

TOWARDS LOW-CARBON SANITATION:

Emission Profiles and Mitigation Strategies for Khulna City

1. Introduction

Global greenhouse gas (GHG) emissions are continuing to increase global heating at alarming rates. Current policies and action globally to reduce GHG emissions are putting the world on track for about 2.7°C mean temperature increase by the year 2100 (Climate Action Tracker, 2023). 1.5°C heating is widely considered the threshold at which extreme and irreversible effects of climate change will take place and each fraction of a degree of heating beyond 1.5°C incurs significant additional planetary risks (IPCC, 2018). Extreme reductions in GHG emissions are required worldwide to prevent worsening effects of climate change. In particular, limiting global heating requires worldwide net zero GHG emissions as soon as possible (IPCC, 2023). Many industries that have been identified as major GHG emitters, such as energy production, transportation, manufacturing, construction, and agriculture, have an abundance of research and practical guidance on assessing their level of emissions and acting to mitigate emissions. While the sanitation sector is likely to be a relatively smaller emitter of GHGs compared to these industries, there is still reason to believe its GHG contributions are significant (Schütze et al., 2019; Cheng et al., 2022). Yet, little research evidence exists that quantifies the amount of GHG emissions from sanitation systems, particularly from decentralized and onsite sanitation systems in low- and middle-income countries (LMICs), and sanitation implementers and planners have scarce resources available to them to inform decision-making on how to mitigate GHG emissions. So, research on quantification of GHG emissions from sanitation systems is important to take appropriate initiatives for reduction of emissions.

In support of the “Transitioning to sustainable urban water cycles in Bangladesh (SUWC)” project funded by the Embassy of the Kingdom of the Netherlands, the University of Technology Sydney, Institute for Sustainable Futures (UTS-ISF) and SNV carried out the climate mitigation study to make recommendations for how all the key actors can contribute to reducing GHG emissions from sanitation systems in Khulna City Corporation (KCC) while still improving public health outcomes.

2. Study Objectives

Through this study, UTS-ISF and SNV identify which parts of the sanitation service chain in KCC is likely to be driving the highest proportion of sanitation GHG emissions, make an estimate of the amount of emissions coming from these parts, and create actionable recommendations towards reducing emissions.

3. Methodology

This study made theoretical estimates of GHG emissions from parts of the sanitation service chain that are most likely to contribute the largest proportion of emissions in the context of KCC. The methodology developed by Johnson et al. (2022) to estimate the GHG emissions was followed to estimate the GHG emissions from the sanitation service chain of KCC. The advantage of this methodology is that it allows us to estimate the entire emissions profile (direct and indirect) of the sanitation system in the city (Johnson et al., 2022, p2). The methodology also improves upon the IPCC methodology because it accounts for greater potential variation between the conditions of on-site sanitation facilities. Also, although with some adaptations, this framework is based on the IPCC methodology, so its emission estimates are globally comparable.

In addition, this methodology permits a disaggregation of GHG emissions by sources (direct, operational, embedded carbon), types (CH₄, CO₂, N₂O) and stages (containment, transport, treatment).

As shown in Table 1, in the storage/containment stage, latrines and septic tanks generate direct emissions such as CH₄ and NO₂ and have embedded carbon incorporated in their construction process. Secondly, in the on-site sanitation system, the emptying/transport stage does not generate direct emissions but operational emissions because it requires trucks to transport the fecal sludge to the treatment facilities, generating more CO₂ in the process. Finally, treatment facilities processing fecal sludge and wastewater from on-site sanitation systems generate direct emissions (CH₄, NO₂) and CO₂ from their energy use. Moreover, they have an important embedded carbon given the amount of construction materials that those facilities require.

Table 1. Potential Sources of GHG Emissions from KCC Sanitation System

| Stages of value chain | Source | Emissions |
|---------------------------|-----------------|---|
| Containment | Direct | CH ₄ , N ₂ O from pits and septic tanks |
| | Embedded carbon | Materials in pits and septic tanks construction |
| Emptying/transport | Operational | CO ₂ trucking |
| Treatment Facilities (TF) | Direct | CH ₄ and N ₂ O from TF |
| | Operational | CO ₂ energy use |
| | Embedded carbon | Materials in TF construction |

The equations used to estimate the GHG emissions from each stage are detailed in the following:

3.1 Containment/Storage stage

The calculation of GHG emissions from the containment/storage stage comprises two main steps. Firstly, the estimation of direct emissions (CH₄, N₂O) for each sanitation technology used in the city (un-lined pits, lined pits, composting latrines, septic tanks, flush toilets, etc). Equations 1 and 2 were used the formulas to calculate the CH₄ and N₂O respectively.

