reliable and year-on-year data on municipal solid waste generation, waste composition for the past decade is lacking as well, with inconsistencies observed in reported data for states available from different sources. Thereby, reliable data is sought on waste generation and on the changing composition of waste across all states in the country. This will limit the need for approximations and assumptions and improve accuracy of the state emission estimates.

Inconsistent and inaccurate reporting in datasets on waste processing/treatment and on the proportion of waste going to landfill is a challenge. Reporting of waste treatment rates is largely done based on the installed capacities of the processing plants and does not account for operational status (non-operational/low capacity utilization) and therefore the volume of waste going to landfill cannot be assessed for the states accurately. Thereby, how well the processing plants are operating and any impacts of improved waste treatment over time cannot be factored into the state estimates. Improved data on these aspects is sought to improve accuracy of estimation and capture corresponding emission reductions for each state.

2) 4D1 Domestic Wastewater Treatment and Discharge

Updated year-on-year data on wastewater generation in urban and rural areas and use of distribution of different treatment systems by households within states is lacking. In the absence of information, constant values for distribution of discharge/treatment systems (i.e. degree of utilization based on Census 2001 and 2011 data have been used for the urban and rural population in the states across the reporting period. Updated and reliable information is sought on deployment of improved wastewater treatment systems, coverage of sewer networks, proportion of untreated wastewater and its method of disposal in order to accurately capture impacts on emission that programmes or interventions for improved sanitation and wastewater management may have in each state.

Reliable information on STPs with regard to volumes treated, underutilization of treatment capacity or any overutilization due to mixing of domestic and industrial wastewater, quality of treatment, and recovery of methane is lacking at the state-level. Updated information on the same will improve accuracy of the state emission estimates.

Updated socio-economic information such as household income levels, actual population distribution by income groups - particularly in line with the IPCC defined income group categorization for urban areas (high-income and low-income) - will help to better capture and report the disaggregated emissions for these income-categories within states and subsequently inform targeted interventions.

3) 4D2 Industrial Wastewater Treatment and Discharge

Constant values of wastewater generated per tonne of product have been used for all the years (2005-2013) for 9 of the 10 industry sectors considered in the state-level emission estimates. In practice, the volume of wastewater generated per unit product should be expected to reduce given the improvements in technology and industrial processes. However, such information is not available for the industry sectors, except for the Pulp & Paper sector. Updated information on changes in wastewater generation due to improved technology is sought across the industry sectors and at the state-level to accurately capture any ensuing impacts on emission.

Updated sector-wise information for each state is also sought on the volume of industrial wastewater generated and its characteristics, prevalent treatment technologies, methane recovery to improve accuracy and better represent the on-ground situation in the states. Due to the lack of reported data on volume of industrial wastewater generated by each industry sector, a tier 1 approach which uses industrial production as a metric to estimate volume of wastewater generation has been adopted in the emission estimation. However, several issues exist in availability, reliability, quality and of reported activity data on state-level industrial production. Lack of reliable state-level data has necessitated undertaking approximations in 8 of the 10 industry sectors. In some cases, state-level production data is not available in the public domain at all. Access to better quality and reliable industry related data that is representative of the industrial activity in each state will contribute to improving reliability of the estimates.

Comparison with national inventories

The aggregated emission estimates for the Waste sector solid waste disposal under this assessment have been compared with the national level GHG estimates reported by the Government of India for the three reference points of 2007, 2010, and 2014. This comparison also serves as a measure of verification for the GHGPI estimates. GHGPI estimates for the Waste sector are seen to be higher than official estimates across the three years of 2007, 2010, and 2014, with domestic wastewater emissions estimated to be much higher than the Government of India estimates. The total Waste sector estimates have a relatively lower deviation of 15.3% in 2010 as compared to deviation of 18.7% in 2007 and 21.2% in 2014.

Overall, the lack of reliable and updated state-specific data is a key challenge encountered for all the 3 Waste sub-sectors in this assessment. The limited availability of reliable state-level data has necessitated the use of national average values, IPCC default values and relevant assumptions to close data gaps in the emission estimates. Further, information reported at the state-level for all 3 sub-sectors is found to not match with national-level information. The methodology provided in 2006 IPCC guidelines has been consistently applied for the calculations across the estimation period in this assessment. Activity data sources and assumptions have been indicated appropriately in the document. It should be noted that BUR 1 report provides little details of data or of the assumptions that have been made used to estimate emissions for 2010. In the absence of such details, further analysis of the BUR 1 inventory is challenging. Additional clarity is required on the methodology and assumptions of official estimates across all 3 years for further conclusive analysis. The plausible reasons for deviation from the officially reported emissions are discussed below for all 3 sub-sectors.

Table 54: Source category wise deviation in GHG estimates between GHGPI and official inventories published by Government of India for Waste sector

Key source category	GHG emission estimates (Mil. tonnes of CO_2e)								
	2007			2010			2014		
	INCCA	GHGPI	Difference	BUR 1	GHGPI	Difference	BUR 2	GHGPI	Difference
Solid Waste Disposal	12.69	8.03	-36.7%	13.96	9.45	-32.3%	15.07	11.26	-25.3%
Domestic Wastewater	22.98	45.24	96.9%	29.38	47.23	60.8%	36.68	60.04	63.7%
Industrial Wastewater	22.1	15.30	-30.8%	21.7	18.30	-15.7%	26.49	60.04	126.6%
Waste sector (total)	**57.77**	**68.57**	**18.7%**	**65.04**	**74.99**	**15.3%**	**78.24**	**94.80**	**21.2%**

Source: Author's analysis

1) 4A2 Unmanaged Waste Disposal Sites

The aggregate GHGPI estimates for solid waste disposal show under-estimation, with a difference of -25.3% in 2014 as compared to official estimates reported in India's BUR 2. Possible reasons for deviation are:

- **Variation in waste generation rates and waste quantum going to disposal:**
  In INCCA, aggregate solid waste quantum reaching disposal sites is 70.8 million tonnes in 2007 as against 36.9 million tonnes in our estimates. In BUR 2, quantum of solid waste going to disposal in 2014 is 56.8 million tonnes as compared to 47.9 million tonnes in our estimates.

This difference results from a variation in per capita generation rates and proportion of solid waste that is being treated and diverted from disposal.

For per capita waste generation rate, the INCCA report and BUR 2 documents indicate that a constant value of 0.55 kg/day is used for year 2007 and 2014. These values however do not reflect the rise in per capita waste generation observed in the country over this period. In our estimates, per capita waste generation rates reported in 2005 across states have been used as a basis to calculate state-wise waste generation. An annual growth rate of 1.2% has been applied to extrapolate per capita generation from 2006 to 2015, based on national-level information reported on increase in generation rates. Thereby, the national average per capita generation rate in the GHGPI estimates works out to 0.405 kg/day in 2007 and 0.515 kg/ day in 2014, which is lower than that reported for these two years in the INCCA and BUR 2 documents. Moreover, to accurately account for accumulated DOC and potential CH_4 emission generation from historic solid waste disposal, the FOD model suggests that emission estimations be done for a 50-year period before the initial year of emission estimation (i.e. year 2005 in this assessment). Since historic and reliable time-series data on solid waste disposal is not available for the states, the waste disposal in our estimates has been calculated based on state-wise population and per capita generation. The INCCA and BUR 2 documents do not provide details on the historic per capita generation values used in the calculations.

Further, in our estimation, state specific information on quantum of municipal solid waste being processed/treated to arrive at the leftover proportion of waste that reaches the disposal sites and contributes to GHG emissions. Thereby, the national average value of percent of total MSW going to disposal, post processing, works out to 66.5% for 2014 in our estimates. The corresponding percent of total MSW going to disposal, post processing, used in official inventory calculations for 2010 is not provided in the BUR 2 report.

- **Variation in DOC values**: A DOC value of 0.11 is used in the emission estimation in the INCCA and BUR 2, which is an aggregate DOC value based on an assumed composition of solid waste for India. The DOC value depends on the composition of waste and should vary over the years with changing waste composition. GHGPI estimates factor in the impact of prevalent composition within each state on the DOC value. Based on available state specific data on waste composition for 2005, a more realistic DOC value for the organic portion of the waste has been calculated for each of the constituent degradable fractions. This calculated state-wise DOC value is used in our estimates across the states from 2005 to 2015. In our estimates, the mathematical average of the state-wise DOC value works out to 0.113. National level waste composition data has been used to estimate historical DOC values of 0.088 and 0.094 for the periods 1954-1994 and 1995-2004 respectively. The use of varying values of DOC over time has possibly resulted in deviation in our estimates as compared to India's official national emission estimates.
- **Urban population**: The urban population used in this assessment from 2005 to 2015 and for the fifty years preceding 2005 is based on state-wise population data and decadal growth trends as per the information reported by the Census of India. In our estimates, aggregate urban population figures used for 2007 and 2014 are 340.7 million persons and 414.54 million persons respectively. Official inventory documents report urban population figures of 404.3 million persons in 2007 and 352.8 million persons in 2014. Thereby, variation in the methods used to arrive at urban population is a source of deviation in the estimates.

2) 4D1 Domestic Wastewater Treatment and Discharge

The aggregate GHGPI estimates for domestic wastewater are higher than corresponding official inventory estimates, with a deviation of 96.9% in 2007 which reduces to 63.7% in 2014. While the INCCA report indicates that both urban and rural centres are covered in the domestic wastewater estimates for 2007. However in the official estimates for 2007, it is assumed that there are no CH_4 emissions from rural wastewater because it is not handled in any way and therefore it decomposes in an aerobic condition. The BUR 2 report does not provide clarity on whether CH_4 emissions from rural domestic wastewater are assumed to be zero in 2014.

On the other hand, our assessment considers rural domestic wastewater to be a source of CH_4 emissions in addition to urban areas, given that release of rural wastewater through treatment/discharge pathways such as on-site septic tanks, latrines and water bodies leads to CH_4 emissions. Thereby, the significant deviation in domestic wastewater emissions as compare to official inventory estimates is likely to be driven by inclusion of the country's sizeable rural population in the estimates. On comparing GHGPI estimates only from urban domestic wastewater with India's official aggregate domestic wastewater estimates, it is seen that the estimates converge and deviation is much lower (-31% in 2007 and -38% in 2014). Variation may exist across various activity data points and assumptions used in our estimation exercise and official inventory. However, given the limited information in this regard in National Communication documents it is difficult to fully comprehend the underlying reasons.

Other possible reasons for deviation from the officially reported emissions, besides geographical coverage, are:

- **Distribution of urban population into income-groups:** The 2006 IPCC Guidelines provide default values at the national level on the distribution of urban population into two income groups - urban high income and urban low income- and indicate corresponding degree of utilization rates (indicating usage of different treatment systems by the population) for these two income groups. India's official inventory estimates follow a same approach to classify urban population into urban high income and low income population. However, since our GHGPI estimates at carried out at the state-level and given that reliable state-level information for distribution of urban high-income and low-income population is not available in country-specific datasets such as the Census of India. Therefore in this estimation, the urban population is not split into two income groups. The estimation is instead done on the basis of wastewater treatment/discharge related information for the aggregate urban population in each state. This difference in the approach and relevant datasets results in deviation as compared to official estimates.
- **Proportion of treated and untreated wastewater:** To estimate CH_4 emissions, the extent of wastewater treated aerobically, anaerobically or not treated at all and the type of treatment system used is critical since this ultimately impacts the GHG emission resulting from each system. Limited clarity and details are provided in the official inventory reports on the breakup of degree of utilization, assumptions and specific data sources used, in particular for the domestic wastewater that is collected and conveyed through sewer networks. Variation in datasets and assumptions used in this regard is a plausible cause of deviation.
- **Aggregate population:** The population used to calculate the CH_4 and N_2O emissions from 2005 to 2015 in this assessment has been estimated based on the population figures and decadal population growth rates as per Census of India 2001 and 2011. In our estimates, country population (i.e. aggregate of states) for 2007 is estimated as 1,137 million persons in

comparison to a total population of 1,150 million persons reported in INCCA. Variation in the methods used to arrive at state-urban population is a likely source of deviation.

