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Evaluation of Green House Gas Emissions from Proposed Sewerage Treatment Plant in Satna City

*Tanya Kaur Bedi[1]
[1]*Student of Master of Environmental Planning, School of Planning and Architecture, Bhopal*
Corresponding Author: Tanya Kaur Bedi

Abstract: *The increasing global temperature is in an alarming situation and the most prominent causes of which is increase in the emission of green house gases. Among numerous sources leading to green house gas emissions, sewage treatment plants are also responsible for GHGs (greenhouse gases) production mainly contributing to increasing carbon dioxide, methane and nitrous oxide that are produced during biological treatment processes and off-site electricity production. Reducing these emissions from the sewage treatment plants is a major concern. In this study, it has been attempted to estimate the emissions of green house gases from the proposed sewage treatment plant in Satna city in Madhya Pradesh and suggest remedial measures for the same.*

Keywords: *Green House Gases, Global Temperature, Activated Sludge Process, Sewage treatment plant, Methane, Sequence Batch Reactor*

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I. INTRODUCTION

The increasing concentration of green house gases in the environment has resulted in additional studies of emission estimation and its diverse sources. Infrastructure sector wastewater or sewage is received by treatment plants that produce treated-water by employing diverse aerobic and anaerobic treatment processes. The GHG emissions from treatment procedures has become noteworthy in recent years and is increasingly calculated and assessed while determining the long-term sustainability of the management system. These treatment plants emit three significant green house gases namely nitrous oxide (N2O), methane (CH4) and carbon dioxide (CO2) both directly and indirectly. The gaseous by-products are the direct emissions and the emission due to energy usage and secondary activities are the indirect emissions. In this study, the data from various secondary sources have been collected for more accurate and appropriate estimation of GHGs emissions from the three proposed sewage treatment plants in Satna.

1.1 Greenhouse Gases and the International Protocol

The Kyoto convention is a union of the Assembled Countries System on Environmental Change received on 11th December 1997 in Kyoto, Japan and came into constrain on 16th February 2005 to lower ozone-depleting substance emanations. Besides, the UNFCCC is a global ecological concurrence with the objective to accomplish adjustment of GHGs fixations in the environment at a level that would anticipate unsafe anthropogenic interruption with the atmosphere framework.

1.2 Global Warming Potential

Gases in the atmosphere can contribute to the greenhouse effect both directly and indirectly. Direct effects occur when the gas itself absorbs radiation. Indirect effects take place when a gas changes the lifetimes of other green house gases, chemical transformations of the substance produce other greenhouse gases, or when a gas affects atmospheric processes (EPA, 2014). For comparing the ability of each greenhouse gas to trap heat in the atmosphere relative to another gas, the IPCC developed the Global Warming Potential (GWP) concept. The GWP of a greenhouse gas gives the ratio of time integrated radiative forcing from the instantaneous release of 1 kg of a trace substance relative to that of 1 kg of a reference gas [1]Thus, the GWP is a relative measure used to compare the radiative effects of different gases. It also means that, the GWP of a GHG is the ratio of heat trapped by one unit mass of the gas compared to one unit mass of CO2 over a certain time period, usually 100 years. The CH4 and N2O gases are able to absorb more heat per unit mass or infrared radiation, this property translates into their higher global warming potential. For example, the global warming potential of N2O is 296 which mean that it is capable of absorbing heat 296 times greater than of an equivalent mass of CO2 over a period of 100 years. (Das, 2011)

Table 1 : Global Warming Potential of Green House Gases

Gas	Global Warming Potential
Carbon Dioxide	1
Methane	28-36
Nitrous Oxide	265-298
Hydrofluorocarbons	12-14,800
Perfluorocarbons	7390-12,200

1.3 Different Types of GHGs Emissions from STP

Carbon dioxide (CO2), Methane (CH4), and Nitrous oxide (N2O) are three major greenhouse gases emitted in a typical wastewater treatment plant.