$$CH_4 = \sum P \times COD \times PR_{COD} \times B_o \times MCF \dots \dots \dots (1)$$

$$N_2O = \sum P \times N_i \times EF \times CF \dots \dots \dots (2)$$

Where CH₄ is the total methane emissions from each sanitation technology (kgCH₄/year), N₂O is the total N₂O emissions (kg N₂O/year), P is population using the sanitation technology, COD is chemical oxygen demand from the excreta of each person (25.915 kg COD/cap/year considered), PR_{cod} is percentage reduction of COD (0.7 considered), B_o is maximum methane-producing capacity (0.25 kgCH₄/kg COD considered), MCF is the methane correction factor for each containment technology as mentioned in Table 2:

Table 2: MCF (Methane Correction Factor) for Containment Technologies

| Containment Technology | MCF |
|------------------------------------|------|
| Septic Tanks | 0.35 |
| Flush toilet connected to pit | 0.6 |
| Open Defecation - Close drains | 0.3 |
| Open Defecation - Open drains | 0.2 |
| Open Defecation - open environment | 0.1 |

N_i is nitrogen influent from urine and faces (4.672 kg N/cap/year considered), CF is the conversion factor for N₂O-N into kg N₂O (1.571 considered) and EF is the emission factor for each sanitation facility (kg N₂O-N/kg N) as mentioned in Table 3:

Table 3: Emission Factor for Sanitation Facilities

| Containment Technology | EF |
|--------------------------------|-------|
| Septic Tanks | 0.005 |
| Flush toilet connected to pit | 0.009 |
| Open Defecation - Close drains | 0.009 |
| Open Defecation - Open drains | 0.008 |

Secondly, the embedded carbon incorporated in the construction process of latrines and septic tanks was estimated as equation 3 describes:

$$ECcs = \sum TF \times M \times EF \dots \dots \dots (3)$$

Where ECcs is the embedded carbon in each sanitation technology (latrines and septic tanks), TF is the total amount of facilities for each sanitation technology, M is the Mass of material in Kg used in each sanitation technology and EF is the emission factor for each material as mentioned in Table 4:

Table 4: Emission Factor for Materials

| Material | EF |
|----------|-------|
| Bricks | 0.108 |
| Concrete | 0.2 |
| Mortar | 0.06 |

This methodology only considers Bricks, Concrete, and Mortar as the material for latrines and septic tanks.

3.2 Empty/transport stage

This stage comprises the estimation of CO₂ emissions generated by the transport of fecal sludge to the treatment plant and equation 4 was used for the estimation purposes:

$$CO_{2,T} = \sum NT \times DT \times EF_v \dots \dots \dots (4)$$

Where $CO_{2,T}$ is the total CO₂ emissions from the transport of fecal sludge (kgCO₂/year), NT is the number of trips that trucks make per year, DT is the average distance travelled per trip (vehicle/km), EF_v is the emission factor (Table 5) for each size of vehicle (kgCO₂/vkm).

Table 5: Emission Factor for Materials

| Material | EF _v |
|----------------------|-----------------|
| 2-3.9 m ₃ | 0.6 |
| 4-5.9m ₃ | 0.8 |
| 6-7.9m ₃ | 0.8 |

3.3 Treatment facilities (TF)

This stage involves three main steps. First, the calculation of the direct emissions from each process within the treatment plant because each one has a different capacity to generate GHG emissions. The treatment processes considered in this methodology were drying beds, and polishing pond (considering the FSTP of KCC). Equations 5 and 6 describe the estimation of CH₄ and NO₂ emissions respectively.

$$CH_4 = \sum [P \times B_o \times MCF \times (TOW) \times (1 - (L + S + R)) \dots \dots \dots (5)$$

Where CH_4 is the total methane emissions from each process in the treatment plant (kgCH₄/year), P is the effective population (the population equivalent of excreta from direct inflow to the process plus effluent from previous process), TOW is total organics in wastewater per year (25.915 kg COD/cap/year considered), B_o is maximum methane-producing capacity (0.25 kgCH₄/kg COD considered), MCF is the methane correction factor for each containment technology (0.25 for Drying Bed and 0.5 for Polishing Pond considered), L is the proportion of organic component removed as effluent (0.2 considered), S is the proportion of organic component removed as sludge (0 considered), R is the proportion of methane recovered through capture processes (0 considered as no methane recovery).

$$N_2O = \sum P \times EF \times TOW \dots \dots \dots (6)$$

Where N_2O is the total N₂O emissions from each process in the treatment plant (kg N₂O/year), EF is the emission factor for each process (0.005 kg N₂O-N/kg N considered for Drying Bed and 0.008 kg N₂O-N/kg N considered for Polishing Pond), and TOW total organics in wastewater per year (4.672 kg N/cap/year considered).