3) 4D2 Industrial Wastewater Treatment and Discharge

The aggregate GHGPI estimates for industrial wastewater are under-estimated when compared to official emission estimates, with a deviation of 30.8% in 2007 and -11.3% in 2014. The deviation in the estimates for this source category can be attributed largely to ambiguity over the values of multiple parameters, assumptions, data sources used in official national inventories across the industrial sectors and the broad approximations used at the state-level due to unavailability of reliable data. The possible reasons for the deviation are discussed further below:

- **Treatment Technology:** In this assessment, the condition of aerobic treatment systems for Iron & Steel, Petroleum, Rubber, and Fish processing industries is assumed to be well managed, and thereby these systems have a corresponding MCF value of '0' and emission factor of '0' (see Table 44), leading to no CH_4 emissions from wastewater treatment in these sectors. The assumptions considered in the official inventory documents in this regard are not reported and this could possibly contribute to deviation in the aggregate emission estimates.
- **Variation in Activity Data:**
    - **Wastewater generation values:** As indicated in section 3.7.3, updated values of wastewater generation per tonne product published in the BUR 2 document have been used in the current GHGPI emission estimates (version 3.0) for the industry sectors of Sugar, Coffee, Petroleum, Dairy, and Tannery for better consonance with the BUR 2 inventory. For the two sectors of Pulp & Paper and Meat, wastewater generation values reported in BUR 2 have not been used (see Table 54 below). Based on sectoral studies by Centre for Science and Environment[146] and by the National Productivity Council and CPCB[147], wastewater generation per unit product is expected to have come down in this sector over the years. However, a comparison of the values reported in NATCOM-II (i.e. 230 m^3/tonne) and BUR 2 (i.e. 250 m^3/tonne) documents reflects an increasing trend and both wastewater generation values reported look to be quite high. Therefore, a lower value of 127.5 m^3/tonne is used for Pulp & Paper sector based on information sourced from the technical EIA guidance manual prepared by a private organization for the MoEF in 2010.

      For the Meat sector, the wastewater generation value of 0.02 m^3/tonne reported in BUR 2 is too low and seems erroneous compared to the NATCOM II value of 11.7 m^3/tonne. The 2006 IPCC Guidelines gives a range of 8 to 18 m^3/tonne for the Meat sector. Therefore, the wastewater generation value from NATCOM-II (i.e. 11.7 m^3/tonne) is used in our estimates. Given these differences in unit wastewater generations values, there are differences as compared to official inventory estimates.
    - **COD values:** As indicated in Table 50 in section 3.7.3, updated COD values published in the BUR 2 document have been used in the current GHGPI emission estimates (version 3.0) for the industry sectors of Sugar, Coffee, Petroleum, Dairy, Pulp & Paper,

[146] A CSE study in 2012-13 for the sector indicates that wastewater generation has reduced to 60 m^3 per tonne in 2011-12 and 57 m^3 per tonne in 2012-13 due to improvements in technology, with an average annual reduction of 7.4% since 1995-96.

[147] Field studies conducted by the National Productivity Council in 10 pulp and paper mills in 2005-06, in consultation with the CPCB, indicate that the wastewater discharge per tonne of product ranges from 65-100 m^3. National Productivity Council and CPCB (2006): Final Report on Development of Guidelines for Water Conservation in Pulp and Paper Sector. Available at http://cpcb.nic.in/newitems/45.pdf

Meat, and Tannery for better consonance with the BUR 2 inventory. COD values used in official inventory estimates for 2007 and 2010 are not reported in corresponding documents and may be different resulting in deviation.

- **Industrial production**: Reliable state-level data on industrial production is not available for most of the industry sectors across the emission estimation period. Industry production data is also found to be partly missing for some years in the reporting period or is not reported in disaggregated manner for some states. To address data gaps, apportionment or approximation has been undertaken in this assessment for 8 out of 11 sectors based on relevant proxy data such as installed production capacity, no. of manufacturers, etc. at the state level. Furthermore, our estimates excludes the industry sectors of Organic chemicals, Alcohol, Vegetable oil, Vegetable and Fruits, Soaps and Detergents, Plastics, and Starch production which are included in the BUR 2 estimates. This is due to the unavailability of industrial production data or any proxy information that can be used to estimate state-level figures for these sectors. It should be noted that the BUR 2 document reports that three of these industry sectors (viz. Organic chemicals, Soaps and Detergents, Plastics) make use of aerobic systems for industrial effluent treatment and would thereby be assumed to be 'well-managed', with zero CH_4 emissions in our assessment. Thus, inclusion of these three sectors would not lead imply additional GHG emissions in our estimates.

Table 55: Comparison of wastewater generation values reported for industry sectors

Industry Sector	GHGPI estimates (v 3.0)	BUR-II	NATCOM-II
Sugar	0.4	0.4	1
Coffee	15	15	5
Petroleum	0.6	0.6	0.7
Dairy	6	6	3
Meat	11.7	0.02	11.7
Pulp & Paper	127.5	250	230
Tannery	35	35	32

Source: Author's analysis

Additional Information

This section is left blank intentionally.

Appendix

6.1 4A2 Unmanaged Waste Disposal Sites

Appendix 0.1 State wise Reported Population from Census of India, 1951-2011

State/Union Territory	1951	1961	1971	1981	1991	2001	2011
Andaman & Nicobar	7,789	14,075	26,218	49,634	74,955	116,198	143,488
Andhra Pradesh	5,420,325	6,274,508	8,402,527	12,487,576	17,887,126	20,808,940	28,219,075
Arunachal Pradesh	-	-	17,288	41,428	110,628	227,881	317,369
Assam	344,831	781,288	1,289,222	1,782,376	2,487,795	3,439,240	4,398,542
Bihar	2,626,261	3,913,920	5,633,966	8,718,990	11,353,012	8,681,800	11,758,016
Chandigarh	-	99,262	232,940	422,841	575,829	808,514	1,026,459
Chhattisgarh	-	-	-	-	-	4,185,747	5,937,237
Dadra & Nagar Haveli	-	-	-	6,914	11,725	50,463	160,595
Daman & Diu	-	-	-	29,023	47,543	57,348	1,82,851
Delhi	1,437,134	2,359,408	3,647,023	5,768,200	8,471,625	12,905,780	16,368,899
Goa		106,664	226,774	351,808	479,752	670,577	906,814
Gujarat	4,427,896	53,16,624	74,96,500	1,06,01,653	1,42,46,061	1,89,30,250	2,57,45,083
Haryana	9,68,494	13,07,680	17,72,959	28,27,287	40,54,744	61,15,304	88,42,103
Himachal Pradesh	1,53,827	1,78,275	2,41,890	3,25,971	4,49,196	5,95,581	6,88,552
Jammu & Kashmir	4,57,213	5,93,315	8,58,221	12,60,403	18,39,400	25,16,638	34,33,242
Jharkhand	-	-	-	-	-	59,93,741	79,33,061
Karnataka	44,53,480	52,66,493	71,22,093	1,07,29,606	1,39,07,788	1,79,61,529	2,36,25,962
Kerala	18,25,832	25,54,141	34,66,449	47,71,275	76,80,294	82,66,925	1,59,34,926
Lakshadweep	-	-	-	18,629	29,114	26,967	50,332
Madhya Pradesh	31,32,937	46,27,234	67,84,767	1,05,86,459	1,53,38,837	1,59,67,145	2,00,69,405
Maharashtra	92,01,013	1,11,62,561	1,57,11,211	2,19,93,594	3,05,41,586	4,11,00,980	5,08,18,259
Manipur	2,862	67,717	1,41,492	3,75,460	5,05,645	5,75,968	8,34,154
Meghalaya	58,512	1,17,483	1,47,170	2,41,333	3,30,047	4,54,111	5,95,450
Mizoram	6,950	14,257	37,759	1,21,814	3,17,946	4,41,006	5,71,771
Nagaland	4,125	19,157	51,394	1,20,234	2,08,223	3,42,787	5,70,966
Odisha	5,94,070	11,09,650	18,45,395	31,10,287	42,34,983	55,17,238	70,03,656
Puducherry	-	-	1,98,288	3,16,047	5,16,985	6,48,619	8,52,753
Punjab	19,89,267	25,67,306	32,16,179	46,47,757	59,93,225	82,62,511	1,03,99,146
Rajasthan	29,55,275	32,81,478	45,43,761	72,10,508	1,00,67,113	1,32,14,375	1,70,48,085
Sikkim	2,744	6,848	19,668	51,084	37,006	59,870	1,53,578
Tamil Nadu	73,33,525	89,90,528	1,24,64,834	1,59,51,875	1,90,77,592	2,74,83,998	3,49,17,440
Telangana	-	-	-	-	-	-	-
Tripura	42,595	1,02,997	1,62,360	2,25,568	4,21,721	5,45,750	9,61,453
Uttar Pradesh	86,25,699	94,79,895	1,23,88,596	1,98,99,115	2,76,05,915	3,45,39,582	4,44,95,063
Uttarakhand	-	-	-	-	-	21,79,074	30,49,338
West Bengal	62,81,642	85,40,842	1,09,67,033	1,44,46,721	1,87,07,601	2,24,27,251	2,90,93,002

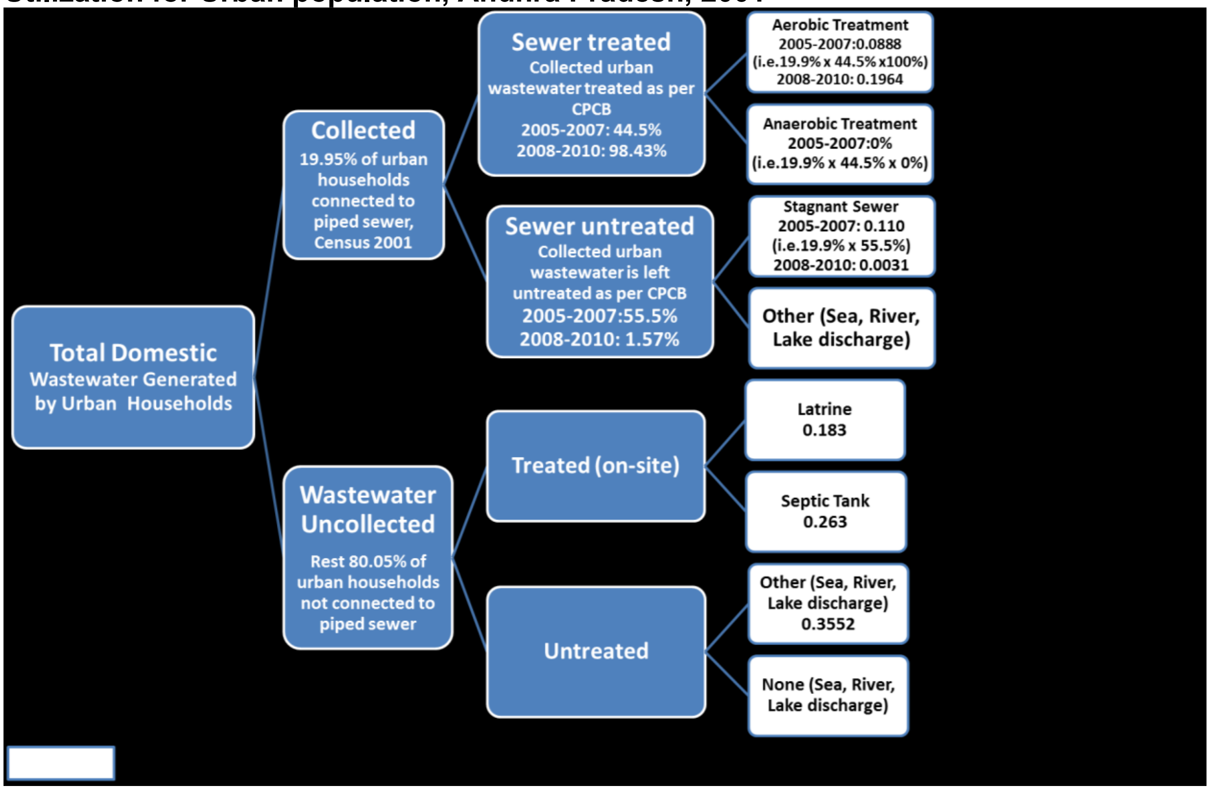
Note: States for which no population has been reported for some years were formed subsequently. The historic data on the population has been acquired by visiting the Census office in Delhi, except for 2001 and 2011.

