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GREENHOUSE GASES EMISSION FROM SANITATION SERVICE CHAIN OF KHULNA CITY CORPORATION: ESTIMATION AND WAY FORWARD FOR REDUCTION

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ABSTRACT

Reduction of GHG emissions from sanitation system is one of the ways to combat global climate change. The amount of GHG emissions from the sanitation service chain of Khulna City Corporation (KCC) is estimated to identify the main sources and recommend measures for reducing the emissions. The estimated GHG emissions from the sanitation service chain of KCC is 57,458,091 kgCO_2e/year where containments (pits and septic tanks) emit about 96.57%, then from fecal sludge treatment plant 3.43% and an insignificant quantity (0.01%) emission from the transportation of fecal sludge. Containments along with the treatment facilities are needed to focus on GHG emission reduction in KCC. Regular emptying (at least once every five years), conversion of pit toilets to septic tanks, and methane capture at containments may reduce the GHG emission at the containment stage. Maintain the use of aerobic treatment methods at fecal sludge treatment plants and consider co-composting of dried sludge with added biochar will reduce the emissions at treatment stage.

Keywords: *Greenhouse Gas, Sanitation Service Chain, Embedded Carbon*

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 2.7ºC mean temperature increase by the year 2100 (Climate Action Tracker, 2023). 1.5ºC 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 1.5ºC incurs significant additional planetary risks (IPCC, 2018). Global heating could reach 1.5ºC as soon as 2030 (IPCC, 2023).

Extreme reductions in GHG emissions are required worldwide to prevent worsening effects of climate change. Particularly, 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, aviation, transportation, manufacturing and 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. The study was conducted under the Sustainable Urban Water Cycles (SUWC) project of SNV Netherlands Development Organisation (with financial support of Embassy of the Kingdom of the Netherlands) through the Institute for Sustainable Future (ISF) of the University of Technology Sydney.

OBJECTIVE OF THE STUDY

The objective of the study is to estimate the amount of GHG emissions from the sanitation service chain in Khulna City Corporation (KCC) based on secondary data, determine the main sources and explore the ways of GHG emissions reduction from the sanitation system of KCC and Bangladesh as well.

METHODOLOGY

Two methods are available to estimate GHG emissions: direct measurements from sanitation facilities (laboratory-based analyses of effluent and waste samples) and theoretical estimations of emission rates based on available evidence. The theoretical estimations methodology developed by Johnson et al. (2022) was followed for this study. 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, both from on-site and off-site services, along the entire sanitation service chain (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 (CO_2, N_2O) and stages (containment, transport, treatment). For instance, the GHG emissions in each stage of the sanitation value chain can be generated by three main sources: the direct emissions (from fecal sludge and wastewater), the operational emissions (related to activities to transport and process the organic residuals), and the embedded carbon within the sanitation infrastructure. Emissions associated with disposal and re-use of treated fecal sludge and wastewater will be scoped out of the modelling because there are no standard practices for disposal/re-use.

As shown in Table 1, in the storage/containment stage, latrines and septic tanks generate direct emissions such as CH_4 and NO_2 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 CO_2 in the process. Finally, treatment facilities processing fecal sludge and wastewater from both on-site and off-site sanitation systems generate direct emissions (CH_4, NO_2) and CO_2 from their energy use. Moreover, they have an important embedded carbon given the amount of construction materials that those facilities require.

Table 1 Sources of GHG Emissions from Sanitation Systems of KCC

Stages of value chain	Source	GHG Emissions
Containment	Direct	CH_4, N_2O from pits and septic tanks
	Operational	n/a
	Embedded carbon	Materials in pits and septic tanks construction
Emptying/ transport	Direct	n/a
	Operational	CO_2 trucking
	Embedded carbon	n/a
Treatment Facilities/ Plants (TF)	Direct	CH_4 and N_2O from TF
	Operational	CO_2 energy use
	Embedded carbon	Materials in TF construction

KCC has on-site sanitation system and following equations were used to calculate the GHG emissions from Containment/Storage Stage, Empty/Transport Stage and Treatment Facilities (TF) stage.

Containment/Storage Stage

The calculation of GHG emissions from the containment/storage stage comprises two main steps. Firstly, the estimation of direct emissions (CH_4, N_2O) for each sanitation technology used in the city (un-lined pits, lined pits, composting latrines, septic tanks, flush toilets, etc in KCC). Equations 1 and 2 describe the formulas to calculate the CH_4 and N_2O respectively.

$$CH_4 = \sum P \times COD \times PR_{COD} \times B_0 \times MCF \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$N_2O = \sum P \times N_I \times EF \times CF \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where CH_4 is the total methane emissions from each sanitation technology (kgCH_4/year), N_2O is the total N_2O emissions (kg N_2O/year), P is population using the sanitation technology, COD is chemical oxygen demand from the excreta of each person (kg COD/cap/year), PR_{COD} is percentage reduction of chemical oxygen demand, B_0 is maximum methane-producing capacity kgCH_4/kg COD, MCF is the methane correction factor for each containment technology, N_I is nitrogen influent from urine and faeces (kg N/cap/year), EF is the emission factor for each sanitation facility (kg N_2O-N/kg N), and CF is the conversion factor for N_2O-N into kgN_2O. Following parameters used in this study (Table 2):