Secondly, the estimation of CO₂ emissions from the energy consumed in the treatment plants is based on equation 7.

$$CO_{2,i} = \sum Ci \times EFi \dots \dots \dots (7)$$

Where $CO_{2,i}$ is the CO₂ emissions associated with electricity or diesel usage (kgCO₂/year), Ci is the electricity or diesel consumption (electricity used in SUWC cities/municipalities) and EFi is the emission factor for electricity or diesel (0.91 tCO₂e/MWh/year considered).

Thirdly, the embedded carbon incorporated in the construction process of the treatment plants was estimated using the equation 3 and factors in Table 4.

Finally, the estimated CH₄ and N₂O emissions converted to CO₂eq using the Global Warming Potential (GWP) factors i.e. 34 for CH₄ and 298 for N₂O.

4. Findings

Table 6 reveals that most emissions originate from containment systems in KCC. Within this stage, direct methane (CH₄) emissions are the most dominant, accounting for 44,119,163 kgCO₂/year, which is 76.78% of total GHG emissions. Nitrous oxide (N₂O) emissions from containments contribute a further 9,689,357 kgCO₂/year (16.86% of total GHG emissions), while embedded carbon adds 1,676,184 kgCO₂/year (2.92%). Altogether, containments are responsible for 55,484,704 kgCO₂/year, representing 96.57% of overall emissions.

Emissions from transport are negligible, with only 4,594 kgCO₂/year (0.01% of total GHG emissions) coming from operational activities. Treatment facilities, on the other hand, contribute a more significant share. Direct CH₄ emissions at this stage amount to 1,709,868 kgCO₂/year (2.98%), while N₂O emissions account for 237,758 kgCO₂/year (0.41%). Operational activities contribute 8,692 kgCO₂/year (0.02%), and embedded carbon adds 12,475 kgCO₂/year (0.02%). Altogether in the treatment facilities stage, it forms a subtotal of 1,968,793 kgCO₂/year (3.43%).

Table 6: GHG Emissions Along the Sanitation Service Chain in Khulna City

| Stages of the Sanitation service chain | Equivalent CO ₂ (kgCO ₂ /year) | % of Total emissions |
|---|--|----------------------|
| A. GHG Emissions from containments | | |
| i. Direct emissions (CH ₄) | 44,119,163 | 76.78 |
| i. Direct emissions (N ₂ O) | 9,689,357 | 16.86 |
| iii. Embedded carbon | 1,676,184 | 2.92 |
| Sub Total | 55,484,704 | 96.57 |
| B. GHG Emissions from transport | | |
| ii. Operational | 4,594 | 0.01 |
| Sub Total | 4,594 | 0.01 |
| C. GHG Emissions from Treatment facilities | | |
| i. Direct emissions (CH ₄) | 1,709,868 | 2.98 |
| i. Direct emissions (N ₂ O) | 237,758 | 0.41 |
| ii. Operational | 8,692 | 0.02 |
| iii. Embedded carbon | 12,475 | 0.02 |
| Sub Total | 1,968,793 | 3.43 |
| Total emissions | 57,458,091 | 100 |
| Per Capita (kgCO ₂ /year) | 79.9 | |

In total, the sanitation service chain in KCC generates 57,458,091 kgCO₂/year of greenhouse gas emissions. The data clearly highlights that containments are the primary source, while treatment facilities contribute a smaller share, and transport-related emissions are almost negligible.

5. Recommendations

Based on the above discussion, five implementation actions are recommended. These recommendations are made with consideration of the available evidence base on GHG emissions from sanitation systems, where GHG emissions may be most significantly reduced, and practicality of implementation in the context of KCC :

- Regular emptying (more frequently than once every five years) may reduce emissions from containment units and have positive public health benefits.
- Conversion of pit toilets to septic tanks may reduce emissions and reduce the likelihood of groundwater contamination. Plastic septic tanks may be an alternative to pit.
- Methane capture at decentralized containment/treatment facilities should be explored where it is feasible to implement a management model for operating and maintaining methane capture systems.
- Maintain the use of aerobic treatment methods at fecal sludge treatment plants which minimize methane emissions.
- Consider co-composting of dried sludge with added biochar to further treat fecal sludge and reduce its emissions.

6. References

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