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Evaluation Of Greenhouse Gas Emissions From Sewage Treatment Plant In Raigarh City

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Abstract: It is commonly accepted that the primary contributor to global warming is the release of greenhouse gases (GHGs) by anthropogenic activities. The accumulation of emitted greenhouse gases has accelerated and now poses a threat not only to humans but also to entire ecosystems on Earth. Wastewater treatment plants (WWTPs) have been identified as one of the largest minor GHG generators due to their production of the three primary GHGs [i.e. carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)] on- and off-site. WWTPs emit greenhouse gases on-site during wastewater treatment, sediment digestion, and system maintenance. Electricity generation for unit process activities, as well as the manufacturing and delivery of chemicals and fuels for on-site use, are the main sources of off-site GHG emissions. The reduction of these emissions from the WWTP process, and the impact of global warming are of paramount concern. Hence, the understanding and estimation of the greenhouse gas emission pathways of the WWTPs is essential to tackle this challenge. In this study, an attempt has been made using the tool suggested by IPCC Guidelines for National Greenhouse Gas Inventories (2006) [Refined in 2019] and GHG protocol to assess the greenhouse gas emissions from the sewage treatment plant of Raigarh city and suggest remedial measures for reducing greenhouse gases from the treatment plant. The result shows GHGs emission from the direct source is 7196 t CO_2e/year and from the indirect source is 897 t CO_2e/year, hence total GHGs emission from the sewage treatment plant is 8093 t CO_2e/year.

Keywords: Greenhouse gas, Wastewater Treatment Plant (WWTP), methane, nitrous oxide, IPCC guideline.

I. INTRODUCTION

Wastewater treatment facilities are vital to environmental preservation. Several pollutants, such as organic matter, nitrogen, and phosphorus, can be removed from effluent through the use of appropriate technologies and well-established operational strategies, thereby preventing their negative environmental impact. Thus play an important part in resource conservation and recycling in the ecosystem. Recent studies have identified WWTPs as potential sources of anthropogenic GHG emissions, contributing to climate change and air pollution. WWTPs have been recognized as one of the largest of minor GHG generators due to their production of the three primary GHGs i.e. carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) both on-site and off-site (Kyung D,2015). WWTPs produce on-site GHGs during wastewater treatment, sludge digestion, and system maintenance (Kyung D,2015). Off-site GHG emissions from electricity production for unit process operations as well as from the production and transportation of chemicals and fuels for on-site consumption (Kyung D,2015). Carbon dioxide released from the WWTP process is considered as biogenic in nature. The disintegration of organic matter anaerobically in the WWTP process produces methane while nitrous oxide is produced from the enhanced nitrification and denitrification process in the WWTPs.

The contribution of GHGs to global warming is commonly expressed by their Global Warming Potential (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 29.8 tonnes of CO_2 and one tonne of nitrous oxide(N_2O) will have a warming effect equivalent to 273 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). But the production of CO_2 from the power generation process is included in the calculations. Because of strict regulation by international climate-change-prevention protocols, WWTPs will soon be confronted with the challenges of mitigating their GHG emissions and maintaining the required quality of treated wastewater (Bani Shahabadi et al., 2009). Therefore, the emission of GHGs from WWTPs needs to be estimated as accurately as possible and effective management plans should be set up as soon as possible.

In this study, data from various sources have been collected for a more accurate and appropriate estimation of GHG emissions from the sewage treatment plants in Raigarh city.

Table 1: The Global warming potential of GHGs

Gas Name	GWP value for 100-year time horizon			
	SAR	AR4	AR5	AR6
Carbon dioxide	1	1	1	1
Methane(fossil origin)	21	25	28	29.8
Methane(non-fossil origin)				27.2
Nitrous oxide	310	298	265	273

Source IPCC Sixth Assessment Report 2021

II. METHODOLOGY

The data required for the evaluation of greenhouse gases emissions were collected from the respective sewage treatment plants namely a) Bade Atermuda Sewage Treatment Plant, Capacity-07MLD (b) Banjinpali Sewage Treatment Plant, Capacity-25MLD. The Procedures and protocols for quantifying the GHG emissions is based on GHG protocol and IPCC Guidelines for National Greenhouse Gas Inventories (2006) [Refined on 2019].

2.1. Procedure and Protocol for Evaluating GHGs Emission

The GHG Protocol is an internationally accepted protocol for quantifying GHG emissions. The protocol is developed by World Business Council on Sustainable Development (WBCSD) and World Resource Institute (WRI) serves as the premier source of knowledge about how to measure, manage and report greenhouse gas emissions. As per protocol firstly, the organizational boundary is identified. The organizational boundary includes the STP and the grid from which electricity is being imported.