Appendix 0.2 State wise GHG emission from Solid Waste Disposal, 2005-2015

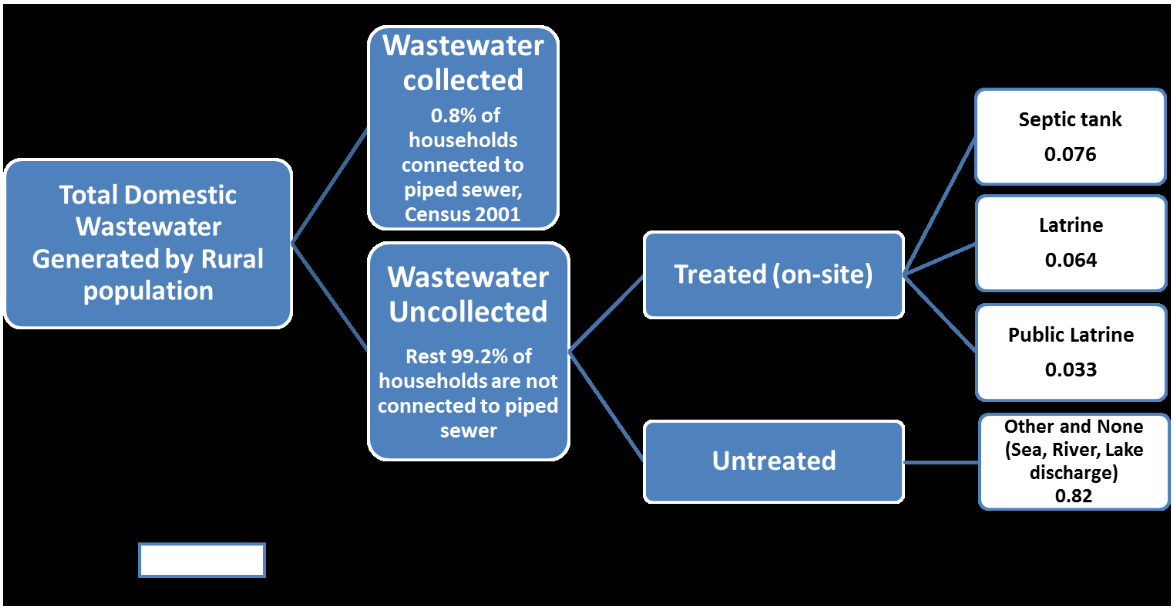
Solid Waste Disposal - GHG emissions 2005-2015 (Mil. tonnes of CO_2e)											
Name of the state	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Andaman & Nicobar	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Andhra Pradesh	0.68	0.74	0.80	0.86	0.92	0.97	1.03	1.08	1.14	1.12	0.98
Arunachal Pradesh	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Assam	0.04	0.04	0.05	0.05	0.06	0.06	0.06	0.07	0.07	0.07	0.08
Bihar	0.21	0.21	0.21	0.22	0.22	0.23	0.23	0.24	0.25	0.26	0.26
Chandigarh	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02
Chhattisgarh	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.11	0.12	0.13
Dadra & Nagar Haveli	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Daman & Diu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Delhi	0.42	0.46	0.49	0.52	0.55	0.58	0.61	0.64	0.67	0.68	0.71
Goa	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04
Gujarat	0.33	0.35	0.36	0.37	0.39	0.40	0.42	0.43	0.45	0.47	0.49
Haryana	0.15	0.16	0.18	0.19	0.20	0.21	0.22	0.24	0.25	0.26	0.28
Himachal Pradesh	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Jammu & Kashmir	0.08	0.09	0.10	0.10	0.11	0.12	0.12	0.13	0.14	0.15	0.15
Jharkhand	0.07	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18
Karnataka	0.42	0.46	0.50	0.53	0.57	0.60	0.63	0.67	0.70	0.74	0.77
Kerala	0.24	0.28	0.31	0.35	0.39	0.42	0.46	0.50	0.55	0.60	0.65
Lakshadweep	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Madhya Pradesh	0.35	0.37	0.39	0.41	0.43	0.44	0.46	0.48	0.50	0.52	0.54
Maharashtra	0.82	0.88	0.94	1.00	1.06	1.11	1.17	1.22	1.27	1.32	1.38
Manipur	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Meghalaya	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02
Mizoram	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Nagaland	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Odisha	0.12	0.12	0.13	0.14	0.14	0.15	0.15	0.16	0.16	0.17	0.18
Puducherry	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04
Punjab	0.24	0.26	0.28	0.30	0.32	0.33	0.35	0.37	0.38	0.40	0.42
Rajasthan	0.31	0.32	0.33	0.34	0.35	0.36	0.38	0.39	0.40	0.42	0.44
Sikkim	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Tamil Nadu	0.80	0.85	0.90	0.95	0.99	1.04	1.09	1.13	1.18	1.23	1.28
Telangana	-	-	-	-	-	-	-	-	-	-	0.09
Tripura	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03
Uttar Pradesh	0.89	0.92	0.96	1.00	1.04	1.08	1.13	1.17	1.21	1.26	1.31
Uttrakhand	0.02	0.03	0.04	0.04	0.05	0.05	0.05	0.06	0.06	0.07	0.07
West Bengal	0.69	0.73	0.76	0.80	0.83	0.87	0.90	0.94	0.98	1.02	1.06
Total emissions (CH_4)	7.05	7.55	8.03	8.51	8.98	9.45	9.92	10.37	10.85	11.26	11.67

6.2 4D1 Domestic Wastewater Treatment and Discharge

Appendix 0.3 Classification of Wastewater Treatment Systems and Estimated Degree of Utilization for Urban population, Andhra Pradesh, 2001



Appendix 0.4 Classification of Wastewater Treatment Systems and Estimated Degree of Utilization for Rural Andhra Pradesh, 2001



Appendix 0.5 State-wise share of Urban and Rural Population for 2001 and 2011

State/Union Territory	Rural-Urban population share (2011)		Rural-Urban population share (2001)	
	Rural	Urban	Rural	Urban
Andaman and Nicobar Islands	62.30%	37.70%	67.37%	32.63%
Andhra Pradesh	66.64%	33.36%	72.70%	27.30%
Arunachal Pradesh	77.06%	22.94%	79.25%	20.75%
Assam	85.90%	14.10%	87.10%	12.90%
Bihar	88.71%	11.29%	89.54%	10.46%
Chandigarh	2.75%	97.25%	10.23%	89.77%
Chhatisgarh	76.76%	23.24%	79.91%	20.09%
Dadra and Nagar Haveli	53.28%	46.72%	77.11%	22.89%
Daman and Diu	24.83%	75.17%	63.75%	36.25%
National Capital Territory of Delhi	2.50%	97.50%	6.82%	93.18%
Goa	37.83%	62.17%	50.24%	49.76%
Gujarat	57.40%	42.60%	62.64%	37.36%
Haryana	65.12%	34.88%	71.08%	28.92%
Himachal Pradesh	89.97%	10.03%	90.20%	9.80%
Jammu and Kashmir	72.62%	27.38%	75.19%	24.81%
Jharkhand	75.95%	24.05%	77.76%	22.24%
Karnataka	61.33%	38.67%	66.01%	33.99%
Kerala	52.30%	47.70%	74.04%	25.96%
Lakshadweep	21.93%	78.07%	55.54%	44.46%
Madhya Pradesh	72.37%	27.63%	73.54%	26.46%
Maharashtra	54.78%	45.22%	57.57%	42.43%
Manipur	67.55%	32.45%	74.89%	25.11%
Meghalaya	79.93%	20.07%	80.42%	19.58%
Mizoram	47.89%	52.11%	50.37%	49.63%
Nagaland	71.14%	28.86%	82.77%	17.23%
Odisha	83.31%	16.69%	85.01%	14.99%
Puducherry	31.67%	68.33%	33.43%	66.57%
Punjab	62.52%	37.48%	66.08%	33.92%
Rajasthan	75.13%	24.87%	76.61%	23.39%
Sikkim	74.85%	25.15%	88.93%	11.07%

State/Union Territory	Rural-Urban population share (2011)		Rural-Urban population share (2001)	
	Rural	Urban	Rural	Urban
Tamil Nadu	51.60%	48.40%	55.96%	44.04%
Telangana	61.33%	38.64%	61.33%	38.64%
Tripura	73.83%	26.17%	82.94%	17.06%
Uttar Pradesh	77.73%	22.27%	79.22%	20.78%
Uttarakhand	69.77%	30.23%	74.33%	25.67%
West Bengal	68.13%	31.87%	72.03%	27.97%

Appendix 0.6 State-wise Proportion of Sewage Treatment and Type of Technology used based on Reported Data on Sewage Treatment Plants

Sewage Treatment Plants	1999			2008-09			2014-15		
States & UTs	Treatment type, Aerobic (%)	Treatment type, Anaerobic (%)	Sewer collected and not treated, %	Treatment type, Aerobic (%)	Treatment type, Anaerobic (%)	Sewer collected and not treated, %	Treatment type, Aerobic (%)	Treatment type, Anaerobic (%)	Sewer collected and not treated, %
Andaman and Nicobar Islands	-	-	100%	-	-	100%	-	-	100.00%
Andhra Pradesh	100.00%	0.00%	55.50%	100.00%	0.00%	1.57%	100.00%	0.00%	0.00%
Arunachal Pradesh	-	-	100%	-	-	100%	-	-	100.00%
Assam	-	-	-	100%	-	-	100.00%	0.00%	0.00%
Bihar	-	-	-	100.00%	0.00%	1.48%	100.00%	0.00%	20.07%
Chandigarh	100.00%	0.00%	13.38%	-	-	-	4.51%	95.49%	0.00%
Chhatisgarh	-	-	100%	-	-	100%	-	-	100.00%
Dadra and Nagar Haveli	-	-	100%	-	-	100%	-	-	100.00%
Daman and Diu	-	-	100%	-	-	100%	-	-	100.00%
Delhi	100%	0%	29%	98.81%	1.19%	-	100.00%	0.00%	0.84%
Goa	100.00%	0.00%	0.00%	100.00%	0.00%	-	100.00%	0.00%	0.00%
Gujarat	100.00%	-	17.81%	100.00%	0.00%	-	77.29%	22.71%	19.15%
Haryana	0.00%	100.00%	45.18%	71.13%	28.87%	-	63.66%	36.34%	0.33%
Himachal Pradesh	-	-	-	0.00%	0.00%	100.00%	64.14%	35.86%	30.69%
Jammu and Kashmir	-	-	-	0.00%	0.00%	100.00%	86.61%	13.39%	2.61%
Jharkhand	-	-	-	0.00%	0.00%	100.00%	98.64%	1.36%	0.00%
Karnataka	99.07%	0.93%	12.42%	100.00%	0.00%	-	91.57%	8.43%	0.00%
Kerala	100.00%	0.00%	0.00%	100.00%	0.00%	-	100.00%	0.00%	2.59%
Lakshadweep	-	-	100%	-	-	100%	-	-	100.00%
Madhya Pradesh	100.00%	0.00%	65.61%	-	-	-	81.07%	18.93%	1.40%
Maharashtra	100.00%	0.00%	43.09%	89.51%	10.49%	-	98.33%	1.67%	7.26%
Manipur	-	-	100%	-	-	100%	-	-	100.00%
Meghalaya	-	-	100%	-	-	100%	-	-	100.00%
Mizoram	-	-	100%	-	-	100%	-	-	100.00%
Nagaland	-	-	100%	-	-	100%	-	-	100.00%
Odisha	100.00%	0.00%	73.53%	-	-	-	100.00%	0.00%	0.00%
Puducherry	100.00%	0.00%	0.00%	-	-	-	71.43%	28.57%	0.00%
Punjab	0%	0%	100%	-	-	-	45.63%	54.37%	1.09%
Rajasthan	100.00%	0.00%	50.00%	-	-	-	90.22%	9.78%	0.00%
Sikkim	-	-	-	0.00%	0.00%	100.00%	100.00%	0.00%	38.46%
Tamil Nadu	99.38%	0.62%	31.44%	100.00%	0.00%	-	100.00%	0.00%	3.83%
Telangana	-	-	-	-	-	-	55.56%	44.44%	0.00%
Tripura	-	-	-	0.00%	0.00%	100.00%	100.00%	0.00%	10.00%
Uttar Pradesh	74.70%	25.30%	10.83%	47.63%	52.37%	-	55.26%	44.74%	3.09%
Uttarakhand	-	-	-	25.00%	75.00%	-	98.62%	1.38%	0.00%
West Bengal	100.00%	0.00%	0.17%	100.00%	0.00%	-	100.00%	0.00%	43.55%