1.4 Carbon Dioxide Emissions

CO2 is produced from combustion of fossil fuel on-site for heating and oxidation of organic material during treatment process of waste water. According to IPCC (1996), the national greenhouse gas inventory does not include the emissions of CO2 from biomass based wastes. However, IPCC (2006) method includes the CO2 emissions from fossil fuel produced for wastewater treatment processes and combustion of these fuels in boilers within the Energy sector. The alkalinity consumption is another major cause of indirect production of CO2, which basically converts inorganic carbon to carbon-dioxide gas. Alkalinity consumption is typically in the bicarbonate form (HCO3-) at pH level near to neutral. The reaction is as follows:

$$HCO_3^- + H^+ \rightleftharpoons CO_2 + H_2O$$

Alkalinity as Calcium Carbonate (CaCO3) is bought in use during the nitrification process and it is produced for the duration of biomass decay and the de-nitrification process.

1.5 Methane Emissions

Anaerobic condition usually produces methane gas during the process of organic matter decomposition. Wastewater which is not treated is also a generator of methane gas under anaerobic conditions. The emission rate from wastewater management practices vary from country to country and depends on three factors, organic content, type of treatment and estimation method adopted. Methane can be emitted from four types of sources. among which energy sector, agriculture and waste management are three major sources and industrial processes are a minor source. In the year 2002, United Nations approximated 28.60 % of methane to be emitted from waste management sector and can be divided into two sub-categories, domestic solid waste anaerobic decomposition in landfills and wastewater treatment.

1.7 Nitrous Oxide Emissions

Both industrial and household wastewaters may possibly be a source of emission of nitrous oxide. Certain industrial wastewaters associated with significant nitrogen loadings are discharged to the municipal sewers, which are generally mixed with domestic, commercial, and institutional wastewaters. Municipal wastewater includes discharges from bath, laundry, kitchen, etc. and human waste. This type of waste water management system can be decentralized treatment facility like septic tanks or centralized system. Other than wastewater and solid waste sludge incineration, biological nutrient removals are also impending N2O emitting sources. Moreover, nitrification and de-nitrification of Nitrogen in the form of ammonia, urea and proteins also contributes in production of N2O which are further converted into nitrates (NO3-). The anaerobic process of de-nitrification converts the nitrates into Di-Nitrogen gas (N2). Both processes produce N2O as an intermediate product. N2O is significant as a greenhouse gas because of its higher potential to absorb infrared radiation. N2O gas atmospheric mixing rate is rising at a rate of 0.2 - 0.3 % per year. Atmospheric lifetime of N2O gas is approximately 114 years and its radiative force is much higher than CO2. N2O is the main source for formation of stratospheric NO which causes stratospheric ozone destruction [2].

II. STUDY AREA

Satna is located in the state of Madhya Pradesh with Uttar Pradesh at one edge. It has two rivers, namely, Satna River and Tamas River flowing on south-west and south-east respectively. The city constitutes the Satna District's administrative headquarters. Presently there is no existing sewerage system in the city. The system is proposed by the municipal corporation in the city development plan 2035. Monthly billing of rupees 80 per households is proposed considering 80% recovery efficiency. The city draws water from Tamas River with a supply of 70LPCD, considering 80% waste water generation it can be approximated to 56 LPCD. The sludge from the households and unhygienic septic tank effluent goes into open drains, Amoudha Nala, Bhrut Nala and Gehra Nala. This waste water finally goes into Tamas River. The present condition of sewage has

BOD5 200mg/l & according to MoEF standards the limit is 30mg/l [3] and the chloride content of sewage is 50mg/l. The city is divided into three zones according to the natural topography with three sewage treatment plants and three septic tanks proposed for each zone which is depicted in fig. 1.

Table 2 : Overview of proposed sewer network in Satna

Implementing Agency	Municial Corporation of Satna
Project Area	72.00 Sq. Kms
Design Population (2047)	4,85,000
Design length	4,95,014 meters
Existing Road network	401 meters
Design	Gravity flow according to topography
Zones	3
Treatment Technology	Sequential Batch Reactor (SBR)
Estimated Cost	17,555 lacs

Table 3 : Zonal details of sewerage treatment facilities

Zones	Zone 1	Zone 2	Zone 3
STP Capacity	15 MLD	16 MLD	11 MLD
STP Location	Ward 30, Shiv Nagar	Ward 33, Mela Ground	Ward 14, Kripalpur
Septic Tank Capacity	0.75 MLD	1.2 MLD	1.8 MLD
Septic Tank Location	Ward 2, Killa	Ward 10, Sant Nagar	Ward 11, Trichy Colony

