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DIRECTORATE OF ENVIRONMENT AND CLIMATE CHANGE
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GHG INVENTORY
METHODOLOGY NOTE

WASTE SECTOR

JUNE, 2024

WASTE SECTOR

Key Highlights

- The Waste sector contributed to almost 8% of gross GHG emissions (excluding LULUCF) of Kerala in 2021.
- In the Waste sector, domestic wastewater is the major contributing key source category with an average share of 94%. It is followed by industrial wastewater (4%) and municipal solid waste (2%).
- GHG emissions from the Waste sector of Kerala declined at a CAGR of 0.33%, from 1.84 Mt CO_2e in 2005, to 1.75 Mt CO_2e in 2021.

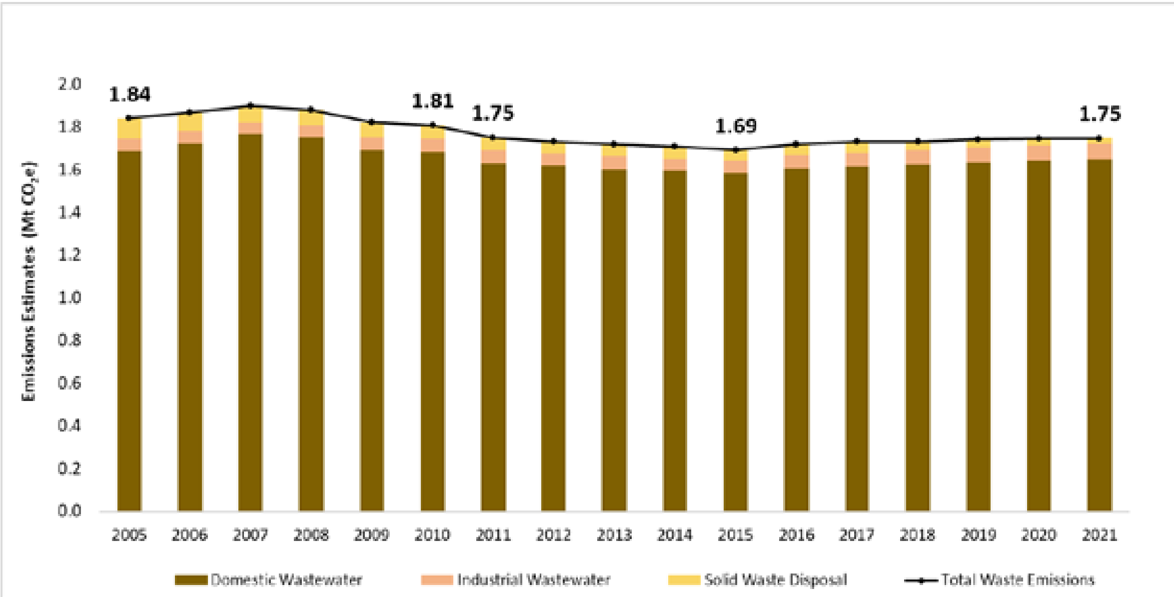

Figure 5: GHG Emissions Estimates of Waste Sector - Kerala (2005 to 2021)

Sector Description

The key economic sectors/categories included in the emission estimates from Waste sector are:

- 4A Solid Waste Disposal
- 4D Wastewater treatment and discharge
    - 4D1 Domestic Wastewater Treatment and Discharge
    - 4D2 Industrial Wastewater Treatment and Discharge

4A Solid Waste Disposal

Category Description

When solid waste is disposed of in landfills or dumpsites under anaerobic conditions, methanogenic bacteria break down the waste's degradable organic component, creating CH_4

emissions. The organic material decomposes slowly, and the CH_4 emissions from a particular quantity of dumped solid waste continue to be released for a few decades (GHGPI Phase III)[23].

The current assessment covers the disposal of municipal solid waste of Kerala. The Municipal Solid Waste includes waste from residential, commercial and institutional waste, street sweeping, parks and gardens which are either in semi-solid or solid form (excludes industrial, hazardous, bio- medical and e-waste). Further, the rural areas have not been included in estimation due to lack of reliable data.

The First order Decay (FOD) model was used in the emissions estimation and it assumes that carbon in waste decays gradually for decades to generate CH_4 emission long after it is disposed of and hence, it is necessary to estimate or collect 50-year data on waste disposal prior to the base year of 2005 (GHGPI Phase III)[24]. For Kerala, the emissions from the solid waste disposal was estimated from 1951 to 2021 keeping the FOD assumptions as reference.

Methodology

The methodology followed for the Methane (CH_4) emission estimations from solid waste disposal of Kerala includes both Tier 1 (T1) and Tier 2 (T2) approach.