Secondly, the operational boundary is identified, it includes emissions associated with the operation and treatment process at the STP.The operational boundary includes Scope1, Scope2, and Scope3 emissions. In this scope three gases i.e. CO_2, CH_4, and N_2O are calculated from 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 source of atmospheric CO_2 which cycles from plants to animals to humans as part of the natural carbon cycle and the food chain do not contribute to global warming. Photosynthesis produces short-cycle CO_2, and removes an equal mass of CO_2 from the atmosphere that returns during respiration or wastewater treatment. In Scope 2 indirect emissions are from the import of electricity and in

Scope 3 emission other indirect emissions can be calculated but, in this study, it is not included because of insufficient data.

Thirdly, the tracking of emissions over a fixed period of time is done. In this study the GHGs emissions are calculated for a

period of one year i.e. from May 2022 to April 2023.

Fourthly, GHGs emissions from STP are calculated. We have followed IPCC Guidelines for National Greenhouse Gas

Inventories (2006) [Refined on 2019] foe calculating GHG emission from sewage treatment plants.

III. STUDY AREA

Raigarh is a city and a Municipal Corporation in Raigarh district of the Indian state of Chhattisgarh. As per 2011 Indian census Raigarh city has a population of 166460. Raigarh district is a rapidly growing industrial city and home to mohan jute mill one of the oldest jute mill in India and the only one in Madhya Pradesh prior to the splitting of Chhattisgarh in 2000.Raigarh is also major producer of steel and iron as well as the cultural and industrial capital of Chhattisgarh. Jindal steel and power limited is a major steel plant based in Raigarh. The Kelo river flows through the city, which is one of its main water sources. In order to eliminate the pollution of kilo river due to municipal residential waste of Raigarh city sewage treatment plant at the strategic location is constructed i.e. Bade Atermuda Sewage Treatment plant, Capacity-07MLD(STP1) and Banjinpali Sewage Treatment Plant, Capacity-25MLD(STP2) is constructed. Raigarh Sewage Treatment Plant (STP) is based on Sequential Batch Reactor (SBR) technology.

3.1. Sequential Batch Reactor (SBR) technology

A sequencing batch reactor is an activated sludge type wastewater treatment system that can carry out various treatment operations in one tank. The main advantage of sequencing batch reactors is that they produce effluent low in organic compounds and thus can be used to meet strict effluent standards. The system can be effectively used as part of a larger system when the removal of the nutrients nitrogen and phosphorus are required. Other advantages are that it can be located on a small area of land, and it is relatively easy to expand this system by adding additional reactors. (Biological Processes Waste Management Series ,2006)

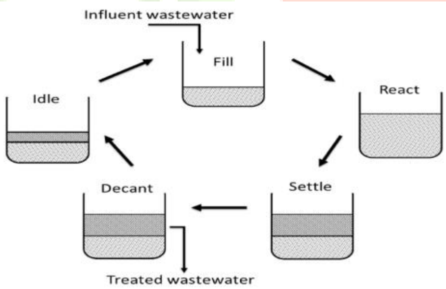


Fig: Process flow diagram of SBR based treatment (Mid, E. C., & Dua, V. 2018)

3.2. Calculation of GHG emissions from the STP

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

3.2.1. Direct GHG emissions

a) CO_2 produced through breakdown of organic matter during the aerobic phases of the SBR process. But not considered.

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 plant and discharge of the effluent into the receiving environment.

d)From the diesel generator used at the site. There is 02 DG set of 250KVA and 750 KVA at the plant.

Table 2 : Parameter values for estimating direct GHGs emission

Parameter	Values		Sources/Reference
	STP1	STP2	
Population	33992	132468	Census 2011
Avg. BOD/day	130mg/l	130mg/l	Monthly Lab Records of STPs
BOD/day/capita	23g/d/person	23g/day/person	calculated
Avg Wastewater generation/day	6MLD	23MLD	Monthly Lab Records of STPs
Methane correction factor(MCF), BO,	0.03,0.06 respectively		IPCC 2006(Refined 2019)
Protein intake (gm/day/capita)	55.8		Gov. of India Ministry of Health and Family Welfare
EF_j, $EF_{EFFLUENT}$, F_{NPR}, N_{HH} ,$F_{NON-CON}$,F_{INDCOM},	0.016,0.005,0.16,1.13,1.2,1.25 respectively		IPCC 2006(Refined 2019)
$N_{REM,j}$ for primary treatment and secondary treatment	0.10,0.40 respectively		IPCC 2006(Refined 2019)
Fraction of population (U_i)	Rural	0.71	M. Karthik NEERI, National Greenhouse Gas Inventory Information (2012)
	Urban High	0.08	
	Urban Low	0.21	
Degree of utilization (T_{ij})	Rural	0	M. Karthik NEERI, National Greenhouse Gas Inventory Information (2012)
	Urban High	0.98	
	Urban Low	0.99	