Table 2 Parameters Used for GHG Estimation at Containment Stage

Parameters	**Values**
COD	0.071 kg COD/capita/day
PR_{COD}	70%
B_0	0.25 kg CH_4/kg COD
N_I	4.672 kg N/capita/year
CF	1.571428571
P (Septic Tanks)	498,601
P (Pit connected to flush toilet)	162,652
P (No containment)	57,482
Total Population in KCC	718,735

The used MCF and EF are mentioned in Table 3:

Table 3 Methane Correction Factor (MCF) and Emission Factors (EF) by Containment Type

Containment type	**CH4 Correction Factor**	**N2O Emission Factor**
Septic Tanks	0.35	0.005
Pit connected to flush toilet	0.6	0.009
No Containment (open/closed drains, open defecation)	0.3 - 0.1	0.008- 0.009

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

$$EC_{CS} = \sum TF \times M \times EF \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where EC_{CS} is the embedded carbon in each sanitation technology (pit latrines and septic tanks), TF is the total amount of facilities for each sanitation technology, M is the Mass of material in Kg usedin each sanitation technology and EF is the emission factor for each material. Notably, there are 38,900 septic tanks and 28,512 pits latrines in the KCC. This methodology only considers Bricks, Concrete, and Mortar as the material for latrines and septic tanks. The used emission factors for embedded carbon emission calculation as follows (Table 4):

Table 4 Emission Factors for Embedded Carbon Emissions

Emission Factors	**Values (kgCO_2/kg)**
Bricks	0.108
Concrete	0.2
Mortar	0.06

Finally, the total GHG emissions in containment stage are calculated as the sum of each step, converting CH_4 and N_2O to carbon equivalents.

Empty/Transport Stage

In KCC vacutugs are used to collect and transport the fecal sludges. The equation 4 used to estimate the CO_2 emissions generated by the transport of fecal sludge to the treatment plant.

$$CO_{2,T} = \sum N_T \times DT \times EF_V \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where $CO_{2,T}$ is the total CO_2 emissions from the transport of fecal sludge ($kgCO_2$/year), N_T is the number of trips that trucks make per year (Table 4), DT is the average distance (10 km considered for this study) travelled per trip (vehicle/km), EF_V is the emission factor for each size of vehicle ($kgCO_2$/vkm). Total 746 trips generated in KCC for sludge transport in 2023 (Table 4) which used to estimate GHG emissions in this stage.

Table 4 Fecal Sludge Transport in KCC by Vacuum Truck Size in 2023 and Emission Factors

Size of Vacuum Truck	No. of trips made per year (N_T)	Emission Factor (EF_V)
2-3.9 m^3	687	0.6
4-5.9m^3	21	0.8
6-7.9m^3	38	0.8

Treatment Facilities/Plants (TF) Stage

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 are anaerobic ponds, facultative ponds, drying beds, thickening tanks, fecal sludge storage and trickling filters. Equations 5 and 6 describe the estimation of CH_4 and NO_2 emissions respectively.

$$CH_4 = \sum P \times B_0 \times MCF \times TOW \times (1 - (L+S+R)) \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where CH_4 is the total methane emissions from each process in the treatment plant ($kgCH_4$/year), P is the effective population (the population equivalent of excreta from direct inflowto the process plus effluent from previous process; 25,874 calculated for KCC), TOW is total organics in wastewater per year (kgCOD/year), B_0 is maximum methane-producing capacity $kgCH_4$/kgCOD, MCF is the methane correction factor for each containment technology, L is the proportion of organic component removed as effluent, S is the proportion of organic component removed as sludge, R is the proportion of methane recovered through capture processes.

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

Where N_2O is the total N_2O emissions from each process in the treatment plant (kgN_2O/year), EF is the emission factor for each process (kg N_2O-N/kg N), and TOW total organics in wastewater per year (kg COD/year). The emission factors used in equation 5 & 6 are as follows (Table 5):

Table 5 Emission Factors by Treatment Plant Processes

Treatment plant processes	**CH_4 Correction Factor (MCF)**	**Emission Factor N_2O**
Unplanted drying beds	0.06	0.005
Polished ponds	0.13	0.008

Secondly, the estimation of CO_2 emissions from the energy consumed in the treatment plants is based on equation 7.

$$CO_{2,i} = \sum C_i \times EF_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where $CO_{2,i}$ is the CO_2 emissions associated with electricity ($kgCO_2$/year), C_i is the electricity consumption and EF_i is the emission factor for electricity (910 kg CO2e/MWH considered for this study). The Khulna treatment plant needs 9.552 MWH per year to function properly.

