Journal of Water Sustainability, Volume 2, Issue 2, June 2012, 131–139

Greenhouse Gas Emissions from Wastewater Treatment Plants: A Case Study of Noida

Diksha Gupta, Santosh Kumar Singh*
Department of Environmental Engineering, Delhi Technological University, Bawana Road, Delhi-110042

ABSTRACT

Wastewater treatment plants (WWTPs) are based in natural processes and provide a high removal of BOD, COD, organic carbon, nutrients and pathogenic microorganisms from wastewater. Wastewater treatment generates significant amount of greenhouse gases mainly methane and nitrous oxide. Reducing these emissions from the treatment process and the contribution of the WWT processes to global warming is a major concern. On the other hand, WWTPs allow recovering energy, and nutrients, thus the reuse of treated wastewater in developing and developed countries can be appropriated. Hence, the understanding and estimation of the greenhouse gases emission pathways of the WW treatment plant is essential to tackle this challenge. This research has attempted to evaluate and quantify the greenhouse gases, mainly methane and nitrous oxide, emissions from the wastewater treatment system.

Keywords: Greenhouse gases; Global warming; Climate Change; Methane

1. INTRODUCTION

During the last 200 years the atmospheric concentrations of greenhouse gases (GHGs) have been increasing. Human activities such as agriculture, industry, waste disposal, deforestation, and especially fossil fuel have been producing increasing amounts of GHGs. For example, the concentrations of CO_2 increased from approximately 280 part per million by volume (ppmv) in pre-industrial age to 372.3 ppmv in 2001 and it will continues increase at about 0.5% per year (IPCC, 2001) whereas current CH_4 atmospheric concentration is going up at a rate 0.02 ppmv per year. Furthermore, the annual sources of N_2O have been increased from the surface of the Earth by about 40–50% over pre-industrial levels. As a result, variations in the radiative forcing of Earth's atmosphere could be being produced, so leading to large and rapid changes in the earth's climate due to global warming produced by these gases.

The major greenhouse gases, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) can all be produced in wastewater treatment operations. Their greenhouse effect is typically weighted by their Global Warming Potentials (GWP) which is dependent on the timeframe of consideration, usually 100 years. The GWP factors for a 100 year horizon are given in Table 1. This means that over a period of 100 years one tonne of methane (CH_4) will have a warming effect equivalent to 25 tonnes of CO_2. In the calculations in this paper, only methane and nitrous oxide are considered since, carbon that is present in wastewater is biogenic (that is to say it was initially drawn down from the atmosphere in the production of food crops). As such, returning the carbon in this material to the atmosphere as CO_2 represents no net flux to the system (IPCC 2006).

* *Corresponding to*: sksinghdce@gmail.com
DOI: 10.11912/jws.2012.2.2.131-139

Table 1 The GWP of GHGs produced in WWTPs

Gas	Chemical name	GWP
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous oxide	N_2O	298

Source: IPCC Fourth Assessment Report, 2007

Beside the actual production of CO_2 and CH_4 in the treatment plant itself, the GHG production in the power generation process needs to be included in the calculations as well. While there are some major differences between various countries, a large number of them use fossil energy (coal, gas, oil) for power generation. These therefore contribute considerably to the overall GHG production. For the calculations in this paper, coal-based power generation has been assumed which is the most common form used in India.

Wastewater from the treatment plants can be a source of methane (CH_4) when treated or disposed anaerobically. It can also be a source of nitrous oxide (N_2O) and carbon dioxide (CO_2).

1.1 Primary Greenhouse Gases of Concern from Wastewater Treatment Plants Are:

a) CO_2;
b) CH_4; and
c) N_2O

The greenhouse gas emitted from waste water treatment plants depend upon the treatment technology employed therein. The paragraphs below detail the emissions sources of a particular GHG from a wastewater treatment plant.

1.1.1 Carbon Dioxide (CO_2)

CO_2 production is attributed to two main factors; treatment process and electricity consumption. During anaerobic process the BOD_5 of wastewater is either incorporated into biomass or it is converted to CO_2 and CH_4. A fraction of biomass is further converted to CO_2 and CH_4 via endogenous respiration. Other emission sources of carbon dioxide are sludge digesters and from digester gas combustion.