Table 69: Source of activity data[25] used for estimating emissions from Waste sector

Parameter	Years	Sources
Urban Population	1987, 1991, 1993 and 2005 to 2021	Annual Vital Statistics, Department of Economics and Statistics, Government of Kerala (1987,1991,1993 and 2005 to 2021)
	1951 to 1986, 1988 to 1990, 1992 , 1994 to 2004	CAGR method
Per Capita Waste Generation	1951 to 1995	Status Of Municipal Solid Waste Generation In Kerala And Their Characteristics (Varma, 2015)
	1996	Status Of Municipal Solid Waste Generation In Kerala And Their Characteristics (Varma, 2015)
	2001 and 2006	Estimated based on Status Of Municipal Solid Waste Generation In Kerala And Their Characteristics study (Varma, 2015)

23 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
24 Ibid.
25 Activity data provided in financial year (FY) format was converted to calendar year (CY) format using the following equations:
CY Activity data = [¼*FY Activity Data Preceding year] + [¾*FY Activity Data Succeeding year]

	2020	Suchitwa Mission (2020) Introduction And Strategic Enviromental Assessment of Waste Management Sector In Kerala (Volume I)
	1997 to 2000; 2002 to 2005; 2007 to 2019	CAGR method
Proportion going to Dumpsites	1951 to 2004	India Second National Communication to United Nations Framework Convention on Climate Change NATCOM 2
	2005 to 2016	Kerala Solid Waste Management Policy, 2018
	2017 to 2021	Based on inputs received from Kerala State Pollution Control Board.
Share of Degradable Organic Content (DOC) in Wet Waste		2006 IPCC Guidelines, Volume 5, Chapter 2 -Waste Generation, Composition, and Management Data, Table 2.4

Table 70: Type of Emission Factor and Level of Methodological Tiers adopted for Solid Waste Disposal Estimates

IPCC ID	GHG source and sink categories	CH_4	
		Method Applied	Emission Factor
4A	Solid Waste Disposal	T1, T2	D, CS
T1: Tier 1; T2: Tier 2; CS: Country-specific; D: IPCC default			

Equations used for Emissions Estimates

The following equations have been used to estimate CH_4 emissions from Solid waste disposal in accordance with 2006 IPCC Guidelines

CH_4 Emissions from Solid Waste Disposal Sites

$$CH_4\ Emissions = \left[\sum_x CH_4\ generated_{x,T} - R_T \right] \bullet (1 - OX_T) \qquad \textit{(IPCC 2006 Equation 3.1)}$$

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)*

OX_T = oxidation factor in year T, (fraction) (default value of 0) *(IPCC, 2006)*

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

$$CH_4\ generated_T = DDOCmdecomp_T \bullet F \bullet 16/12 \qquad \textit{(IPCC 2006 Equation 3.6)}$$

CH_4 generated$_T$ = amount of CH_4 generated from decomposable material
DDOCmdecomp$_T$ = Decomposable Degradable Organic Carbon (DDOC) decomposed in year T, Gg
F = fraction of CH_4, by volume, in generated landfill gas (fraction)
16/12 = molecular weight ratio CH_4/C (ratio)

Decomposable DOC from Waste Disposal Data

$$DDOCm = W \bullet DOC \bullet DOC_f \bullet MCF \qquad \textit{(IPCC 2006 Equation 3.2)}$$

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)
MCF = CH_4 correction factor for aerobic decomposition in the year of deposition (fraction)

Estimated DOC using Default Carbon Content Values

$$DOC = \sum_i (DOC_i \bullet W_i) \qquad \textit{(IPCC 2006 Equation 3.7)}$$

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

DDOCm Accumulated in the SWDS at the end of Year T

$$DDOCma_T = DDOCmd_T + (DDOCma_T - 1 \bullet e^{-k}) \qquad \textit{(IPCC 2006 Equation 3.4)}$$

DDOCm Decomposed at the end of the Year T

$$DDOCm\ decomp_T = DDOCma_T - 1 \bullet (1 - e^{-k}) \qquad \textit{(IPCC 2006 Equation 3.5)}$$

Where,

T = inventory year

$DDOCma_T$ = $DDOC_m$ accumulated in the SWDS at the end of year T, Gg

$DDOCma_{T-1}$ = $DDOC_m$ accumulated in the SWDS at the end of year (T-1), Gg

$DDOCmd_T$ = $DDOC_m$ deposited into the SWDS in year T, Gg

DDOCm $decomp_T$ = DDOCm decomposed in the SWDS in year T, Gg

k = reaction constant (0.17) , k = ln(2)/t1/2 (y-1)

t1/2 = half-life time (y)