I. CH_4 EMISSION CALCULATION

Steps for calculating CH_4 emissions are as follows:

Step 1: Estimation of organically degradable material in domestic wastewater

a) Total organically degradable material in wastewater

TOW(STP1)=P*BOD*0.001*365
=33992*23*0.001*365
=285363 kg BOD/year

TOW(STP2)=P*BOD*0.001*365
=132468*23*0.001*365
=1112069 kg BOD/year

Where,

TOW=total organics in wastewater, kg BOD/year.

P =human population.

BOD=biochemical oxidation demand per capita ,g/person/day.

0.001=conversion from gram BOD to kg BOD.

b) Total organics in wastewater by Treatment/discharge pathway or system

$TOW_j(STP1)=\sum i[TOW(STP1)*U_i*T_{ij}*I_j]$
=(285363*0.71*0*1)+(285363*0.08*0.98*1)+(285363*0.21*0.99*1)
=81699 kg BOD/year

$TOW_j(STP2)=\sum i[TOW(STP2)* U_i*T_{ij}* I_j]$
=(1112069*0.71*0*1)+(1112069*0.08*0.98*1)+(1112069*0.21*0.99*1)
=318385 kg BOD/year

Where

TOW_j = total organics in wastewater,kg BOD/year for income group i and treatment/discharge pathway or system,j.

TOW= total organics in wastewater,kg BOD/year.

U_i =fraction of population in income group i.

T_{ij} =degree of utilization of treatment/ discharge pathway or system,j for each income group

I_j =correction factor for additional industrial BOD discharge into treatment / discharge pathway or system,j(for uncollected the default value is 1.00)

Step 2: Estimation of methane emission factor for domestic wastewater

a) CH_4 Emission Factor

EF_j=BO *MCF_j

=0.6*0.03

=0.018 kg CH_4/kg BOD

Where

EF_j=emission factor, kg CH_4/kg BOD.

BO=maximum CH_4producing capacity,kg CH_4/kg BOD

MCF =methane correction factor.

Step 3:Estimation of CH_4 emission from domestic wastewater

CH_4 Emission j= ∑[(TOW_j – S_j)* EF_j - R_j]

= [(TOW(STP1) – S)*EF-R]+ [(TOW(STP2) – S)*EF-R]

= [(81699-0)*0.018-0]+ [(318385-0)*0.018-0]

=1471+5731

=7202 kg CH_4/year

Where,

CH_4 Emission j = CH_4 emissions from treatment/discharge pathway or system,j, kg CH_4/year.

TOW_j = organics in wastewater of treatment/discharge pathway or system,j, kg BOD/year.

S_j =organic component removed from wastewater(in form of sludge) from treatment/discharge pathway or system,j,kg BOD/year.

j = each treatment/discharge pathway or system.

EF_j = emission factor for treatment/discharge pathway or system,j, kg CH4/kg BOD.

R_j = amount of CH_4 recovered or flared from treatment discharge pathway or system,j,kg CH_4/kg.

Global Warming Potential(GWP) for Methane=27.2

(Source:IPCC Sixth Assessment Report,2021)

Total CO_2e= 7202*27.2=195894.4 kg CO_2e/year

=196 t CO_2 e/year.

II. N_2O EMISSION CALCULATION

Steps for calculating N_2O emissions are as follows:

Step 1:Estimation of nitrogen in the effluent

a) Total Nitrogen in the domestic wastewater by treatment pathway

TN_{DOM} (STP1) =(P*Protein*FNPR*NHH*FNON-CON*FIND-COM)

=(33992*.0558*365*0.16*1.13*1.1*1.25)

=172109 kg N/year

TN_{DOM} (STP2) =(P*Protein* F_{NPR} * N_{HH} * $F_{NON-CON}$ * $F_{IND-COM}$)

=(132468*.0558*365*0.16*1.13*1.1*1.25)

=670717 kg N/year.

Where,

TN_{DOM} =total annual amount of nitrogen in wastewater effluent, kg N/year.

P =human population.

Protein=annual per capita protein consumption, kg protein/person/year.

F_{NPR} =fraction for nitrogen in protein, default=0.16 kg N/kg protein.

$F_{NON-CON}$ =factor for nitrogen in non-consumed protein disposed in sewer system, kg N/kg N.