Appendix 0.7 State-wise GHG emissions from Domestic Wastewater, 2005-2015

Industrial Wastewater- GHG emissions 2005-2015 (Mil. tonnes of CO2e)											
Name of the state	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Andaman & Nicobar	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03
Andhra Pradesh	3.24	3.27	3.31	3.32	3.44	3.47	4.35	4.40	4.45	2.62	2.64
Arunachal Pradesh	0.05	0.05	0.06	0.06	0.05	0.05	0.07	0.07	0.07	0.07	0.07
Assam	1.08	1.10	1.12	1.14	1.15	1.16	1.29	1.31	1.33	1.36	1.38
Bihar	2.79	2.86	2.92	2.98	2.99	3.06	3.68	3.78	3.87	3.97	4.06
Chandigarh	0.07	0.07	0.08	0.15	0.15	0.15	0.23	0.23	0.24	0.24	0.24
Chhattisgarh	0.84	0.85	0.87	0.89	0.90	0.92	1.11	1.14	1.16	1.19	1.21
Dadra & Nagar Havel	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03
Daman & Diu	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03
Delhi	0.79	0.80	0.82	0.81	0.80	0.81	1.00	1.02	1.04	1.06	1.08
Goa	0.07	0.07	0.07	0.07	0.07	0.07	0.10	0.10	0.10	0.10	0.10
Gujarat	2.19	2.23	2.27	2.28	2.32	2.36	3.12	3.18	3.24	3.30	3.36
Haryana	0.87	0.88	0.90	0.90	0.91	0.93	1.41	1.43	1.46	1.49	1.52
Himachal Pradesh	0.19	0.19	0.19	0.19	0.20	0.20	0.31	0.31	0.32	0.32	0.32
Jammu & Kashmir	0.43	0.44	0.45	0.46	0.47	0.49	0.59	0.60	0.61	0.63	0.62
Jharkhand	0.89	0.90	0.92	0.94	0.94	0.96	1.08	1.11	1.13	1.15	1.18
Karnataka	1.99	2.02	2.05	2.07	2.13	2.16	2.57	2.61	2.65	2.69	2.73
Kerala	2.06	2.07	2.08	2.09	2.10	2.11	2.12	2.14	2.17	2.19	2.21
Lakshadweep	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Madhya Pradesh	2.32	2.37	2.41	2.45	2.51	2.55	3.03	3.09	3.15	3.22	3.28
Maharashtra	4.73	4.80	4.87	4.92	5.07	5.14	5.69	5.78	5.88	5.97	6.06
Manipur	0.09	0.09	0.09	0.09	0.09	0.09	0.12	0.12	0.12	0.13	0.13
Meghalaya	0.10	0.10	0.11	0.11	0.11	0.11	0.14	0.14	0.14	0.15	0.15
Mizoram	0.05	0.05	0.05	0.05	0.05	0.05	0.07	0.07	0.08	0.08	0.08
Nagaland	0.09	0.09	0.09	0.09	0.09	0.09	0.12	0.12	0.12	0.12	0.12
Odisha	1.42	1.44	1.46	1.48	1.53	1.55	1.75	1.77	1.80	1.82	1.85
Puducherry	0.06	0.06	0.07	0.07	0.07	0.07	0.08	0.09	0.09	0.09	0.09
Punjab	1.18	1.19	1.21	1.24	1.26	1.27	2.02	2.05	2.08	2.11	2.14
Rajasthan	2.49	2.54	2.58	2.63	2.67	2.72	3.22	3.29	3.36	3.43	3.49
Sikkim	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.05	0.05	0.05
Tamil Nadu	2.85	2.89	2.93	2.96	3.07	3.12	3.51	3.56	3.62	3.67	3.73
Telengana	-	-	-	-	-	-	-	-	-	1.97	1.99
Tripura	0.13	0.13	0.13	0.13	0.14	0.15	0.16	0.16	0.16	0.17	0.17
Uttar Pradesh	6.83	6.96	7.09	7.23	7.12	7.25	9.12	9.30	9.49	9.67	9.86
Uttrakhand	0.38	0.38	0.39	0.40	0.40	0.40	0.59	0.60	0.62	0.63	0.64
West Bengal	3.48	3.52	3.57	3.61	3.62	3.66	4.13	4.19	4.25	4.31	4.37
Total GHG emissions, Urban Million tCO2e	**43.82**	**44.53**	**45.24**	**45.90**	**46.51**	**47.23**	**56.90**	**57.92**	**58.94**	**60.04**	**61.03**

6.3 4D2 Industrial Wastewater Treatment and Discharge

Appendix 0.8 State-wise GHG emissions from Industrial Wastewater, 2005-2015

Industrial Wastewater- GHG emissions 2005-2015 (Mil. tonnes of CO2e)											
Name of the state	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Andaman & Nicobar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Andhra Pradesh	1.29	1.37	1.46	1.55	1.65	1.73	1.81	2.07	2.19	1.92	1.79
Arunachal Pradesh	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00
Assam	0.17	0.18	0.19	0.20	0.21	0.21	0.22	0.27	0.31	0.36	0.38
Bihar	0.06	0.06	0.07	0.07	0.07	0.08	0.08	0.08	0.09	0.10	0.10
Chandigarh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chhattisgarh	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.05	0.06	0.06	0.05
Dadra & Nagar Haveli	(0.00)	(0.00)	(0.00)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Daman & Diu	0.00	(0.00)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	(0.00)
Delhi	0.07	0.07	0.07	0.08	0.08	0.08	0.09	0.10	0.10	0.11	0.11
Goa	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Gujarat	2.15	2.29	2.42	2.55	2.71	2.93	2.94	3.28	3.52	3.69	3.74
Haryana	0.18	0.20	0.25	0.27	0.29	0.33	0.35	0.36	0.36	0.37	0.37
Himachal Pradesh	0.12	0.13	0.14	0.15	0.15	0.17	0.18	0.19	0.19	0.20	0.19
Jammu & Kashmir	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05
Jharkhand	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Karnataka	0.67	0.72	0.75	0.79	0.84	0.88	0.95	1.01	1.02	1.06	1.11
Kerala	0.26	0.27	0.28	0.30	0.32	0.35	0.36	0.38	0.39	0.44	0.45
Lakshadweep	0.02	0.02	0.03	0.03	0.03	0.03	0.09	0.10	0.10	0.03	0.00
Madhya Pradesh	0.25	0.26	0.28	0.29	0.31	0.33	0.35	0.36	0.38	0.59	0.70
Maharashtra	1.44	1.54	1.68	1.78	1.88	2.03	2.15	2.24	2.29	2.48	2.59
Manipur	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Meghalaya	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Mizoram	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nagaland	0.02	0.02	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.01
Odisha	0.31	0.33	0.37	0.39	0.42	0.46	0.49	0.49	0.51	0.57	0.69
Puducherry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Punjab	0.98	1.05	1.12	1.19	1.27	1.37	1.46	1.51	1.64	1.68	1.61
Rajasthan	0.18	0.18	0.19	0.20	0.21	0.22	0.23	0.24	0.28	0.31	0.32
Sikkim	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tamil Nadu	1.39	1.48	1.60	1.70	1.81	1.92	1.95	2.12	2.38	2.56	2.66
Telangana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.50
Tripura	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Uttar Pradesh	2.22	2.35	2.58	2.76	2.92	3.11	3.22	3.52	3.84	4.02	4.16
Uttrakhand	0.89	0.97	1.04	1.10	1.17	1.30	1.39	1.46	1.41	1.48	1.58
West Bengal	0.60	0.59	0.65	0.70	0.74	0.61	0.90	0.98	0.98	0.99	0.97
Total CO2e emissior	**13.39**	**14.22**	**15.30**	**16.27**	**17.26**	**18.31**	**19.38**	**20.96**	**22.18**	**23.50**	**24.22**

6.4 Sample Calculations for Emission Estimation

Appendix 0.9 Sample Emission Estimate Calculation for 4A2 Unmanaged Waste Disposal Sites

Step 1: Calculation of per capita waste generation rates and mass of waste deposited (W)

Based on the 2006 IPCC Guidelines for National GHG Inventories**Error! Bookmark not defined.**, t he FOD model is used to estimate emissions from decomposition of solid waste in waste disposal sites in this assessment. The FOD model considers that waste deposited in a disposal site at a point of time decomposes gradually over time and the residual waste (material that remains after the partial decomposition of waste during anaerobic digestion process) continues to undergo anaerobic digestion again and generate CH_4 over a subsequent period of time (around 50 years). The FOD model estimates the actual methane generation at a given point of time, accounting for the total methane generation over a preceding time period. Thereby it is necessary to estimate 50-year data on waste disposal prior to the base year 2005 i.e. from 1954-2004.
As time series data on mass of waste deposited (W) for the 50 year period before 2005 is not available at state-level, the quantum of waste deposited in disposal sites is estimated based on

urban population, per capita waste generation, and the proportion of generated waste that reaches disposal sites and leads to CH_4 emission as shown in the sample calculation that follows.

Based on reported data on per capita waste generation rate for Andhra Pradesh in year 2005, the per capita waste generation for the preceding and subsequent years is calculated as using national-level annual growth rates as shown in Table 55.

Table 56: Calculation of growth rates for per capita waste generation based on reported data

Year	Applicable Annual Growth rate[148]	Estimated Daily Per capita Waste generation (kg/day)[149]
1951	1.15%	0.280
1961	1.03%	0.317
1971	1.47%	0.353
1981	0.70%	0.414
1991	1.22%	0.445
2007	1.22%	0.533[150]

Calculation of mass of Waste deposited W

Year 1954

- Total urban population for Andhra Pradesh = 5,676,580 persons[151]
- Applicable annual growth rate for per capita waste generation from Table 88= 1.15%
- Per capita waste generation, 1951 from Table 88= 0.280 kg/day/person
- Estimated per capita waste generation, 1954= 0.280 x [1+ (1.15% x 3)] = 0.291 kg/day/person
- Percent of generated waste that is sent to disposal sites = 70%[152]

Mass of waste deposited, year 1954 (W_{1954})
= Total urban population x per capita waste generation x 365 days x percent of generated waste sent to disposal site
= 5,676,580 persons x 0.291 kg/day/person x 365 days x 70%[152]
= 422.69 gigagram (Gg)[153]

Year 1955

- Total urban population for Andhra Pradesh = 5,761,998 persons

[148] Annual growth rates have been estimated based on per capita generation rates reported at national-level for certain years as given in the Table 25 of this note and have been used in the emission estimation to calculate per capita generation rates for the rest of the years for Andhra Pradesh, using reported capita generation for the state in 2005 as the basis.
[149] Reported capita generation for the state in 2005 is used as the basis to calculate per capita generation for the rest of the years using applicable annual growth rate in per capita generation across time periods as indicated in Table 58
[150] Reported data from CPCB: Waste Generation and Composition, Table 1. State-wise per capita waste generation is based on reported per capita waste generation for cities in the state. Available at http://www.cpcb.nic.in/wast/municipalwast/Waste_generation_Composition.pdf
[151] Estimated based on urban population for year 1951 and annual growth rate of 1.58% calculated based on decadel growth rate from 1951-1961 as per Census of India data.
[152] Ministry of Environment and Forests, Government of India (2012): India - Second National Communication Report, 2012 to the UNFCCC, Page 76. Available at:
https://unfccc.int/sites/default/files/resource/indnc2.pdf

[153] 1 gigagram= 1,000,000 kg

- Applicable annual growth rate for per capita waste generation from Table 88= 1.15%
- Reported per capita waste generation, 1951 from Table 88= 0.280 kg/day/person
- Estimated per capita waste generation, 1955= 0.280 x [1+ (1.15% x 4)] = 5,761,998 kg/day/person
- Percent of generated waste that is sent to disposal sites = 70%[152]

Mass of waste deposited, year 1955 (W_{1955})
= Total urban population x per capita waste generation x 365 days x percent of generated waste sent to disposal site
= 5,761,998 persons x 0.280 kg/day/person x 365 days x 70%
= 434.41 Gg

Similarly calculated for the intermediate years up to 2015

Year 2015

- Total urban population for Andhra Pradesh = 16,764,766 persons[154]
- Estimated per capita waste generation, 2015 = 0.521 kg/day/person
- Percent of generated waste that is sent to disposal sites = 23%

Mass of waste deposited, year 2015 (W_{2005})
= Total urban population x per capita waste generation x 365 days x percent of generated waste sent to disposal site
= 16,764,766 persons x 0.521 kg/day/person x 365 days x 23%[152]
= 739.66 Gg

Step 2: Calculation of DOC based on Waste Composition data as per Equation 4
Waste composition available across the three years of 1971, 1995 and 2005 is assumed to be applicable for adjacent time periods i.e. 1954-1994, 1995-2004 and 2005-2015 (see Table 89). Using the default values for DOC content for degradable wet waste fractions **(DOC_i)** in waste, the DOC values for the organic portion of the waste are calculated for the time periods 1954-1994, 1995-2004 and 2005-2014 as shown in Table 56.