Euler's Constant e = 2.718

Table 71: Default Values for Emissions Estimations of Solid Waste Disposal[26]

Parameter	Default Values
Fraction of Degradable Organic Carbon which decomposes ($DDOC_f$)	0.5
Methane Correction Factor *(Unmanaged shallow solid waste disposal site with depth less than 5 meter)*	0.4
Fraction of CH_4 in Generated Landfill Gas (F)	0.5
Oxidation Factor (OX)	0
Methane Recovery (R)	0
Reaction Constant (k)	0.84

Source : IPCC,2019 (Volume5, Chapter 3-Solid Waste Disposal)

<u>Data Sources and Assumptions:</u>

1. **Population:**

- The urban population for years 1987, 1991, 1993 and 2005 to 2021 data were obtained from Annual Vital Statistics Report, published by the Department of Economics and Statistics, Government of Kerala
- For the years in between, the urban population was calculated using the CAGR method.

2. **Mass of Waste Deposited**

The mass of waste deposited to the dumpsite was estimated using the urban population , per capita waste generation and proportion of waste going to the dumpsite.

[26] As per 2019 IPCC Guidelines, Volume 5, Chapter 3 - Solid Waste Disposal
Available at https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/5_Volume5/19R_V5_3_Ch03_SWDS.pdf

a. **Per capita waste generation**

- The per capita waste generation data for the year 1996 was obtained from the study conducted in Kerala by Varma (2015) and for the years 2001 and 2006, the per capita waste generation data was derived based on the reported total waste generation data in the study.
- For the year 2020, the per capita waste generation data was derived based on the total waste generation data reported in the Suchitwa Mission Report (2020)[27].
- The per capita waste generation for all the intermediate years between 1996 and 2021 was estimated using CAGR.

Table 72: Per capita waste generation of Kerala

Year	Solid Waste Generation (TPD)	Urban Population	Per Capita Waste Generation (g/person/day)
1996	-	-	210
2001	1752	4903172	357.32
2006	1941	5411995	358.65
2020	Low land (Coastal area)– 2115 Mid Land – 1275 Highland - 365	Low land (Coastal area)– 4162180 Mid Land – 2941234 Highland - 872437	453.34 (average value)

- An Annual Growth rate in per capita waste generation (1.41%) was applied backward from 1995 to 1951 for accounting potential emissions from legacy waste. This annual growth rate in per capita waste generation was obtained from Varma (2015).

b. **Proportion of Waste Going to the Dumpsites**:

- The proportion of solid waste going to the dumpsite for years between 1951 and 2004 was taken as 70% (National Average) as per NATCOM 2 .
- Based on the Suchitwa Missions inputs with reference to the Kerala Solid Waste Management Policy, 2018, the proportion of non-biodegradable waste was estimated as 12.6%. This proportion was applied between 2005 to 2016, due to unavailability of data in the said period.
- The proportion of waste going to the dumpsite for the period 2017 to 2021 was applied as Zero, as per inputs from Kerala State Pollution Control Board.

3. Degradable Organic Carbon (DOC) :

Aggregate Degradable Organic Carbon (DOC) was calculated based on the shares of degradable fraction in Waste Composition (Compostable, Paper and Rags) and Default DOC content values as per 2006 IPCC Guidelines (as seen in Table 73).

[27] Suchitwa Mission (2020) Introduction And Strategic Environmental Assessment of Waste Management Sector In Kerala (Volume I)

- The Aggregate Degradable Organic Carbon (DOC) value for year 1971 was estimated using the National-level share of degradable fraction in Waste Composition (Compostable, Paper and Rags) and was applied for years between 1951 to 1994.
- The shares of degradable organic fraction in Waste Composition (Compostable, Paper and Rags) data for years 1995 and 2005 were taken from GHGPI Phase III. The calculated Aggregate Degradable Organic Carbon (DOC) value for 1995 and 2005 was applied for years 1995 to 2004 and 2005 to 2021 respectively.

Table 73: Default Degradable Organic Content (DOC) Values in Wet Waste[28]

Component	Default DOC Content values (in percentage)
Compostable Matter	15
Rags	24
Paper	40

Source: IPCC, 2006

(Volume 5, Chapter 2-Waste Generation, Composition, and Management Data, Table 2.4)

Table 74: Degradable Organic Carbon values estimated based on reported Waste composition

Reported Year	Waste Composition (in %)			Aggregate DOC Value *(in fraction)*	Applicable Years
	Compostable	Paper	Rags		
1971	41.24	4.14	3.83	0.088	1954-1994
1995	41.8	5.78	3.5	0.094	1995-2004
2005	65.15	16.86	5.87	0.129	2005-2021

4. <u>DDOC decomposed in year T</u> ($DDOC_{m,decompT}$)