$F_{IND-COM}$ =factor for industrial and commercial co-discharged protein into the sewer system, kg N/kg N.

N_{HH} = additional nitrogen from household products added to the wastewater.

b) Total nitrogen in domestic wastewater effluent discharged to aquatic environment

$N_2O_{EFFLUENT,DOM}$ (STP1)= ∑j[(TN_{DOM} * T_j)*(1- $N_{REM,j}$)]
=[(172109*1.97)*(1-0.10)]+[(172109*1.97)*(1-0.4)]
=508582 kg N/year

$N_2O_{EFFLUENT,DOM}$ (STP2)= ∑j[(TN_{DOM} * T_j)*(1- $N_{REM,j}$)]
=[(670717*1.97)*(1-0.10)]+[(670717*1.97)*(1-0.4)]
=1981968 kg N/year

Where,
$N_2O_{EFFLUENT,DOM}$ = total nitrogen in the wastewater effluent discharge to aquatic environment in inventory year,kg N/yr
TN_{DOM} = total annual amount of nitrogen in domestic wastewater, kg N/year.
T_j = Degree of utilization of treatment system in inventory year(∑Tij).
j= each wastewater treatment type used in inventory year.
$N_{REM,j}$ = fraction of total wastewater nitrogen removed during wastewater treatment type j.

Step 2:Estimation of emission factor and emission of N_2O

a) N_2O emission from domestic wastewater treatment plants

N_2O plant(STP1)=[∑ij(U_i * T_{ij}* EF_j)] *TN *44/28
=[(0.71*0*0.016)+(0.08*0.98*0.016)+(0.21*0.99*0.016)] *172109* 44/28
=1238 kg N_2O /year

N_2O plant(STP2)=[∑ij(U_i * T_{ij}* EF_j)] *TN *44/28
=[(0.71*0*0.016)+(0.08*0.98*0.016)+(0.14*0.99*0.016)] *670717* 44/28
=4828 kg N_2O /year

Where,
N_2O plant= N_2O emission from domestic wastewater treatment plant in inventory year, kg N_2O /year.
TN =total annual nitrogen in wastewater,kg N/year.
U_i =fraction of population in income group i.
T_{ij} = degree of utilization of treatment/ discharge pathway or system,j.for each income group
i = income group:rural,urban high income and urban low income
j =each treatment/discharge pathway/system.
EF_j =emission factor fot treatment/discharge pathway or system j,kg N_2O -N/kg N.
The factor 44/28 is for the conversion of kg N_2O -N into Kg N_2O

b) N_2O emission from domestic wastewater effluent

N_2O $_{EFFLUENT,DOM}$ (STP1)= $N_{EFFLUENT,DOM}$ * $EF_{EFFLUENT}$ *44/28
=508582*0.005*44/28
=3996 kg N_2O /year

N_2O $_{EFFLUENT,DOM}$ (STP2)= $N_{EFFLUENT,DOM}$ * $EF_{EFFLUENT}$ *44/28
=1981968*0.005*44/28
=15573 kg N_2O /year

Where,
$N_2O_{EFFLUENT,DOM}$=N2O emissions from domestic wastewater effluent in inventory year ,kg N_2O /year.
$N_{EFFLUENT,DOM}$ =nitrogen in the effluent discharged to aquatic environment ,kg N/year
$EF_{EFFLUENT}$=emission factor for N2O emissions from wastewater discharged to aquatic system ,kg N_2O -N/kgN
The factor 44/28 is for the conversion of kg N_2O -N into Kg N_2O

Total N_2O emission = N_2O plant(STP1)+ N_2O plant(STP2)+ N_2O $_{EFFLUENT,DOM}$(STP1) + N_2O $_{EFFLUENT,DOM}$ (STP2)
=1238+4828+3996+15573 =25635 kg N_2O /year

Global Warming Potential(GWP) for Nitrous Oxide=273
(Source:IPCC Sixth Assessment Report,2021)
Total CO_2e= 25635*273= 6998355 kg CO_2e/year
=6998 t CO_2e/year

III)Emission from Diesel generator set

i)Emission from Banjhinpali STP1(t CO_2e/yr)=1

ii) Emission from Badeatermuda STP2(t CO_2e/yr)=1

Table 3:Total CO_2 equivalent direct emission from STPs

Plant	Total Diesel Consumption	Emission Factor (t CO_2eq/L)	Total CO_2 Equivalent Emission (t CO_2eq/yr)
Bade Atermuda Sewage Treatment Plant, Capacity-07MLD(STP1)	384	0.0029	1
Banzinpali Sewage Treatment Plant, Capacity-25MLD (STP2)	500	0.0029	1

The emission factor is taken from IPCC,2006 , volume 2, Energy.