In the aerobic process CO_2 is produced through the breakdown of organic matter in the activated sludge process and some through the primary clarifiers.

1.1.2 Methane (CH_4)

Wastewater as well as its sludge components can produce CH_4 if it degrades anaerobically. The extent of CH_4 production depends primarily on the quantity of degradable organic material in the wastewater, the temperature, and the type of treatment system. With increases in temperature, the rate of CH_4 production increases. This is especially important in uncontrolled systems and in warm climates.

1.1.3 Nitrous Oxide (N_2O)

N_2O is associated with the degradation of nitrogen components in the wastewater, e.g., urea, nitrate and protein. Domestic wastewater includes human sewage mixed with other household wastewater, which can include effluent from shower drains, sink drains, washing machines, etc. Centralized wastewater treatment systems may include a variety of processes, ranging from lagooning to advanced tertiary treatment technology for removing nitrogen compounds. After being processed, treated effluent is typically discharged to a receiving water environment (e.g., river, lake, estuary, etc.). Direct emissions of N_2O may be generated during both NDN of the nitrogen present. Both processes can occur in the plant and in the water body that is receiving the effluent. Nitrification is an aerobic process converting ammonia and other nitrogen compounds into nitrate (NO_3^-), while denitrification occurs under anoxic conditions (without free oxygen), and involves the biological conversion of nitrate into nitrogen gas (N_2). N_2O can be an intermediate product of both processes, but is more often associated with denitrification.

2. METHODOLOGY

The methodology of this paper is based on GHG protocol and IPCC Guidelines for National Greenhouse Gas Inventories (2006).

2.1 The Greenhouse Gas Protocol (GHG Protocol)

The GHG Protocol is an internationally accepted protocol for quantifying GHG emissions. It is a joint initiative by WBCSD and WRI and serves as the premier source of knowledge about corporate GHG accounting and reporting.

2.2 Steps Followed for Preparing A GHG Inventory Are as Follows:

Step 1: Setting organizational boundaries: The organizational boundary for this study includes the WWTP and the grid from which the electricity is being imported.

Step 2: Setting operational boundaries: This study identifies following emissions associated with operation and the treatment process at WWTP:

- **Scope 1: Direct GHG emissions** – In scope 1 three gases i.e. CO_2, CH_4 and N_2O are calculated for WWTP. CO_2 emissions from WWTP are not considered in the IPCC Guidelines because these are of biogenic origin and should not be included in national total emissions. Biogenic origin means short cycle or natural sources of atmospheric CO_2 which cycles from plants to animals to humans as part of the natural carbon cycle and food chain do not contribute to global warming. Photosynthesis produced short-cycle CO_2, removes an equal mass of CO_2 from the atmosphere that returns during respiration or wastewater treatment.

- **Scope 2: Indirect GHG emissions**: Scope 2 emissions are from import of electricity, steam or gas; and

- **Scope 3: Other Indirect GHG emissions:** Scope 3 emissions have not been included because of insufficient data.

Step 3: Tracking emissions over time: In this study GHG emissions are calculated for a period of one year from Jan. 2011 – Dec. 2011 (both months inclusive).

Step 4: Identifying and calculating GHG emissions: We have followed IPCC Guidelines for National Greenhouse Gas Inventories, 2006 for calculating GHG emissions from WWTPs.

3. GHG EMISSIONS FROM WW TREATMENT AT GLOBAL LEVEL

Worldwide wastewater is the fifth largest source of anthropogenic CH_4 emissions, contributing approximately 9% of total global CH_4 emissions in 2000. India, China, United States, and Indonesia combined account for 49% of the world's CH_4 emissions from wastewater. Global CH_4 emissions from wastewater are expected to grow by approximately 20% between 2005 and 2020.

Also, worldwide wastewater as a source is the sixth largest contributor to N_2O emissions, accounting for approximately 3 % of N_2O emissions from all sources. Indonesia, the United States, India, and China accounted for approximately 50 % of total N_2O emissions from domestic wastewater in 2000. Global N_2O emissions from wastewater are expected to grow by approximately 13% between 2005 and 2020.