The $DDOC_m$ (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 accumulated at the end of the previous year (T-1) ($DDOC_{maT-1}$). It is assumed the DDOC accumulated in the initial year of the 50-year time period considered under the FOD model (i.e. 1954) is zero. Using the values estimated for DDOC deposited and DDOC accumulated, the $DDOC_m$ decomposed is

[28] As per 2006 IPCC Guidelines, Volume 5, Chapter 2 -Waste Generation, Composition, and Management Data, Table 2.4

Available at https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_2_Ch2_Waste_Data.pdf calculated for all the 50-year period from 1954-2004 and subsequently is used to estimate CH_4 emissions from 2005-2021 (GHGPI Phase III)[29].

Limitations:

a. The per capita waste generation of Kerala data was available only for the years 2001,2006 and 2020.
b. The Aggregate Degradable Organic Carbon (DOC) was estimated using 2006 IPCC Guideline's default Degradable Organic Carbon (DOC) values,since state specific DOC values were not available.

4D1 Domestic Wastewater Treatment and Discharge

Category Description

Wastewater can be a source of methane (CH_4) when treated or disposed of anaerobically. The breakdown of protein in domestic wastewater can also be a source of nitrous oxide (N_2O) emissions. Carbon dioxide (CO_2) emissions from wastewater are not considered in the IPCC Guidelines because these are of biogenic origin and should not be included in national total emissions.[30]

Methodology

The table 75 below details the sources of activity data used for estimating emissions from the Domestic Wastewater category

Table 75: Source of activity data used for estimating emissions from Domestic Wastewater category

Activity data	Source
State population	Vital Statistics Division, Department of Economics and Statistics, Government of Kerala, Annual Vital Statistics Reports (2005-2021)
Fractions of urban and rural population	Vital Statistics Division, Department of Economics and Statistics, Government of Kerala, Annual Vital Statistics Reports (2005-2021)

29 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

30 Because the methodology is on a per person basis, emissions from commercial wastewater are estimated as part of domestic wastewater. To avoid confusion, the term municipal wastewater is not used in this text. Municipal wastewater is a mix of household, commercial and non-hazardous industrial wastewater, treated at wastewater treatment plants.

Activity data	Source
Urban degree of utilization	NSS Division, Department of Economics & Statistics, Government of Kerala. Report on NSS Socio Economic Survey Report on NSS Socio economic Survey 65th Round: Housing Conditions and amenities in Kerala 2008-2009 Report on NSS Socio economic Survey 76th Round: Drinking water, sanitation and Housing Condition in Kerala 2018
STP Status	**Ratio of treatment type (aerobic/anaerobic)** •Central Public Health and Environmental Engineering Organization (CPHEEO),Status of Water Supply, Sanitation and Solid Waste Management in Urban Areas- 1999, . •For the year 2008-09, data taken from Central Pollution Control Board, (2013)- Performance Evaluation of Sewage Treatment Plants Under NRCD- 2013 report of CPCB •Central Pollution Control Board- Inventorization of Sewage Treatment Plants 2015, 2020 and based on expert opinion from Kerala Water Authority (KWA). **% of sewer collected and not treated if any** •Based on expert opinion from Kerala Water Authority (KWA)
Rural degree of Utilization	NSS Division, Department of Economics & Statistics, Government of Kerala. Report on NSS Socio Economic Survey Report on NSS Socio economic Survey 65th Round: Housing Conditions and amenities in Kerala (2008-2009) Report on NSS Socio economic Survey 76th Round: Drinking water, sanitation and Housing Condition in kerala (2018) Percentage of piped sewer system in rural areas from 2005-2021 is considered nil based on expert opinion from Kerala Water Authority.
Protein intake (g/person/day)	National Sample Survey Organization, Ministry of Statistics & Programme Implementation, Government of India, Nutritional intake in India 2004-05, 2009-10, 2011-12
Average per capita BOD	National Environmental Engineering Research Institute (NEERI), 2010: Inventorisation of Methane Emissions from Domestic & Key Industries Wastewater – Indian Network for Climate Change Assessment

The overall methodology followed for domestic wastewater related state-level CH_4 and N_2O emissions estimates are consistent with the IPCC Tier 1 approach. While a majority of the activity data used is state specific, default values of the emission factors as per the 2006 IPCC Guidelines have been used for estimation of CH_4 and N_2O emissions.