Total CO_2 (t CO3e/yr)=1+1= 2 t CO_2e/year

3.2.2.Indirect GHG emissions

Indirect GHG emissions resulting from the off-site generation of electric power consumed at STP.The expected power use on the site was calculated based on the electricity consumption from the following components: a)pump house(b)Primary units(Grit mechanism, Grit conveyor)(c)C-T basins(d) Blower room (e)sludge pump (f) lighting in the premises etc.

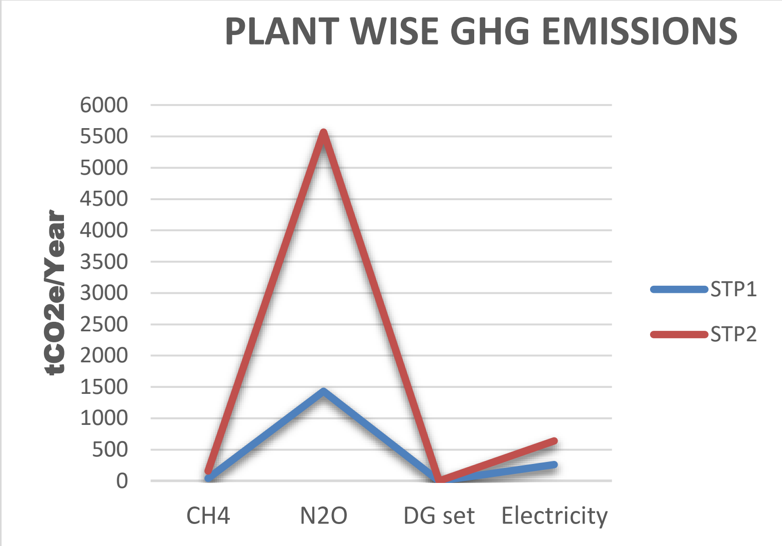
i)Emission from Bade Atermuda STP1(t CO_2e/yr)=260

ii)Emission from Banjhinpali STP2(t CO_2e/yr)=637

Table 4:Total CO_2 equivalent indirect emission from STPs

Plant	Power Consumption (MWH/yr)	Emission Factor (t CO_2/MWH)	Total CO_2Equivalent Emission(t CO_2e/yr)
Bade Atermuda Sewage Treatment Plant, Capacity-07MLD	321.48	0.81	260.4
Banjhinpali Sewage Treatment Plant, Capacity-25MLD	786.636	0.81	637

The emission factor is available from Central Electricity Authority, CO_2baseline database for Indian Power Sector 2022.



IV. RESULT AND DISCUSSION

The result obtained shown in table 5, of greenhouse gas emissions from the sewage treatment plants in Raigarh city reveals that the facility contributes significantly to the emission of carbon dioxide, methane, and nitrous oxide.

Table 5:Plant wise detail of GHG emissions

Name of STP	Methane(CH_4) (t CO_2/year)	Nitrous Oxide (N_2O) (t CO_2/year)	DG set (t CO_2/year)	Electricity (t CO_2/year)
Bade Atermuda Sewage Treatment Plant, (STP1) Capacity-07MLD	40	1429	1	260 t CO_2e/year
Banjhinpali Sewage Treatment Plant, (STP2) Capacity-25MLD	156	5569	1	637 t CO_2e/year

The calculated direct GHG emission is 7196 t CO_2e and the indirect GHG emission is 897 t CO_2e. Hence, the total GHG emission is 8093 t CO_2e.The study shows that major emission is from direct source i.e. due the treatment process followed in SBR and the rest is from indirect source i.e. Electricity consumption in the treatment plant.

V.CONCLUSION

The study has estimated greenhouse gas emissions from SBR-based WWTPs in Raigarh city, Chhattisgarh for the current operation. The GHG emissions from the two STPs combined is 8093 t CO_2e/yr. The result indicates that the amount of on-site greenhouse gas emissions were significantly higher than the off-site emissions. The sewage treatment plants which have been studied are the major treatment plants that combined together will treat more than 75% of the total sewage generated in Raigarh city. The recommendations could be capturing of methane produced during the treatment process and using it for the generation of energy, carbon dioxide from the power generation can be eliminated if primarily anaerobic processes are used and controlling the DO concentration at a proper level and raising the utilization rate of organic carbon in the influent for denitrification are the two most critically effective methods for N_2O reduction during the wastewater treatment.(Sun, Shichang; Bao, Zhiyuan; Sun, Dezhi,2015).

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