The highest regional percentages for CH_4 emissions from wastewater are from Asia (especially China, India) (US EPA, 2006). Other countries with high emissions in their respective regions include Turkey, Bulgaria, Iran, Brazil, Nigeria and Egypt. Total global emissions of CH_4 from wastewater handling are expected to rise by more than 45% from 1990 to 2020 with much of the increase from the developing countries of East and South Asia, the Middle East, the Caribbean, and Central and South America. The EU has projected lower emissions in 2020 relative to 1990 (US EPA, 2006).

4. GHG EMISSIONS FOR WWTP AT NOIDA- CASE STUDY

4.1 Description of system

The plant is situated in Uttar Pradesh, Noida Sector-54. The capacity of the plant is 33 MLD at present. This 33 MLD sewage treatment plant is based on Sequencing Batch Reactor (SBRs). Flow diagram of the WWTP is shown below in figure 1.

4.2 Calculation of GHG emissions from the plant

The GHG emissions for the plant were estimated based on the technology used for treatment of WW and the anticipated energy used in the plant during operation.

- **Scope 1: Direct GHG emissions**

a. CO_2 produced through breakdown of organic matter during the aerobic phases of the SBR process.
b. CH_4 emissions from SBR are primary clarifiers and aeration basins in small quantities or if improperly managed.
c. N_2O emissions from the discharge of the effluent into the receiving environment.
d. From the diesel generator used at the site. There is one DG set of 1250 KVA at the plant.

- **Scope 2: Indirect GHG emissions**

Indirect GHG emissions resulting from the off-site generation of electric power consumed at WWTP. The expected power use on site was calculated based on the electricity consumption from the following components:

a. Raw sewage pump and pump house
b. Primary units
    - Grit mechanism
    - Grit screw conveyor
c. C-Tech basins
    - Return activated sludge pumps (RAS)
    - Surplus activated sludge pumps (SAS)
d. Blower room for C-Tech
    - Blower for C-Tech
    - Service water pumps for after cooler
e. Sludge sump, centrifuge platform and pump house
    - Blower for sludge sump

- Centrifuge feed pumps (roto pumps)
- DWPE dosing pumps
- DWPE agitators

f. Chlorination room and pump house
- Booster pumps
- Blower for caustic soda pump
- Caustic solution pump
- Service water pumps for DWPE

I. Steps for calculating CH_4 emissions are as follows:

Step 1: Estimation of organically degradable material in domestic wastewater is shown in Table 2.

Step 2: Estimation of methane emission factor for domestic wastewater is shown in Table 3.

Step 3: Estimation of CH_4 emissions from domestic wastewater is summarized in Table 4.

II. Steps for calculating N_2O emissions

Step 1: Estimation of nitrogen in effluent is shown in Table 5.

Step 2: Estimation of emission factor and emissions of indirect N_2O emissions from wastewater is shown in Table 6.

III. Emissions from DG set used at site are depicted in Table 7.

IV. Indirect GHG emissions from the consumption of electricity at WWTP are summarized in Table 8.

Calculations of CO_2, CH_4 and N_2O emissions are shown below in the following tables:

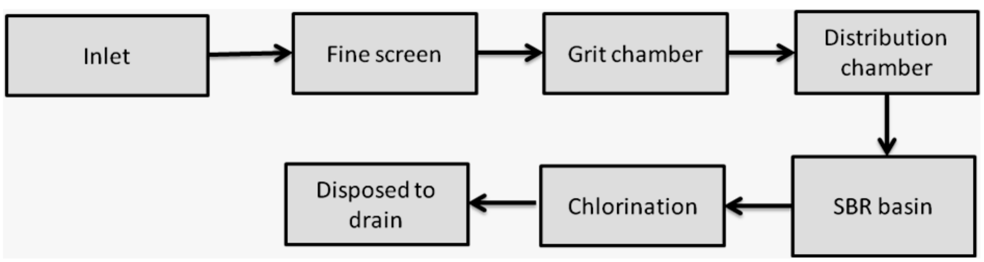

Figure 1 Flow diagram of the WWTP

Table 2 Estimation of organically degradable material in domestic wastewater

Sector	**Waste**			
Category	Domestic wastewater treatment and discharge			
Sheet	1 of 3 Estimation of organically degradable material in domestic wastewater			
	STEP 1			
	A	B	C	D
City (region)	Population (P) cap	Degradable organic component (BOD) (kg BOD/cap/yr)[1]	Correction factor for industrial BOD discharged into sewers (I)[2]	Organically degradable material in wastewater (TOW) (kg BOD/yr)
Uttar Pradesh (Noida)				D= A x B x C
	610394	12.41	1.25	9468736.925