Table 76: Type of Emission Factor and Level of Methodological Tier adopted for Domestic Wastewater Treatment and Discharge

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
T1: Tier 1; D: IPCC Default					

Equation Used:

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

$$CH4\ Emissions = \left[\sum_{i,j}\left(U_i \bullet T_{i,j} \bullet EF_j\right)\right](TOW - S) - R \text{ (IPCC 2006 Equation 6.1)}$$

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)

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)

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) content of wastewater generated per person. It is expressed in terms of biochemical oxygen demand (kg BOD/year)[31]. The equation for TOW in domestic wastewater is

[31] 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

$$TOW = P \bullet BOD \bullet 0.001 \bullet I \bullet 365$$ *(IPCC 2006 equation 6.3)*

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
(for collected the default is 1.25, for uncollected the default is 1.00)

The emission factor (see table 77) for a wastewater treatment and discharge pathway and system is a function of the maximum CH_4 producing potential (Bo) and the methane correction factor (MCF) for the wastewater treatment and discharge system. The Bo is the maximum amount of CH_4 that can be produced from a given quantity of organics (as expressed in BOD or COD) in the wastewater. The MCF, on the other hand, reflects the degree to which the methane-producing capacity (Bo) is realized in various types of treatment and discharge systems, serving as an indicator of the system's anaerobic nature[32].

$$EF_j = B_0 \bullet MCF_J$$ *(IPCC 2006 equation 6.2)*

Where:
EF_j = emission factor, kg CH_4/kg BOD
j = each treatment/discharge pathway or system
B_o = maximum CH_4 producing capacity, kg CH_4/kg BOD (Default value 0.6) (IPCC,2006)
MCF_j = methane correction factor (fraction) see table 76.

Table 77: Default MCF values by treatment type and discharge pathway

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		

[32] 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories , Volume 5, Waste, Chapter 6

Type of treatment and discharge pathway or system	Description	MCF
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:IPCC 2006 (Vol. 5, Chapter 6; Table 6.3)

In the emission estimates, corresponding default MCF values as per the 2006 IPCC Guidelines (given in table 77) have been used based on the applicable treatment/discharge pathways or systems for urban and rural population.

Table 78: MCF values considered for various treatment types for Urban and Rural Population[33].

Treatment/ discharge pathway or system (j)	Classification of the system (Collected/ Uncollected and Treatment)	Specific Treatment/Discharge pathway or system (j) selected from Table 68	MCFj
Urban population			
Sewer	Collected (Anaerobic treatment)	Anaerobic reactor/Anaerobic digester for sludge	0.80
	Collected (Aerobic treatment)	Centralized, aerobic treatment plant, well managed	0
	Collected (No Treatment)	Stagnant Sewer	0.50
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
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

[33] 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

Table 79: Methane emission factor used for estimating emissions from domestic wastewater category

Type of latrine	Emission factor (kg CH_4/kg BOD)
Septic tank	0.3
Latrine	0.06
Others & none	0.06
Sewer (collected and aerobic treatment, well managed)	0
Sewer collected and not treated	0.3
Sewer (collected and anaerobic treatment)	0.48

N_2O Emissions from Domestic Wastewater

$$N_2O\ Emissions = N_{EFFLUENT} \bullet EF_{EFFLUENT} \bullet 44/28$$ *(IPCC 2006 equation 6.7)*

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 total nitrogen in the effluent is estimated as follows

$$N_{EFFLUENT} = \left(P \bullet Protein \bullet F_{NPR} \bullet F_{NON-CON} \bullet F_{IND-COM}\right) - N_{SLUDGE}$$

(IPCC 2006 equation 6.8)

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)

$F_{NON-CON}$ = factor for non-consumed protein added to the wastewater (default value of 1.1) (IPCC, 2006)

$F_{IND-COM}$ = factor for industrial and commercial co-discharged protein into the sewer system, (default value of 1.25) (IPCC, 2006)

N_{SLUDGE} = nitrogen removed with sludge, kg N/yr (default value of 0) (IPCC, 2006)

Table 80: N_20 emission factor used for estimating emissions from domestic wastewater category

Gas	Emission factor (kg N_2O-N/kg N)
N_2O	0.005

Source: IPCC 2006 (Volume 5, Chapter 6)

Assumptions

1. **Fraction of Population in income group i (Ui)**
Population data from Annual Vital Statistics 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, the two categories considered in the state emission estimation are solely based on urban/rural population.

2. **BOD**
Year-wise values of BOD generated per person are not available for the state, hence an average national value for BOD of 40.5 gm/person/day is 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.

3. **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. 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[34].
4. **Per Capita Protein Consumption**
Updated year-wise values of per capita protein consumption are not available for urban and rural populations. 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 2021 respectively. While converting protein consumption values from daily basis to an annual basis, 365 days have been assumed across all years, including for leap years(Kolsepatil et al., 2019)[35].

[34] 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

[35] Ibid.