Table 57: Calculation of DOC content value using Waste Composition data

Year	Fraction of waste type i by waste category (Wi)			Calculation for DOC for overall waste (in fraction) $DOC = \sum_i (\mathrm{DOCi} * \mathrm{Wi})$	Applicable time period considered for estimated DOC value
	Paper	Textiles	Compostable Matter		
1971 Error! Bookmark not defined.	4.14%	3.83%	41.24%	(40% x 4.14%) + (24% x 3.83%) + (15% x 41.24%) =0.088	**1954-1994**
1995 Error! Bookmark not defined.	5.78%	3.50%	41.80%	(40% x 5.78%) + (24% x 3.5%) + (15% x 41.8%) =0.094	**1995-2004**
2005[53]	7.37%	3.99%	53.19%	(40% x 7.37%)+ (24% x 3.99%) + (15% x 53.19%) =0.119	**2005-2015**

[154] Estimated based on urban population for year 2001 and 2011 and decadel growth rate from 2001-2011 as per Census of India data. Available at http://planningcommission.nic.in/data/datatable/data_2312/DatabookDec2014%20307.pdf

Year	Fraction of waste type i by waste category (Wi)			Calculation for DOC for overall waste (in fraction) $DOC = \sum_i (\mathrm{DOCi} * \mathrm{Wi})$	Applicable time period considered for estimated DOC value
	Paper	Textiles	Compostable Matter		
Default DOC Content values (Wet waste) in fraction (DOC_i)[155]	40%	24%	15%	-	-

Step 3: Calculation of decomposable DOC deposited ($DDOC_m$)

$DDOC_m$=W x DOC x DOCf x MCF

Year 1954

- Mass of waste deposited (W_{1954}) **=**422.69 Gg
- $DOC_{1954-1994}$= 0.088 Gg C/Gg waste
- DOCf = 0.5
- MCF = 0.4

$DDOC_{m(1954)}$ = W x DOC x DOCf x MCF
= 422.69 Gg x 0.088 Gg C/Gg waste x 0.5 x 0.4
= 7.41Gg C

Year 1955

- Mass of waste deposited (W_{1955}) **=** 434.41 Gg
- $DOC_{1954-1994}$= 0.088 Gg C/Gg waste
- DOCf = 0.5
- MCF = 0.4

$DDOC_{m(1955)}$ = W x DOC x DOCf x MCF
= 434.41 Gg x 0.088 Gg C/Gg waste x 0.5 x 0.4
= 7.61Gg C

Similarly calculated for the intermediate years up to 2015

Year 2015

- Mass of waste deposited (W_{2005}) **=** 739.66 Gg
- $DOC_{2005-2015}$= 0.119 Gg C/Gg waste
- DOCf = 0.5
- MCF = 0.4

$DDOC_{m(2015)}$ = W x DOC x DOCf x MCF
= 739.66 Gg x 0.119 Gg C/Gg waste x 0.5 x 0.4
= 17.58 Gg C

155 As per 2006 IPCC Guidelines, Vol. 5, Chapter 2: Waste Generation, Composition and Management Data, Table 2.6. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

Step 4: Calculation of $DDOC_m$ Accumulated in the Disposal Site at the End of Year T ($DDOC_{maT}$)

$DDOC_{maT} = DDOC_{mdT} + (DDOC_{maT-1} \times e^{\wedge(-k)})$

<u>Year 1954</u>

- $DDOC_{m\ (1954)} =$ 7.41 Gg C
- $DDOC_{maT-1\ (1953)} =$ 0 Gg C[156]
- Euler's constant e = 2.718
- k = 0.17

$DDOC_{maT\ (1954)} = DDOC_{m\ (1954)} + (DDOC_{maT-1\ (1953)} \times e^{\wedge(-k)})$
$= 7.41 + (0 \times 2.718^{\wedge(-0.17)})$
$= 7.41$ Gg C

<u>Year 1955</u>

- $DDOC_{m\ (1955)} =$ 7.61 Gg C
- $DDOC_{maT-1\ (1954)} =$ 7.61 Gg C
- Euler's constant e = 2.718
- k = 0.17

$DDOC_{maT\ (1955)} = DDOC_{m\ (1955)} + (DDOC_{maT-1\ (1954)} \times e^{\wedge(-k)})$
$= 7.61 + (7.41 \times 2.718^{\wedge(-0.17)})$
$= 13.86$ Gg C

Similarly calculated for the intermediate years up to 2015

<u>Year 2015</u>

- $DDOC_{m\ (2015)} =$ 17.58 Gg C
- $DDOC_{maT-1\ (2015)} =$ 16.76 Gg C
- Euler's constant e = 2.718
- k = 0.17

$DDOC_{maT\ (2015)} = DDOC_{m\ (2015)} + (DDOC_{maT-1\ (2014)} \times e^{\wedge(-k)})$
$= 17.58 + (16.76 \times 2.718^{\wedge(-0.17)})$
$= 394.75$ Gg C

Step 5: Calculation of $DDOC_m$ Decomposed at the end of year T ($DDOC_{m\ decompT}$)
$DDOC_{mdecompT} = DDOC_{maT-1} \times (1 - e^{\wedge(-k)})$

<u>Year 1954</u>

- $DDOC_{maT-1\ (1953)} =$ 0 Gg C
- Euler's constant e = 2.718
- k = 0.17

[156] Waste disposal is considered from 1954 onwards and therefore DDOCm accumulated in 1953 is assumed to be zero

$DDOC_{mdecompT\ (1954)} = DDOC_{maT\text{-}1\ (1953)} \times (1 - e^{\wedge(-k)})$
$= 0 \times (1\text{-}2.718^{\wedge(-0.17)})$
$= 0$ Gg C

Year 1955

- $DDOC_{maT\text{-}1\ (1954)} =$ 7.41 Gg C
- Euler's constant e = 2.718
- k = 0.17

$DDOC_{mdecompT\ (1955)} = DDOC_{maT\text{-}1\ (1954)} \times (1 - e^{\wedge(-k)})$
$= 7.41 \times (1\text{-}2.718^{\wedge(-0.17)})$
$= 1.16$ Gg C

Similarly calculated for the intermediate years up to 2015

Year 2015

- $DDOC_{maT\text{-}1\ (2014)} =$ 447.06 Gg C
- Euler's constant e = 2.718
- k = 0.17

$DDOC_{mdecompT\ (2015)} = DDOC_{maT\text{-}1\ (2014)} \times (1 - e^{\wedge(-k)})$
$= 447.06 \times (1\text{-}2.718^{\wedge(-0.17)})$
$= 69.88$ Gg C

Step 6: Calculation of CH_4 generated ($CH_{4generatedT}$) from decomposed $DDOC_m$

$CH_{4generatedT} = DDOC_{mdecompT} \times F \times 16/12$

Year 1954

- $DDOC_{mdecompT\ (1954)} = 0$ Gg C
- F = default value of 0.5

$CH_{4generatedT\ (1954)} = DDOC_{mdecompT\ (1954)} \times F \times 16/12$
$= 0 \times 0.5 \times 16/12$
$= 0$ Gg CH_4

Year 1955

- $DDOC_{mdecompT\ (1955)} = 1.16$ Gg C
- F = default value of 0.5

$CH_{4generatedT\ (1955)} = DDOC_{mdecompT\ (1955)} \times F \times 16/12$
$= 1.16 \times 0.5 \times 16/12$
$= 0.77$ Gg CH_4

Similarly calculated for the intermediate years up to 2015

Year 2015

- $DDOC_{mdecompT\ (2015)} = 69.88$ Gg C
- F = default value of 0.5

$CH_{4generatedT\ (2015)} = DDOC_{mdecompT\ (2015)} \times F \times 16/12$
$= 69.88 \times 0.5 \times 16/12$
$= 46.59$ Gg CH_4

Step 7: Calculation of Total CH_4 emission from solid waste disposal sites

CH_4 Emissions = $[\sum CH_{4\ generatedT} - R_T] \times (1-OX_T)$

Year 1954

- $CH_{4generatedT\ (1954)} = 0$ Gg CH_4
- R_T = default value of 0
- OX_T = default value of 0

CH_4 Emissions $_{(1954)} = [CH_{4generatedT\ (1954)} - R_T] \times ((1-OX_T)$
$= [0 – 0] \times (1- 0)$
$= 0$ Gg $CH_4 = 0 \times 10^3$ tonnes of CH_4
$= 0$ tonnes of CH_4

Year 1955

- $CH_{4generatedT\ (1955)} = 0.77$ Gg CH_4
- R_T = default value of 0
- OX_T = default value of 0

CH_4 Emissions $_{(1955)} = [CH_{4generatedT\ (1955)} - R_T] \times ((1-OX_T)$
$= [0.77 – 0] \times (1- 0)$
$= 0.77$ Gg $CH_4 = 0.77 \times 10^3$ tonnes of CH_4
$= 771.86$ tonnes of CH_4

Similarly calculated for the intermediate years up to 2015

Year 2015

- $CH_{4generatedT\ (2015)} = 46.59$ Gg CH_4
- R_T = default value of 0
- OX_T = default value of 0

CH_4 Emissions $_{(2015)} = [CH_{4generatedT\ (2015)} - R_T] \times ((1-OX_T)$
$= [46.59 – 0] \times (1- 0)$
$= 46.59$ Gg $CH_4 = 46.59 \times 10^3$ tonnes of CH_4
$=$ 46,589.39 tonnes of CH_4

Step 8: Calculation of Total CH_4 emissions from Solid Waste Disposal in tonnes of CO_2e

Total CH_4 emissions from Solid Waste Disposal for Andhra Pradesh in tonnes of CO_2e (2015)
= (Emission in tonnes of CH_4 x GWP of CH_4)
= 46,589.39 x 21[157]
= 978,377.09 tonnes of CO_2e

[157] 100-year GWP values specified for CH_4 is 21 as per the IPCC Second Assessment Report, 1996, Technical Summary, Table 4. Available at https://www.ipcc.ch/ipccreports/sar/wg_I/ipcc_sar_wg_I_full_report.pdf

Appendix 0.10 Sample Emission Estimate Calculation for 4D1 Domestic Wastewater Treatment and Discharge

1) Sample Calculation for CH_4 Emission from Domestic Wastewater Emission for Andhra Pradesh for Year 2015

Step 1: Calculation of TOW

- State Population P (2005) = 79,558,315 persons[158]
- BOD = 40.5 gm/person/day[159]
- I= default value[160] (1.00 for uncollected wastewater; 1.25 for collected wastewater)

TOW (total country)
$= P * BOD * 0.001 * I * 365$
= 79,558,315 persons x 40.5 gm/person/day x 0.001 x 1 x 365 days
= 1,176,070,791.49 kg BOD/Year

TOW, collected portion of wastewater - urban
= Total State TOW x 19.95%[161] (share of piped sewer system for urban areas) x 1.25
= 1,176,070,791.49 kg BOD/Year x 50.8% x 1.25
=293,258,584.17 kg BOD/Year

TOW, uncollected portion of wastewater - urban
= Total State TOW x (1-19.95%) (uncollected share of wastewater for urban areas) x 1.00
= 1,176,070,791.49 kg BOD/Year x 80.05% x 1.00
= 941,463,924.15 kg BOD/Year

TOW, uncollected portion of wastewater - rural[162]
= Total Country TOW x (1-0.77%) (uncollected share of wastewater for rural areas) x 1.00
= 1,176,070,791.49 kg BOD/Year x 99.23%[163] x 1.00
= 1,167,019,164.93 kg BOD/Year