[1] g BOD/cap/day x .001x365 = kg BOD/cap/yr

[2] Correction factor for additional industrial BOD discharged into sewers, (for collected the default is 1.25, for uncollected the default is 1.00)

Table 3 Estimation of methane emission factor for domestic wastewater

Sector	**Waste**		
Category	Domestic wastewater treatment and discharge		
Sheet	1 of 2 Estimation of CH_4 emission factor for domestic wastewater		
	STEP 2		
	A	B	C
Type of treatment or discharge	Maximum methane producing capacity (Bo) (kg CH_4/ kg BOD)	Methane correction factor or each treatment system (MCF_j)	Emission factor (EF_j) (kg CH_4/kg BOD)
Aerobic treatment			C=AXB
	0.6	0.05	0.03

Table 4 Estimation of methane emissions from domestic wastewater

Sector	**Waste**					
Category	Domestic wastewater treatment and discharge					
Sheet	3 of 3 Estimation of CH_4 emissions from domestic wastewater					
			STEP 3			
		A	B	C	D	E
Income group	Type of treatment or discharge	Fraction of Population income group (U_i) fraction	Degree of utilization (T_{ij}) fraction	Emission factor (EFj) (kg CH_4/ kg BOD)	Organically degradable material in wastewater (TOW) (kg BOD/yr)	Sludge removed (S) (kg BOD/yr)
	Aerobic treatment			Step 2 of 3	Step 1 of 3	
Rural		0.71	0.1	0.03	9468736.92	0
Urban high income		0.06	0.07			
Urban low income		0.23	0.03			
Total		0.333	0.066			
		F	G	F	H	I
Income group	Type of treatment or discharge	Methane recovered and flared (R) (kg CH_4/yr)	Net methane Emissions (CH_4) (kg CH_4/yr)	GWP for $CH_{4\ 298}$ (IPCC FAR, 2007)	Total CO_2e kg CO_2e/yr	Total CO_2e t CO_2e/yr
	Aerobic treatment		G=[(AxBxC) x (D-E)]-F	25		
Rural		0				
Urban high income						
Urban low income						
Total			6243		156077.75	156.07

Table 5 Estimation of nitrogen in effluent

Sector	**Waste**						
Category	Domestic wastewater treatment and discharge						
Sheet	1 of 2 Estimation of nitrogen in effluent						
	STEP 1						
	A	B	C	D	E	F	G
	Population (P)	Per capita protein consumption (Protein)	Fraction of nitrogen in protein (F_{npr})	Fraction of non consumption protein ($F_{non\text{-}con}$)	Fraction of industrial and commercial co-discharged protein ($F_{ind\text{-}com}$)	Nitrogen removed with sludge (default is zero) (N_{sludge})	Total nitrogen in effluent ($N_{effluent}$)
Units	people	kg/person/yr	kgN/ kg protein	-	-	kg	kg N/year
							G= (AXBXCX DXE) – F
	610394	0.056	0.16	1.4	1.25	0	9570.97

Table 6 Estimation of emission factor and emissions of indirect N_2O emissions from wastewater

Sector	**Waste**							
Category	Domestic wastewater treatment and discharge							
Sheet	2 of 2 Estimation of emission factor and emissions of indirect N_2O emissions from wastewater							
	STEP 2							
	A	B	C	D	E	F	G	H
	Nitrogen in effluent	Emission factor	Conversion factor of kg N_2O-N into kg N_2O	Emissions from wastewater plants (default as zero)	Total N_2O emissions	GWP for N_2O	Total CO_2e	Total CO_2e
Units	kg N/ year	(kg N_2O-N/kg N)	44/28	kg N_2O/ year	kg N_2O/ year	298 (IPCC FAR, 2007)	kg CO_2e/yr	t CO_2e/yr
	9571	0.0005	1.57	0	7.52	298	2240.98	2.24

Table 7 Emissions from diesel generator set

Total Diesel consumption (L/year)	**Emission factor (t CO_2e/ L) of diesel**	**Total CO2e (t CO_2e/ year)**
18200	0.00255	46.41