5. **Degree of Utilization of treatment/discharge pathway or system j, for each income group fraction i (Ti,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. Each of treatment/discharge pathways or systems will have different CH_4 emission factors (based on IPCC defined MCF values as listed in table 77; thereby having a varying contribution to the GHG emissions. 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 degree of utilization values considered for urban and rural domestic wastewater in this assessment, based on NSS Socio economic surveys are listed in table 81.

Table 81 : Urban and rural degree of utilization

Population Group	Treatment type/discharge type	Share of population using treatment/ Discharge pathway or system (2008-09)	Share of population using treatment/ Discharge pathway or system (2018)
Urban	Septic tank	51.213%	29.80%
	Pit latrine	45.90%	68.80%
	Sewer	0.687%	0.40%
	Others/None	2.30%	1.00%
Rural	Septic tank	21.9%	15.30%
	Pit latrine	76.48%	83.50%
	Sewer	0.0%	0.0%
	Others/None	1.60%	1.20%

- The treatment/discharge type across urban and rural population groups were obtained from the NSS Socio Economic Survey 2008-09 and 2018.
- The corresponding degree of utilization estimated for the urban and rural population based on the 2008-09 survey is assumed to be applicable for the period 2005-2014, and the survey results of 2018 was applied for the period 2015-2021, based on expert inputs.
- The change in latrine type-wise shares between 2005 and 2015 was applied incrementally by using CAGR.

- The categories mentioned in NSS Socio Economic Survey-Housing Condition and Amenities in Kerala 2008-09 *(Table 10 -Appendix A)* are service latrine, pit latrine, septic tank/flush, not known, others,n.r. They have been reconciled with NSS 2018 categories (see table 82) based on inputs from sector experts from Suchitwa Mission and Directorate of Environment and Climate Change (DoECC), Kerala.

Table 82:Latrine System Categories

Categorisation followed in GHG inventory	NSS 2018 categories
Piped sewer system	Flush/pour-flush to piped sewer system
Septic tank	Flush/pour-flush to septic tank
Other system	Flush/pour-flush to twin leach pit/single pit Flush/pour-flush to elsewhere
Pit latrine	Ventilated improved pit latrine
	Pit latrine with slab
	Pit latrine without slab/open pit
	Flush/pour-flush to single pit
	Composting latrine (0 for both urban and rural)
	Others
	Not used (0 for both urban and rural)

Rural degree of utilization

1. The percentage of piped sewer system in rural for 2008-09 and 2018 is considered zero based on expert opinion from Kerala Water Authority. The percentage of piped sewer system (rural) which is considered as zero is incorporated into 'others' and 'none' categories.
2. In order to get the percentage of septic tank for 2008-09 the corresponding proportions from NSS 2018 has been applied to septic tank/flush % of NSS 2008-09 data.
3. Others and none category constitute**:**

   In NSS 2008-09: service latrine, others, not known

   In NSS 2018: Others, Flush/pour-flush to twin leach pit/single pit, Flush/pour-flush to elsewhere, piped sewer system (only for rural).

Urban degree of utilization

1. In order to get the percentage of piped sewer system and septic tank for 2008-09 the corresponding proportions from NSS 2018 has been applied to septic tank/flush % of NSS 2008-09 data.
2. Others and none category constitute**:**

   In NSS 2008-09: service latrine, others, not known

   In NSS 2018: Others, Flush/pour-flush to twin leach pit/single pit, Flush/pour-flush to elsewhere, piped sewer system (only for rural).

6. 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 the 'piped sewer system' category, it is necessary to further assess the proportion of wastewater discharged by this subset undergoing aerobic/anaerobic treatment or whether 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 78). Therefore, reported data on operational and non operational capacity of sewage treatment, the treatment technologies used in STPs has been analyzed for the state and subsequently the fractions for degree of utilization for 'sewer systems' have been further split up into three pathways

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

State information related to STPs is not available for all the years from 2005-2021. Therefore, reported state information on STPs that is available for the four years from CPCB and Central Public Health and Environmental Engineering Organization (CPHEEO) of 1999, 2008, 2014 and 2020 has been used in the assessment. All the sewage treatment plants in Kerala are aerobic and well managed and hence, the 'sewer collected and not treated' percentage will be zero (expert opinion from Kerala Water Authority).