Step 2: Calculation of CH_4 Emission Factor for each Treatment Discharge Pathway

[158] Estimated based on country population for year 2001 and 2011 and decadel growth rate from 2001-2011 as per Census of India data. Available at http://planningcommission.nic.in/data/datatable/data_2312/DatabookDec2014%20307.pdf
[159] NEERI document on Inventorization of Methane Emissions from Domestic & Key Industries Wastewater – Indian Network for Climate Change Assessment, 2010. Available at: http://www.moef.nic.in/sites/default/files/M%20Karthik.pdf
[160] Based on 2006 IPCC Guidelines, Vol. 5, Chapter 6: Wastewater Treatment and Discharge, Equation 6.3. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf
[161] Refer to Table 42 in this note for details of sources and calculation of this value
[162] As reported in India's Second National Communication, the waste water generated in rural areas is not handled or treated in any way and decomposes under aerobic conditions. Using this basis, the proportion of rural wastewater that is collected and conveyed through sewer systems is also assumed to not undergo any treatment downstream and decomposes under aerobic conditions, thereby not leading to CH_4 emissions. Therefore emissions are estimated only for uncollected portion for rural domestic wastewater
[163] Refer to Table 47 in this note for details of sources and calculation of this value

Table 58: CH_4 Emission factor calculation for Treatment Pathway in Urban and Rural income groups

Income Group (i)	Treatment/ discharge pathway or system (j)	Degree of utilization of treatment/ Discharge pathway or system j, for each income group fraction i (Ti,j)[164]	MCFj[165]	Bo (kg CH_4/kg bod)	EFj = Bo x MCFj (kg CH_4/kg bod)
Urban	Septic Tank (uncollected)	0.26	0.5	0.6	0.30
	Latrine (uncollected)	0.15	0.1	0.6	0.06
	Public Latrine (uncollected)	0.03	0.5	0.6	0.30
	Others/None (Uncollected)	0.36	0.1	0.6	0.06
	Sewer (collected and not treated)	0.199 (Sewer) x 55.5% of waste water collected and not treated in Andhra Pradesh = 0.11071	0.5	0.6	0.30
	Sewer (collected and anaerobic treatment)	(0.199 (Sewer) – 0.11071) (Sewer collected and not treated) x 0% (share of wastewater collected through sewer and treated anaerobically in Andhra Pradesh) = 0	0.8	0.6	0.48
	Sewer (collected and aerobic treatment, not well managed)	(0.199 (Sewer) – 0.11071) x 100% (share of wastewater collected through sewer and treated anaerobically in Andhra Pradesh) = 0.089	0.3	0.6	0.18
Rural	Septic Tank uncollected)	0.076	0.50	0.6	0.30
	Latrine (uncollected)	0.064	0.10	0.6	0.06
	Public Latrine (Uncollected)	0.033	0.50	0.6	0.30
	Sewer (Open and closed drainage)	0.008	0	0.6	0
	Other & None (Uncollected)	0.820	0.10	0.6	0.06

Step 3: CH_4 Emission Calculation for each income Group by Treatment type

$$CH4\ Emissions = \sum_{i,j} [(U_i * Ti_{,j} * EFj)](TOW - S) - R$$

A) Urban

- Ui =0.273[166]
- Ti,j for different treatment/discharge pathways from Table 90 above
- EFj for different treatment/discharge pathways from Table 90 above

<u>CH_4 emissions from Treatment/Discharge Pathways classified as 'Uncollected'</u>

a) CH_4 emissions from Septic tank (uncollected)
= (0.273 x 0.26 x 0.30 kg CH_4/kg BOD) x 941,463,924.15 kg BOD/Year
= 20,268,575.16 kg CH_4/year

b) CH_4 emissions from Latrine (uncollected)
= (0.273 x 0.15 x 0.06 kg CH_4/kg BOD) x 941,463,924.15 kg BOD/Year

[164] Refer to Table 42 and Table 47 in this note for details of sources and calculation of these values
[165] Refer to Table 50 in this note for further details
[166]Based on share of urban population reported for Andhra Pradesh for year 2001 as per Census of India statistics. http://planningcommission.nic.in/data/datatable/data_2312/DatabookDec2014%20307.pdf

= 2,329,001.87 kg CH_4/year

c) CH_4 emissions from Public Latrine (uncollected)
= (0.273 x 0.03 x 0.30 kg CH_4/kg BOD) x 941,463,924.15 kg BOD/Year
= 2,430,089.14 kg CH_4/year

CH_4 emissions from Other/None (uncollected and not treated)
= (0.273 x 0.36 x 0.06 kg CH4/kg BOD) x 941,463,924.15 kg BOD/Year
= 5,478,312.48 kg CH4/year

<u>CH_4 emissions from Treatment/Discharge Pathways classified as 'Collected'</u>
e) CH_4 emissions from Sewer (collected and not treated)
= (0.273 x 0.11071 x 0.30 kg CH_4/kg BOD) x 293,258,584.17
= 2,659,501.12 kg CH_4/year

f) CH_4 emissions from Sewer (collected and anaerobic treatment)
= (0.273 x 0 x 0.48 kg CH_4/kg BOD) x 293,258,584.17 kg BOD/Year
= 0 kg CH_4/year

g) CH_4 emissions from Sewer (collected and Aerobic treatment, not well managed)
= (0.273 x 0.089 x 0.18 kg CH_4/kg BOD) x 293,258,584.17 kg BOD/Year
= 1,279,501.92 kg CH_4/year

Total Urban Domestic Wastewater CH_4 emissions (tonnes of CH_4)
= (20,268,575.16 + 2,329,001.87 + 2,430,089.14 + 5,478,312.48 + 2,659,501.12 + 0 + 1,279,501.92) kg CH_4/year /1000
= 34,446.9867 tonnes of CH_4

Total CH_4 emissions from Urban Domestic Wastewater in tonnes of CO_2e (2005)
= Emission in tonnes of CH_4 x GWP of CH_4
= 34,446.9867 x 21[157]
= 723,386.72 tonnes of CO_2e

B) Rural

- Ui =0.727[167]
- Ti,j for different treatment/discharge pathways from Table 90 above
- EFj for different treatment/discharge pathways from Table 90 above

<u>CH_4 emissions from Treatment/Discharge Pathways classified as 'Uncollected'</u>
a) CH_4 emissions from Septic tank (uncollected)
= (0.727 x 0.076 x 0.30 kg CH_4/kg BOD) x 1,167,019,164.93 kg BOD/Year
= 19,247,713.14 kg CH_4/year

[167] Based on share of rural population reported for Andhra Pradesh for year 2001 as per Census of India statistics. http://planningcommission.nic.in/data/datatable/data_2312/DatabookDec2014%20307.pdf

b) CH_4 emissions from Latrine (uncollected)
= (0.727 x 0.064 x 0.06 kg CH_4/kg BOD) x 1,167,019,164.93 kg BOD/Year
= 3,257,731.90 kg CH_4/year

c) CH_4 emissions from Other (uncollected and not treated)
= (0.727 x 0.033 x 0.30 kg CH_4/kg BOD) x 1,167,019,164.93 kg BOD/Year
= 8,300,864.84 kg CH_4/year

d) CH_4 emissions from None
= (0.727 x 0.820 x 0.06 kg CH_4/kg BOD) x 1,167,019,164.93 kg BOD/Year
= 41,742,845.78 kg CH_4/year

<u>CH_4 emissions from Treatment/Discharge Pathways classified as 'Collected'</u>
a) CH_4 emissions from Sewer (collected and not treated)
= 0 kg CH_4/year[168]

Total Rural Domestic Wastewater CH_4 emissions (tonnes of CH_4)
= (19,247,713.14 + 3,257,731.90 + 8,300,864.84 + 0 + 41,742,845.78) CH_4/year /1000
= 72,549.16 tonnes of CH_4

Total CH_4 emissions from Rural Domestic Wastewater in tonnes of CO_2e (2005)
= Emission in tonnes of CH_4 x GWP of CH_4
= 72,549.16 x 21[157]
= 1,523,532.27 tonnes of CO_2e

Grand Total CH_4 emissions from Domestic Wastewater for Andhra Pradesh, year 2005
= Urban wastewater CH_4 emission + Rural wastewater CH_4 emission
= 723,386.72 + 1,523,532.27
= 2,246,918.99 tonnes of CO_2e

2) <u>Sample Calculation for N2O Emission from Domestic Wastewater for Andhra Pradesh for Year 2015</u>

A) N_2O Emissions from Urban Population for Andhra Pradesh

Step 1: Calculation of Total Nitrogen in the wastewater effluent

$N_{EFFLUENT} = (P \times Protein \times F_{NPR} \times F_{NON\text{-}CON} \times F_{IND\text{-}COM}) - N_{SLUDGE}$

[168] As reported in India's Second National Communication, rural wastewater that is collected and conveyed through sewer systems is also assumed to not undergo any treatment downstream and decomposes under aerobic conditions, thereby not leading to CH_4 emissions.

- Urban population, 2005 = 23,772,994 persons[169]
- Annual per capita protein consumption = 50.9 gm/person/day[170] x 365 day=18.58 kg/capita/day
- Fraction of Nitrogen in Protein (F_{NPR}) = 0.16
- Factor for Non-consumed protein added to the wastewater ($F_{NON-CON}$) = 1.40
- Factor for industrial and commercial co-discharged protein into the sewer system ($_{FIND-COM}$)= 1.25
- Nitrogen removed with sludge (N_{SLUDGE}) = 0

Total annual nitrogen in the wastewater effluent
= (23,772,994 persons x 18.58 kg/person/year x 0.16 x 1.4 x 1.25) – 0
=123,666,639.33 kg N/Year

Step 2: Calculation of N_2O emissions

N_2O Emissions = $N_{EFFLUENT}$ x $EF_{EFFLUENT}$ x 44/28

- Total annual amount of nitrogen in the wastewater effluent ($N_{EFFLUENT}$) = 123,666,639.33 kg N/Year
- Emission Factor for N_2O emissions from discharged to wastewater ($EF_{EFFLUENT}$) = 0.005 kg N_2O-N/kg N
- 44/28 - The factor is the conversion of kg N_2O-N into kg N_2O = 1.57

Total N_2O Emission from Domestic Wastewater (Urban) (tonnes of N_2O)
= (123,666,639.33 kg N/Year x 0.005 kg N_2O-N/kg N x 1.57)/1000
= 971.67 tonnes of N_2O

Total N_2O Emission from Domestic Wastewater (Urban) (tonnes of CO_2e)
= Emission in tonnes of N_2O x GWP of N_2O
= 971.67 x 310[171]
= 301,216.60 tonnes CO_2e

B) N_2O emissions from Rural Population

Step 1: Calculation of Total Nitrogen in the wastewater effluent

$N_{EFFLUENT}$ = (P x Protein x F_{NPR} x $_{FNON-CON}$ x $F_{IND-COM}$) - N_{SLUDGE}

- Rural population = 55,785,321 persons[172]
- Annual per capita protein consumption = 49.8 gm/person/year[170] x 365 days= 18.18 kg/person/year
- Fraction of Nitrogen in Protein (F_{NPR}) = 0.16

[169] Estimated based on urban population for year 2001 and 2011 and decadel growth rate from 2001-2011 as per Census of India data. Available at http://planningcommission.nic.in/data/datatable/data_2312/DatabookDec2014%20307.pdf
[170] Refer Table 52 in this note for further details
[171] 100-year GWP values specified for N2O is 310 as per the IPCC Second Assessment Report, 1996, Technical Summary, Table 4. Available at https://www.ipcc.ch/ipccreports/sar/wg_I/ipcc_sar_wg_I_full_report.pdf
[172] Estimated based on urban population for year 2001 and decadel growth rate from 2001-2011 as per Census of India data. Available at http://planningcommission.nic.in/data/datatable/data_2312/DatabookDec2014%20307.pdf

- Factor for Non-consumed protein added to the wastewater ($F_{NON\text{-}CON}$) = 1.40
- Factor for industrial and commercial co-discharged protein into the sewer system ($_{FIND\text{-}COM}$)= 1.25
- Nitrogen removed with sludge (N_{SLUDGE}) = 0