Table 8 Electricity consumption of the plant

Area	Total MWH Used yearly	Emissions Factor 0.91 t CO_2e	Total Scope 2 Emissions CO_2e
Pump house	215.715	0.91 t CO_2/ MwH	196 t CO2e
Primary units	39.420	0.91 t CO_2/ MwH	36 t CO2e
C-Tech basins	3.394	0.91 t CO_2/ MwH	3 t CO2e
Blower room	2842.642	0.91 t CO_2/ MwH	2587 t CO2e
Sludge pump	45.260	0.91 t CO_2/ MwH	41 t CO2e
Chlorination room	-	-	-
Total	**3146**	**0.91 t CO_2/ MwH**	**2863 t CO_2e**

Note: Power used for chlorination room is not included because it was not found operational during visit.

Table 9 Total emissions of the plant

Area	Source	CO_2e Emissions
Scope 1	CH_4	156 t CO_2e
	N_2O	2.24 t CO_2e
	DG set	46.41 t CO_2e
Scope 2	Electricity use	2863 t CO_2e
Scope 3	Not Assessed	
Total		**3027.84 t CO_2e**

5. TOTAL EMISSIONS OF THE PLANT

Total emissions of the plant are shown in Table 9.

CONCLUSIONS

The study is used for estimating energy use and GHG emissions from WWTPs. Under the proposed configuration, the plant's GHG is comprised mainly of scope 2 emissions related to the operation of the SBR process and associated equipment. CH_4 production is assessed as 157 t CO_2e and N_2O emissions to the receiving environment are also very less.

- CH_4 produced in the treatment process should be captured and used for generation of electricity or used as a fuel at site, if it is not captured it will discharged into the atmosphere and which will cause increased concentration of GHGs in the atmosphere.
- The CO_2 from the power generation can be eliminated if primarily anaerobic processes are used. Overall, a largely anaerobic degradation of the wastewater pollutants seems economically, and technically feasible and would have major environmental benefits in terms of greenhouse gas production.

NOMENCLATURE

GWP: Global warming potential
CH_4: Methane
N_2O: Nitrous oxide
CO_2: Carbon dioxide
CO_2e: Carbon dioxide equivalent
WWTP: Wastewater Treatment Plant
GHG: Greenhouse Gas

REFERENCES

Alley, B., Berntsen, L. and Chen, B. (2007). Intergovernmental Panel on Climate Change Fourth Assessment Report.

Casey, T. (2010). *Greenhouse Gas Emissions from Wastewater Treatment Plants Get Closer Scrutiny*. Scientific American. Available at http://www.scientificamerican.com/article.cfm?id=greenhouse-gas-emissions-from waste- 2010-05 (accessed 10 February2011).

CEA (2011). Central Electricity Authority, Ministry of Power, Govt of India, CO_2 Baseline Database for Indian Power Sector.

Foley, J., de Haas, D., Hartley, K., Lant, P. (2010). Comprehensive life cycle inventories of alternative wastewater treatment systems. *Water Research*, 44, 1654 – 1666.

Foley, J., Lant PA and P Donlon (2008). Fugitive Greenhouse Gas Emissions from Wastewater Systems. *WATER*, March, 18-23.

Gallaher, O. (2006). *Global Mitigation of non CO_2 Greenhouse Gases*, Section –III, Waste.

Keller, J. and Hartley, K (2003). Greenhouse gas production in wastewater treatment: process selection is the major factor. *Water Sci Technol*, 47, 43-48.

MOEF (Ministry of Environment and Forests) (2010). *India Greenhouse Gas Emissions 2007*, Report of Ministry of Environment and Forests, Government of India.

Penman, Gytarsky, Hiraishi (2006). Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories, Volume 5, *Waste*.

Ranganathan, Corbier, Bhatia (2001). World Resources Institute, *The Greenhouse Gas protocol: A Corporate Accounting and Reporting Standard*, World Business Council for Sustainable Development.

Watson, T. Albritton, L. and Barker. Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories, Volume 5, *Waste*.

U.S. EPA (Environmental Protection Agency). 2010a. 2010 U.S. Greenhouse Gas Inventory Report: *Inventory of U.S. Greenhouse Gas Emissions and Sinks*, 1990–2008. EPA-430-R-10-006.