- 1999 STP data is used to find GHG emissions from Sewer until 2007
- 2008 STP data is used to find GHG emissions from Sewer until 2010
- 2014 STP data is used to find GHG emissions from Sewer from 2011 to 2015
- 2020 STP data is used to find GHG emissions from sewers from 2016 to 2021

The degree of utilization for the three sewer pathways – sewer (collected and not treated), sewer (collected and anaerobic treatment), and sewer (collected and aerobic treatment) considered in the emission estimates is as follows:

Table 83: **Degree of Utilization for 'Sewer' to account for Untreated Wastewater and Type of Treatment (Aerobic/Anaerobic)**

	1999	2008-09	2014-15	2020
Treatment type, Aerobic (%)	100%	100%	100%	100%
Treatment type, Anaerobic (%)	0.00%	0.00%	0.00%	0.00%
Sewer collected and not treated* (%)	0.00%	0.00%	0.0%	0.0%

4D2: Industrial Wastewater Treatment and Discharge

Category Description

CH_4 is emitted from industrial wastewater when it is treated or disposed of anaerobically. Wastewater from industrial sources may be treated on-site, transferred through a sewer to a centralized treatment plant or disposed off untreated in nearby areas or via an outfall[36].

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. Nine industry sectors have been included for estimating CH_4 from industrial wastewater based on a list of products identified in India's National Communications/ 2006 IPCC guidelines for National GHG inventories.[37] The product categories for the 9 industry sectors included in the estimates are listed in the table below.

[36] 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories , Volume 5, Waste, Chapter 6

[37] This list was further refined based on GHGPI phase 4 methodology for the waste sector as well as inputs from the line departments concerned in Kerala.

Table 84 : Industrial Sectors and products considered[38]

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
Paper and Pulp	Production of paper from all pulp and paper industries
Petroleum	Refining and production of Petroleum, Oil and Lubricants
Rubber	Production of Finished Natural and Synthetic Rubber
Dairy	Production of milk in the Dairy Sector
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

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[39].

Methodology

The table 85 below details the sources of activity data used for estimating emissions from the Industrial Wastewater category.The production data (2019, 2020, 2021) used in estimating emissions from the industrial wastewater category are listed in table 86.

[38] 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

[39] 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

Table 85: Source of activity data[40] used for estimating emissions from Industrial Wastewater category

Category	Source of production data	Effluent generation data
Fertilizer	The Fertilisers and Chemicals Travancore Limited Annual Reports 2005-06 to 2014-15, 2015-16, 2016-17, 2017-18, 2018-19, 2019-20, 2020-21, 2021-22, Kolsepatil et al. (2019) author's analysis for 2004-05	Dossier for sewage/trade effluent generation/coastal discharge/STP/ETP details in the State of Kerala, KSPCB (As of 2020) Annexure 2:Consented effluent generating and sewage & sullage generating units with their quantity.
Petroleum	Petroleum Planning & Analysis Cell (PPAC), Ministry of Petroleum & Natural Gas (2004-05 to 2008-09), Bharat Petroleum Kochi Refinery Performance, (2009-10 to 2021-22)	
Dairy	KSPCB	
Meat	KSPCB	
Fish processing	KSPCB	
Paper and pulp	KSPCB	
Tannery	KSPCB	
Rubber	GHGPI Phase III	NATCOM 2

[40] Activity data provided in financial year (FY) format was converted to calendar year (CY) format using the following equations:

$$\text{CY Activity data} = [\tfrac{1}{4} * \text{FY Activity Data}_{\text{Preceding year}}] + [\tfrac{3}{4} * \text{FY Activity Data}_{\text{Succeeding year}}]$$

Table 86 : Activity data used in Industrial Wastewater category in 2019, 2020 and 2021.

Category	Industry Production (Mt)		
	2019	2020	2021
Fertilizer	0.36	0.39	0.37
Petroleum	15.45	13.34	13.92
Dairy	3.25	3.25	3.25
Meat	0.023	0.023	0.023
Fish processing	0.33	0.33	0.33
Paper and pulp	0.21	0.21	0.21
Tannery	0.005	0.005	0.005

Table 87: Type of Emission Factor and Level of Methodological Tiers adopted for Industrial Wastewater category

IPCC ID	GHG source and sink categories	CH_4	
		Method Applied	Emission Factor
4A	Industrial wastewater Treatment and Discharge	T2	CS
T1: Tier 1; T2: Tier 2; CS: Country-specific; D: IPCC Default			

Equation Used

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

$$CH_4\,Emissions = \sum_i \left[\left(TOW_i - S_i \right) EF_i - R_i \right] \quad \textit{(IPCC 2006 Equation 6.4)}$$

Where

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)

EF_i= emission factor for industry i,kg CH4/kg COD for treatment/discharge pathway or system(s) used in inventory year

R_i = amount of CH_4 recovered in inventory year, kg CH4/yr (0)(IPCC 2006)

$$TOW_i = P_i \cdot W_i \cdot COD_i$$ *(IPCC 2006 Equation 6.6)*

Where:

TOW_i = 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

Wastewater generated per tonne of product (W_i) from effluent generation data provided by KSPCB