Total annual nitrogen in the wastewater effluent
= (55,785,321 persons x 18.18 kg/person/year x 0.16 x 1.4 x 1.25) – 0
= 283,922,738.35 kg N/Year

Step 2: Calculation of N_2O emissions

N_2O Emissions = $N_{EFFLUENT}$ x $EF_{EFFLUENT}$ x 44/28

- Total annual amount of nitrogen in the wastewater effluent ($N_{EFFLUENT}$) = 283,922,738.35 kg N/Year kg N/Year
- Emission Factor for N_2O emissions from discharged to wastewater ($EF_{EFFLUENT}$) = 0.005 kg N_2O-N/kg N
- 44/28 - The factor is the conversion of kg N_2O-N into kg N_2O = 1.57

Total N_2O Emission from Domestic Wastewater (Rural) (tonnes of N_2O)
= (283,922,738.35 kg nitrogen x 0.005 N_2O-N/kg N x 1.57)/1000
= 2,230.82 tonnes of N_2O

Total Emission from Domestic Wastewater (Rural) (tonnes of CO_2e)
= Emission in tonnes of N_2O x GWP of N_2O
= 2,230.82x 310[171]
= 691,554.67 tonnes CO_2e

Grand Total N_2O emissions from Domestic Wastewater at the National-level, year 2005
= Urban wastewater N_2O emission + Rural wastewater N_2O emission
= 301,216.60 + 691,554.67
= 992,771.27 tonnes of CO_2e

Appendix 0.11 Sample Emission Estimate Calculation for 4D1 Industrial Wastewater Treatment and Discharge

Emission estimate calculation for Karnataka State for 2015

Step 1: Calculation of TOW

TOWi = Pi ∗ Wi ∗ CODi

- Pi: Production for industry sector i (2015), tonnes[173]
- Wi: Wastewater generated for industry sector i, m^3/tonne product[174]

[173] Refer Table 64 of this note for details of data sources for production data for all industry sectors
[174] Refer Table 65 of this note for details of sources of this parameter for all industry sectors

- CODi: Chemical oxygen demand for industry sector i[175], kg COD/m^3

(a) Pulp & Paper

= Pi $_{Pulp \& Paper}$ x Wi $_{Pulp \& Paper}$ x CODi $_{Pulp \& Paper}$
= 736,563 tonnes x 127.50 m^3/tonne x 2.0 kg COD/m^3
= 187,823,438 kg COD/yr

(b) Fertilizer

Nitrogenous

= Pi $_{Fertilizer}$ x Wi $_{Fertilizer}$ x CODi $_{Fertilizer}$
= 143,627 tonnes x 8 m^3/tonne x 3 kg COD/m^3
= 3,447,040 kg COD/yr

Phosphatic

= Pi $_{Fertilizer}$ x Wi $_{Fertilizer}$ x CODi $_{Fertilizer}$
= 155,647 tonnes x 8 m^3/tonne x 3 kg COD/m^3
= 3,737,905 kg COD/yr

(c) Sugar

= Pi $_{Sugar}$ x Wi $_{Sugar}$ x CODi $_{Sugar}$
= 4,283,250 tonnes x 0.4 m^3/tonne x 5.0 kg COD/m^3
= 8,566,500 kg COD/yr

(d) Coffee

= Pi $_{Coffee}$ x Wi $_{Coffee}$ x CODi $_{Coffee}$
= 246,948 tonnes x 15 m^3/tonne x 9 kg COD/m^3
= 33,337,913 kg COD/yr

(e) Dairy

= Pi $_{Dairy}$ x Wi $_{Dairy}$ x CODi $_{Dairy}$
= 6,110,310 tonnes x 6 m^3/tonne x 3 kg COD/m^3
= 109,985,573 kg COD/yr

(f) Meat

= Pi $_{Meat}$ x Wi $_{Meat}$ x CODi $_{Meat}$
= 192,815 tonnes x 11.70 m^3/tonne x 5 kg COD/m^3
= 11,279,678 kg COD/yr

(g) Tannery

= Pi $_{Tannery}$ x Wi $_{Tannery}$ x CODi $_{Tannery}$
= 9,840 tonnes x 32 m^3/tonne x 3.10 Kg COD/m^3
= 976,172 kg COD/yr

(h) Iron & Steel
Pig Iron

= Pi $_{Iron \& Steel}$ x Wi $_{Iron \& Steel}$ x CODi $_{Iron \& Steel}$

[175] Refer Table 66 of this note for details of sources of this parameter for all industry sectors

= 2,073,994 tonnes x 60 m^3/tonne x 0.55 kg COD/m^3
= 68,441,794 kg COD/yr

Sponge Iron
= $Pi_{\text{Iron \& Steel}}$ x $Wi_{\text{Iron \& Steel}}$ x $CODi_{\text{Iron \& Steel}}$
= 307,522 tonnes x 60 m^3/tonne x 0.55 kg COD/m^3
= 10,148,215 kg COD/yr

Finished Steel
= $Pi_{\text{Iron \& Steel}}$ x $Wi_{\text{Iron \& Steel}}$ x $CODi_{\text{Iron \& Steel}}$
= 4,927,211 tonnes x 60 m^3/tonne x 0.55 kg COD/m^3
= 162,597,979 kg COD/yr

(i) Petroleum
= $Pi_{\text{Petroleum}}$ x $Wi_{\text{Petroleum}}$ x $CODi_{\text{Petroleum}}$
= 15,482,270 tonnes x 0.6 m^3/tonne x 1.0 kg COD/m^3
= 9,289,362 kg COD/yr

(j) Rubber
= Pi_{Rubber} x Wi_{Rubber} x $CODi_{\text{Rubber}}$
= 37,330 tonnes x 26.3 m^3/tonne x 6.12 Kg COD/m^3
= 6,008,545 kg COD/yr

Step 2: Calculation of CH_4 Emission Factors for Industry Sectors based on Treatment/Discharge Pathway

Table 59: Calculation of the Industry-wise Methane Correction Factor

Industry[176]	Bo (kg CH_4/kg COD)[177]	MCF[178]	EFi= B_o x MCF (kg CH_4/kg COD)
Iron & Steel	0.25	0	0
Fertilizer	0.25	0.2	0.05
Sugar	0.25	0.8	0.2
Coffee	0.25	0.8	0.2
Petroleum Refineries	0.25	0	0
Dairy	0.25	0.8	0.2
Meat	0.25	0.8	0.2
Pulp & Paper	0.25	0.8	0.2
Rubber	0.25	0	0
Tannery	0.25	0.2	0.05

Step 3: Calculation of CH_4 Emission

CH_4 Emissions (tonnes) = $\sum_i$ ((TOWi -Si) x EFi/1000) – Ri

(a) Pulp & Paper

- TOWi = 187,823,438 kg COD/yr

---

[176] Refer Table 67 in this note for further details on the prevalent treatment technology and corresponding MCF values
[177] Bo value is taken as default value as per 2006 IPCC Guidelines, Vol. 5, Chapter 6.
Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf
[178] MCF value is taken based on treatment systems listed in 2006 IPCC Guidelines, Vol. 5, Chapter 6, Table 6.8 (see Table 63 in this note). Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

- Si = 0.35 kg COD/yr
- EFi = 0.20 kg CH_4/kg BOD
- Ri = 0

CH_4 Emissions (tonnes)
= ((TOWi – Si) x EFi / 1000) - Ri
= ((187,823,438 kg COD/yr – 0.35 kg COD/yr) x 0.20 kg CH_4/kg BOD)/1000 - 0
= 37,565 tonnes CH_4

(b) Fertilizer
Nitrogenous
- TOWi = 3,447,040 kg COD/yr
- Si = 0.35 kg COD/yr
- EFi = 0.20 kg CH_4/kg BOD
- Ri = 0

CH_4 Emissions (tonnes)
= ((3,447,040 kg COD/yr – 0.35 kg COD/yr) x 0.20 kg CH_4/kg BOD)/1000 - 0
= 172 tonnes CH_4

Phosphatic
- TOWi = 3,737,905 kg COD/yr
- Si = 0.35 kg COD/yr
- EFi = 0.20 kg CH_4/kg BOD
- Ri = 0

CH_4 Emissions (tonnes)
= ((3,737,905 kg COD/yr – 0.35 kg COD/yr) x 0.20 kg CH_4/kg BOD)/1000 - 0
= 187 tonnes CH_4

(c) Sugar
- TOWi = 8,566,500 kg COD/yr
- Si = 0.35 kg COD/yr
- EFi = 0.20 kg CH_4/kg BOD
- Ri = 70%

CH_4 Emissions (tonnes) (without methane recovery)
= ((8,566,500 kg COD/yr – 0.35 kg COD/yr) x 0.20 kg CH_4/kg BOD)/1000
= 1713.30 tonnes CH_4

CH_4 Emission (tonnes) (post Methane recovery)
= CH_4 emission (without methane recovery) x (1 – Methane recovery fraction)
= 1713.30 x (1-0.70)
= 513.99 tonnes CH_4

(d) Coffee
- TOWi = 33,337,913 kg COD/yr
- Si = 0.35 kg COD/yr
- EFi = 0.20 kg CH_4/kg BOD
- Ri = 0%

CH_4 Emissions (tonnes)
= ((33,337,913 kg COD/yr – 0.35 kg COD/yr) x 0.20 kg kg CH_4/kg BOD)/1000 - 0
= 6,668 tonnes CH_4

(e) Dairy
- TOWi = 109,985,573 kg COD/yr
- Si = 0.35 kg COD/yr
- EFi = 0.20 kg CH_4/kg BOD
- Ri = 75%

CH_4 Emissions (tonnes) (without methane recovery)
= ((109,985,573 kg COD/yr – 0.35 kg COD/yr) x 0.20 kg CH_4/kg BOD)/1000
= 21,997.11 tonnes CH_4

CH_4 Emission (tonnes) (post Methane recovery)
= CH_4 emission (without methane recovery) x (1 – Methane recovery fraction)
= 21,997.11 x (1 – 0.75)
= 5,499 tonnes CH_4

(f) Meat
- TOWi = 11,279,678 kg COD/yr
- Si = 0.35 kg COD/yr
- EFi = 0.20 kg CH_4/kg BOD
- Ri = 0

CH_4 Emissions (tonnes)
= ((11,279,678 kg COD/yr – 0.35 kg COD/yr) x 0.20 kg CH_4/kg BOD))/ 1000 - 0
= 2,256 tonnes CH_4

(g) Tannery
- TOWi = 976,172 kg COD/yr
- Si = 0.35 kg COD/yr
- EFi = 0.20 CH_4/kg BOD
- Ri = 0

CH_4 Emissions (tonnes)
= ((976,172 kg COD/yr – 0.35 kg COD/yr) x 0.20 kg CH_4/kg BOD))/ 1000 - 0
= 91.50 tonnes CH_4

(h) Iron & Steel
Pig Iron
- TOWi = 68,441,794 kg COD/yr
- Si = 0.35 kg COD/yr
- EFi =0 CH_4/kg BOD
- Ri = 0

CH_4 Emissions (tonnes)
= ((68,441,794 kg COD/yr – 0.35 kg COD/yr) x 0 kg CH_4/kg BOD))/ 1000 - 0

= 0 tonnes CH_4

Sponge Iron

- TOWi = 10,148,215 kg COD/yr
- Si = 0.35 kg COD/yr
- EFi =0 CH_4/kg BOD
- Ri = 0

CH_4 Emissions (tonnes)
= ((10,148,215 kg COD/yr – 0.35 kg COD/yr) x 0 kg CH_4/kg BOD))/ 1000 - 0
= 0 tonnes CH_4

Finished Steel

- TOWi = 162,597,979 kg COD/yr
- Si = 0.35 kg COD/yr
- EFi =0 CH_4/kg BOD
- Ri = 0

CH_4 Emissions (tonnes)
= ((162,597,979 kg COD/yr – 0.35 kg COD/yr) x 0 kg CH_4/kg BOD))/ 1000 - 0
= 0 tonnes CH_4

(i) Petroleum

- TOWi = 9,289,362 kg COD/yr
- Si = 0.35 kg COD/yr
- EFi= 0 CH_4/kg BOD
- Ri = 0

CH_4 Emissions (tonnes)
= ((9,289,362 kg COD/yr – 0.35 kg COD/yr) x 0 kg CH_4/kg BOD))/ 1000 - 0
= 0 tonnes CH_4