Thirdly, the embedded carbon incorporated in the construction process of the treatment plants is estimated as equation 8 describes:

$$EC_{CS,i} = \sum TM \times M \times EF \text{ ……………………… } (8)$$

Where EC_{CS} is the embedded carbon in treatment plants, TM is the total amount of main materials, *M* is the mass of each material in kg and *EF* is the emission factor for each material. This methodology only considers concrete as the main material for treatment plants.

Finally, converting the CH_4 and N_2O to carbon equivalents, the total GHG emissions in each stage are calculated as the sum of each step (Table 6).

FINDINGS AND DISCUSSION

The estimated GHG emissions are 57,458,091 kgCO_2e/year from sanitation service chain of KCC. The study reveals that containments are the main source (about 96.57%) of GHG emission, then from fecal sludge treatment plant (3.43%) and insignificant quantity (0.01%) emission from transportation of fecal sludge (Table 6). Containments along with the treatment facilities are needed to focus for GHG emission reduction in KCC.

Table 6 GHG Emissions from the Sanitation Service Chain of KCC

Stages of the Sanitation service chain		**Total GHG Emissions (kgCO_2e/year)**	**Total GHG Emissions per capita (kgCO_2e/year)**	**% Total emissions**
A.	**GHG Emissions from containments**			
i.	Direct emissions (CH_4)	44,119,163	61.38	76.78
ii.	Direct emissions (N_2O)	9,689,357	13.48	16.86
ii.	Embedded carbon	1,676,184	2.53	2.92
	Sub-Total	**55,484,704**	**77.4**	**96.57**
B.	**GHG Emissions from transport**			
i.	Operational	4,594	0.03	0.01
	Sub-Total	**4,594**	**0.03**	**0.01**
C.	**GHG Emissions from Treatment Facilities**			
i.	Direct emissions (CH_4)	1,709,868	26.43	2.98
ii.	Direct emissions (N_2O)	237,758	3.68	0.41
ii.	Operational	8,692	0.13	0.02
v.	Embedded carbon	12,475	0.19	0.02
	Sub-Total	**1,968,793**	**30.4**	**3.43**
	Total emissions	**57,458,091**	**79.9**	**100.00**

RECOMMENDATIONS

Based on the study findings and available evidence on GHG emissions from sanitation systems following are the recommendations to reduce the GHG emissions from sanitation service chain of KCC:

1. Regular emptying (at least once every five years) may reduce emissions from containment units and have positive public health benefits. Several authors recommend more frequent emptying of containment units to reduce emissions, but empirical evidence of this is lacking. One study in Vietnam found that septic tanks that had not been emptied for more than five years had significantly more emissions than septic tanks emptied within the past five years (Huynh et al., 2021). However, it is unclear if this finding would hold true for similar technologies in the context of Bangladesh. It is

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also unclear from existing studies what an optimal frequency would be for emptying. More frequent emptying could also increase emissions from vacuum trucks making more trips. Regardless, an emptying frequency of more than once every five years is advisable from a public health perspective, even if its effects on emissions are inconclusive.

2. Conversion of pit toilets to septic to tanks may reduce emissions (as pit has higher Methane Correction Factor than septic tank) and reduce the likelihood of groundwater contamination.

3. Methane capture at decentralized and centralized containment/treatment facilities should be explored where it is feasible to implement a management model for operating and maintaining methane capture systems.

4. Maintain the use of aerobic treatment methods at fecal sludge treatment plants which minimize methane emissions.

5. Consider co-composting of dried sludge with added biochar to further treat fecal sludge and reduce its emissions.

STUDY LIMITATIONS

The methodology employed in this study is highly dependent on parameters and assumptions. Firstly, this study used parameters presented in Johnson et al (2022) since they are based on other papers. For example, the chemical oxygen demand from the excreta of each person (kg COD/cap/year) is based on the characterization of feces and urine study (Rose et al., 2015) which reviews several papers on that topic.

Secondly, it is important to highlight that this study also used the methane correction factors, and emission factors of sanitation technologies estimated by Johnson et al (2022) for Kampala, Uganda. Ideally, these variables would be calculated for the Bangladesh context to have more accurate figures. However, this type of analysis will require the collection of field data on sanitation technology conditions, which was beyond the scope of this study, as only secondary data was used.

CONCLUSION

KCC has the opportunity to reduce the GHG emissions from the sanitation service chain by adopting the recommendations. For emptying the containments once every five years, KCC requires improved emptying service (online/easy application and payment process, timely service delivery, reasonable service charge, subsidized service charge for low-income households) along with enforcement and public awareness-raising initiatives. It will increase the revenue generation for the sustainability of the emptying services. Conversion of pit toilets to septic tanks requires public awareness. Though pit toilets are a low-cost on-site sanitation solution for Bangladesh, it is not environmentally friendly (likelihood of groundwater contamination due to high water table). Methane capture from the containments can be piloted at a small scale. Fecal Sludge Treatment Plants (FSTP) should be designed using aerobic treatment methods to reduce GHG emissions. Co-composting of dried sludge with added biochar can also be piloted.

In conclusion, the cities/municipalities of Bangladesh having a similar service chain can follow the recommendations to contribute to the global GHG emissions reduction.

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