1) Wastewater generated per tonne of product Wi (m^3/tonne product)

   = [(Effluent generated per day/ 1000) / (Industrial production per day)]

2) Effluent generated per day (litres/day)

   = Effluent generated given in million litres per day (MLD) * 10^6

3) Industrial production per day (tonnes/day)= Total industrial production for the year 2020 / 365

$$EF_j = B_o \cdot MCF_j$$ *(IPCC 2006 Equation 6.5)*

Where

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

Bo = maximum CH_4 producing capacity, kg CH_4/kg COD (0.2594) (MoEFCC 2023)

MCF_j = methane correction factor (fraction)

The value of the MCF is based on the prevalent wastewater treatment system used in the respective industrial sector. The data sources to identify the prevalent wastewater treatment technologies for the industrial sectors are indicated in Table 88 . State-level information for the emission factor related parameters is not available. Therefore, the national level values listed for each industry sector are used in the emission estimation for the state.

Table 88: COD and MCF used for estimating emissions from Industrial Wastewater category

Industry	Category	Factor	Source
Petroleum	CODi	1 Kg COD/m^3	BUR 3
	MCF	0.3	BUR 3

Industry	Category	Factor	Source
Dairy	CODi	2.24 Kg COD/m^3	BUR 3
	MCF	0.5	BUR 3
Rubber	CODi	6.12 Kg COD/m^3	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.
	MCF	0	GHGPI Phase III, ICLEI analysis of ●Central Pollution Control Board (CPCB), Pollution Control Implementation Division – III report on 'Pollution Control in Natural Rubber Processing Industry'. ● Woodard, F. (2001) Woodard, F. (2001). Industrial waste treatment handbook.
Tannery	CODi	5.9 Kg COD/m^3	BUR 3
	MCF	0.8	BUR 3
Meat	CODi	5 Kg COD/m^3	BUR 2
	MCF	0.8	IPCC 2006
Pulp and paper	CODi	5.9 Kg COD/m^3	BUR 3
	MCF	0.8	BUR 3
Fish processing	CODi	2.5 Kg COD/m^3	BUR 3

Industry	Category	Factor	Source
	MCF	0.3	BUR 3
Fertilizers	CODi	3 Kg COD/m^3	BUR 3
	MCF	0.3	BUR 3
Iron and steel	CODi	0.55	NEERI (2010): Status of Methane Emissions from Wastewater and Role of Clean 152 Kerala GHG Inventory Report Development Mechanisms in India. Published in the TERI Information Digest on Energy and Environment, [S.l.], p. 155-166, June. 2010. ISSN 0972- 6721.
	MCF	0	GHGPI Phase III, ICLEI analysis of Sirajuddin, Ahmed, Umesh Chandra, R. K. Rathi, (2010) "Wastewater 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.

Methane Recovery Rates

CH_4 is recovered in some of the industries such as 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 from NATCOM 2 have been used for the state[41].

Dairy: 75% methane recovery rate

[41] 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

Assumptions

- As per expert opinion from KPSCB, the installed capacity itself was taken as the average production quantity where average production data was not available.
- Except for petroleum and fertilizer, active years of production for the industrial units were not available. Hence the average production and effluent generated data provided by KSPCB was applied for the entire evaluation period (2005-2021).
- Wastewater generation per tonne of product would likely vary over the years, with improvements in production processes and technologies leading to a reduction in wastewater generation. However, due to the lack of such updated information, the constant values of wastewater generated per tonne of product have been used for all the years (2005-2021) in this assessment for the industry sectors. Wastewater generated per tonne of product (see table 89) is calculated using the 2020 production data in order to have the data almost in-sync with the effluent generated data in the most recent dossier released by Kerala State Pollution Control Board[42].
- State data on production of Petroleum is not available for 2004-05 to 2008-09. Reported data on the 'volume of crude oil processed' is available for different refineries along with their location for the period 2004-05 to 2008-09. National level data available on cumulative production of Petroleum products for 2004-05 to 2008-09 has been apportioned to the state based on the corresponding proportion of 'volume of crude oil processed' by each refinery to the 'total volume of Crude Oil processed' by all refineries[43].

Table 89: Wastewater generated per tonne of product

Category	Wastewater generated (m^3) per tonne of product
Fertilizer	18.7
Petroleum	0.72
Dairy	0.29
Meat	0.028
Fish processing	1.68
Paper and pulp	4.09
Tannery	2.52

[42] Dossier for sewage/trade effluent generation/coastal discharge/STP/ETP details in the state of Kerala, KSPCB (As on 2020), Annexure 2:Consented effluent generating and sewage & sullage generating units with its quantity

[43] 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

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