(j) Rubber

- TOWi = 6,008,545 kg COD/yr
- Si = 0.35 kg COD/yr
- EFi = 0 CH_4/kg BOD
- Ri = 0

CH_4 Emissions (tonnes)
= ((6,008,545 kg COD/yr – 0.35 kg COD/yr) x 0 kg CH_4/kg BOD))/ 1000 - 0
= 0 tonnes CH_4

Step 4: Total CH_4 emissions from industrial wastewater in tonnes of CO_2e

CH_4 Emission (tonnes CO_2e) = Emission in tonnes of CH_4 x GWP of CH_4[157]

(a) Pulp & Paper
= 37,565 x 21
= 788,858 tonnes CO_2e

(b) Fertilizer

Nitrogenous Fertilizer

= 172 x 21
= 3,619 tonnes CO_2e

Phosphatic Fertilizer
= 187 x 21
= 3,925 tonnes CO_2e

(c) Sugar
= 513.99 x 21
= 10793.79 tonnes CO_2e

(d) Coffee
= 6,668 x 21
= 140,019 tonnes CO_2e

(e) Dairy
= 5,499 x 21
= 115,485 tonnes CO_2e

(f) Meat
= 2,256 x 21
= 47,375 tonnes CO_2e

(g) Tannery
= 91.50 x 21
= 1,921.54 tonnes CO_2e

(h) Iron & Steel
= 0 x 21
= 0 tonnes CO_2e

(i) Petroleum
= 0 x 21
= 0 tonnes CO_2e

(j) Rubber
= 0 x 21
= 0 tonnes CO_2e

Total CH_4 emissions from industrial wastewater in tonnes of CO_2e (2015)
= Sum of CH_4 emissions from all industrial sectors (i.e. Pulp & Paper + Fertilizer + Sugar + Coffee + Dairy + Beer + Meat + Soft Drink + Tannery + Iron & Steel + Petroleum + Rubber)
= 1,111,997 tonnes of CO_2e

References

ADB. (2010). Project Document on Best Practices for Municipal Solid Waste Management in South Asia: A New Knowledge Product.

GoI. (2016). *India's Intended Nationally Determined Contribution.* Government of India.

ICRIER. (2018, April). *Working Paper No. 356. Solid Waste Management in India: An Assessment of Resource Recovery and Environmental Impact.* Retrieved August 2019, from http://icrier.org/pdf/Working_Paper_356.pdf

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* National Greenhouse Gas Inventories Programme. Japan: IGES.

Joshi, R. A. (2016). Status and challenges of municipal solid waste management in India: A review. Cogent OA. Retrieved from https://www.cogentoa.com/article/10.1080/23311843.2016.1139434.pdf

Ministry of Home Affairs. (2012). Retrieved December 12, 2018, from Census of India: http://censusindia.gov.in/2011census/hlo/Data_sheet/India/Latrine.pdf

MoEFCC. (2012). *India - Second National Communication to the UNFCCC.* New Delhi: Ministry of Environment, Forest and Climate Change, Goverment of India.

MoEFCC. (2015). *India First Biennial Update Report to the UNFCCC.* New Delhi: Ministry of Environment, Forest and Climate Change, Goverment of India.

MoEFCC. (2018). *India: Second Biennial Update Report to the United Nations Framework.* New Delhi: Ministry of Environment, Forest and Climate Change, Goverment of India.

MOSPI. (2018, November 28). *National accounts Statistics: Back-Series 2004-05 to 2011-12.* Retrieved March 2, 2019, from http://pibphoto.nic.in/documents/rlink/2018/nov/p2018112801.pdf

MOSPI. (2019, January 31). Retrieved February 2, 2019, from http://www.mospi.nic.in/sites/default/files/press_release/FRE%20of%20National%20Income%2C%20Consumption%20Expenditure%2C%20Saving%20and%20Capital%20Formation%20For%202017-18_0.pdf

NEERI. (2010). Retrieved December 16, 2018, from Ministry of Environment, Forests and Climate Change.

Planning Commission. (2014). Retrieved December 11, 2018, from http://planningcommission.nic.in/data/datatable/data_2312/Databook

Abbreviations

ASI	Annual Survey of Industries
BUR 1	First Biennial Update Report to the UNFCCC
BUR 2	Second Biennial Update Report to the UNFCCC
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CPCB	Central Pollution Control Board
CPHEEO	Central Public Health and Environmental Engineering Organisation
CSE	Centre for Science and Environment
CAGR	Compound annual growth rate
CH_4	Methane
DOC	Degradable organic carbon
FOD	First Order Decay
GDP	Gross Domestic Product
GHG	Greenhouse gas
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
MCF	Methane Correction Factor
MOSPI	Ministry of Statistics & Programme Implementation
Mil. tonnes	Million tonnes
NEERI	National Environmental Engineering Research Institute
NSSO	National Sample Survey Office
N_2O	Nitrous oxide
QA	Quality Assurance
QC	Quality Control
SAIL	Steel Authority of India Limited
STP	Sewage Treatment Plant
SPCB	State Pollution Control Board
UNFCCC	United Nations Framework Convention on Climate Change

List of Tables

Table 1: Snapshot of GHG estimates by gas and source category for Waste sector 7
Table 2: Global warming potential as per IPCC assessment reports 9
Table 4: Trend of GHG emission estimates by source categories 16
Table 5: Distribution of GHG emission contribution by source category for 2015 17
Table 6: Aggregated GHG emission estimates for the Waste sector for 2005 and 2015 19
Table 7: Waste Sector GHG emission estimates by source category, 2005-2015 20
Table 8: Change in Production and Wastewater emission by industry sector, 2005-2015 26
Table 9: Average industrial wastewater GHG emission per tonne of product and per m3 of wastewater generated for Industrial Sectors in India (2005-2015) 26
Table 10: GHG estimates by State for Waste sector, 2005-2015 27
Table 11: Share of Urban CH_4 Emission in the top five emitting states by type of treatment/discharge system, 2015 31
Table 12: Share of Rural CH_4 Emission in the top five emitting states by type of treatment/discharge system, 2015 32
Table 13: Principal Sources and Quality of Data for Solid Waste Disposal Estimates 36
Table 14: Qualitative Assessment of Year-wise Activity and Emission Factor Data used in the Solid Waste Disposal Estimates 38
Table 15: Type of Emission Factor and Level of Methodological Tiers adopted for Solid Waste Disposal Estimates 38
Table 16: Default DOC content of different MSW components 40
Table 17: State-wise estimated per capita waste generation based on data reported by NEERI and CPCB 43
Table 18: Decadal daily Per capita Waste generation and Annual growth rates at national-level for India 44
Table 19: Initial Estimate of state-wise waste to disposal site based on treatment reported by CPCB 45
Table 20: Adjusted Estimate of State-wise Proportion of waste going to Disposal Site and corresponding time periods considered in the estimates 47
Table 21: Estimated Degradable Organic Content using Waste Composition 48
Table 22: Estimated State-wise DOC Value applicable for the time period 2005-2014 48
Table 23: Principal Sources and Quality of Data for Domestic Wastewater Treatment and Discharge Estimates 51
Table 24: Qualitative Assessment of Year-wise Activity Data used in the State Domestic Wastewater Treatment and Discharge Estimates 53
Table 25: Type of Emission Factor and Level of Methodological Tier adopted for Domestic Wastewater Treatment and Discharge State-level Estimates 54
Table 26: Default MCF values by treatment type and discharge pathway 55
Table 27: Default India specific Degree of Utilization Rates for Domestic Wastewater Treatment/Discharge Pathways or Systems 58
Table 28: Latrine facility types as reported in Census of India for Urban Households in Andhra Pradesh 59
Table 29: Estimated degree of utilization of treatment/ Discharge pathway or system j, for Andhra Pradesh State Urban group fraction i (Ti,j), 2011 based on Census of India data 65
Table 30: Estimated Degree of utilization of treatment/ Discharge pathway or system j, for Andhra Pradesh State Urban group fraction i ($T_{i,j}$), 2001 based on Census of India data 67
Table 31: State-wise Degree of utilization considered in the estimates- Urban, 2011 70
Table 32: State-wise Degree of utilization considered in the estimates- Urban, 2001 71
Table 33: Latrine facility types as reported in Census of India for Rural Households in Andhra Pradesh . 72
Table 34: Estimated degree of utilization of treatment/ Discharge pathway or system j, for Andhra Pradesh State Rural group fraction i (Ti,j), 2011 based on Census of India data 74
Table 35: Estimated Degree of utilization of treatment/ Discharge pathway or system j, for Andhra Pradesh Rural group fraction i (Ti,j), 2001 based on Census of India data 75
Table 36: State-wise Degree of utilization considered in the estimates- Rural, 2011 77

Table 37: State-wise Degree of utilization considered in the estimates- Rural, 2001 78
Table 38: MCF values considered for various treatment types for Urban and Rural Population 79
Table 39: State level average per capita BOD 81
Table 40: State-wise Daily Per Capita Protein Consumption considered for Urban and Rural Population 84
Table 41: Industrial Sectors and products considered 86
Table 42: Principal Sources and Quality of Data for Industrial Wastewater Treatment and Discharge Estimates 87
Table 43: Qualitative Assessment of Year-wise Activity and Emission Factor Data used in the Industrial Wastewater Treatment and Discharge Estimates 90
Table 44: Type of Emission Factor and Level of Methodological Tier adopted for Industrial Wastewater Treatment and Discharge Estimates 91
Table 45: Default MCF values based on treatment type and discharge pathway or system for Industrial Wastewater 93
Table 46: Data sources for Industrial Production data 93
Table 47: Industry-wise Wastewater generation per tonne of Product 102
Table 48: Estimated wastewater generation value for Pulp and paper sector 103
Table 49: Industry-wise degradable organic concentration in the Wastewater 104
Table 50: Industry-wise Methane Correction Factor based on the prevalent treatment system 105
Table 51: Changes in Activity Data for Industry sectors 108
Table 52: Recalculation of CH_4 emission estimates for Industrial Wastewater Treatment and Discharge 108
Table 53: Comparison of GHG emission estimates in phase 3 and phase 2 for Industry Sectors with recalculation 109
Table 54: Source category wise deviation in GHG estimates between GHGPI and official inventories published by Government of India for Waste sector 117
Table 55: Comparison of wastewater generation values reported for industry sectors 121
Table 55: Calculation of growth rates for per capita waste generation based on reported data 131
Table 56: Calculation of DOC content value using Waste Composition data 132
Table 57: CH_4 Emission factor calculation for Treatment Pathway in Urban and Rural income groups .. 138
Table 58: Calculation of the Industry-wise Methane Correction Factor 144

List of Figures

Figure 1: Aggregate GHG Emission for the Waste Sector, 2005-2015 8
Figure 2: Trend of Aggregate GHG Emission Estimates from Waste Sector, 2005-2015 16
Figure 3: Trend of Gas-wise emission estimates for Waste Sector, 2005-2015 17
Figure 4: Trend of GHG emission per unit GDP* and per capita emissions for Waste sector, 2005-2015 21
Figure 5: GHG emission per tonne of MSW disposed, 1954-2015 22
Figure 6: Aggregate GHG emission from Urban and Rural Domestic wastewater treatment and discharge, 2005-2015 23
Figure 7: GHG Emission from Industrial wastewater treatment and discharge, 2005-2015 25
Figure 8: Share of GHG emission from solid waste disposal across states, 2015 28
Figure 9: Trend of GHG emission from solid waste disposal in key states, 2005-2015 28
Figure 10: Share of GHG emissions from domestic wastewater across states, 2015 29
Figure 11: Trend of GHG emissions from domestic wastewater in key states, 2005-2015 29
Figure 12: CH_4 emissions and utilization of different treatment/discharge systems for urban areas in top five emitting states, 2015 31
Figure 13: CH_4 emissions and utilization of different treatment/discharge systems for rural areas in top five emitting states, 2015 32
Figure 14: Share of Urban and Rural N_2O Emissions across states, 2015 33
Figure 15: GHG emission from industrial wastewater in key states, 2005-2015 34

Figure 17: Classification of Wastewater Treatment Systems and Estimated Degree of Utilization for Urban population, Andhra Pradesh, 2011 64
Figure 18: Classification of Wastewater Treatment Systems and Estimated Degree of Utilization for Rural Andhra Pradesh, 2011 74