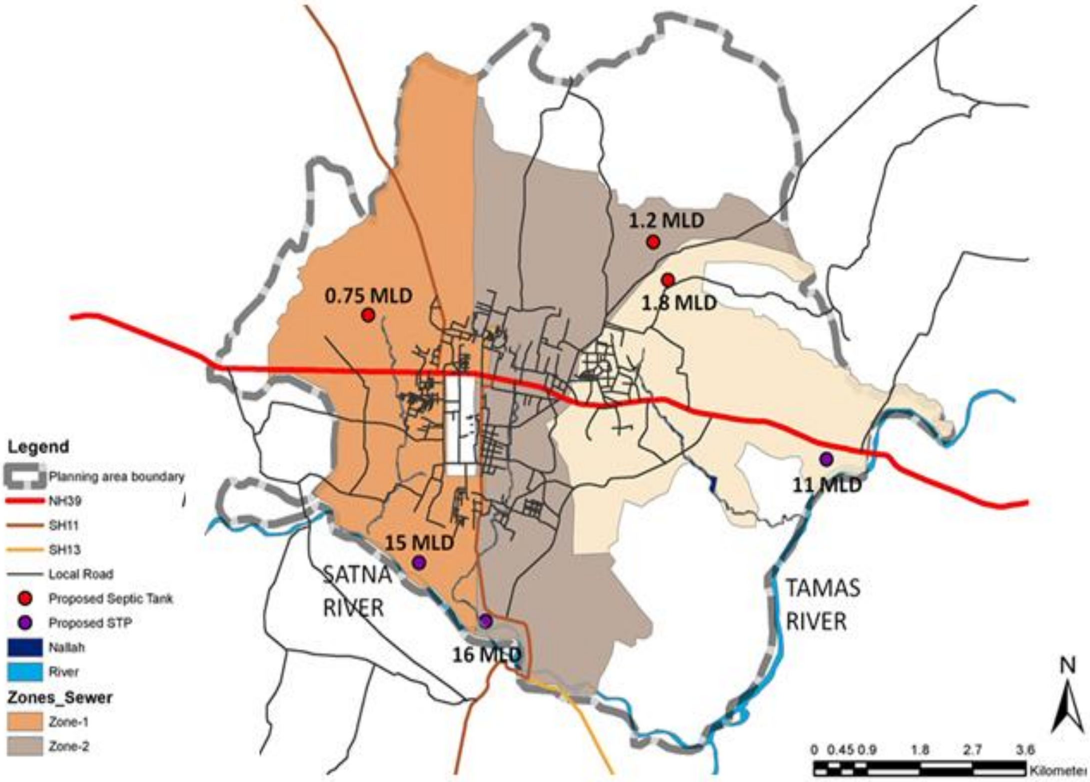

Figure 1: Map showing three zones for sewerage management and location of proposed STPs

2.1 Wastewater issues in the study area

There are three major issues that were identified during primary survey which are pollution, improper road network and land availability. The open drains/nallahs finally drain into Tamas River. The sewerage water pollutes the river and creates nuisance for the common man. There is no separate collection system for the waste water coming from meat market and hospital for which treatment is very important. Open defecation is still in practice and pollutes the lakes. The colour is murky and oil is seen floating on the surface. The total road length of Satna is approximately 401kms comprising of cement concrete / WBM/ Bituminous road surface. The width of the road varies from 3.0 meters to 22.0 meters which is insufficient for providing sewage network in many areas. The major portion of roads network in the town is of 4meters. The project also includes construction of various civil structures like STPs and Septic Tank of total cumulative capacity of 95 KL In Satna town and laying Sewer lines. Moreover, sensitive locations include wholesale markets, grain market, vegetable markets, meat market, marble market, schools and hospitals [4].

2.2 Sequencing Batch Reactor Technology for Sewage Treatment

Sequencing batch reactor is a modified version of the activated sludge process. It is viable in areas with limited space availability like in case of Satna city. In this technology of wastewater treatment, all phases of the treatment process take place sequentially in the same tank (Slater, 2006). Zone wise population projection and sewage generation as per the CDP which is taken into account for calculation is mentioned in Table 4.

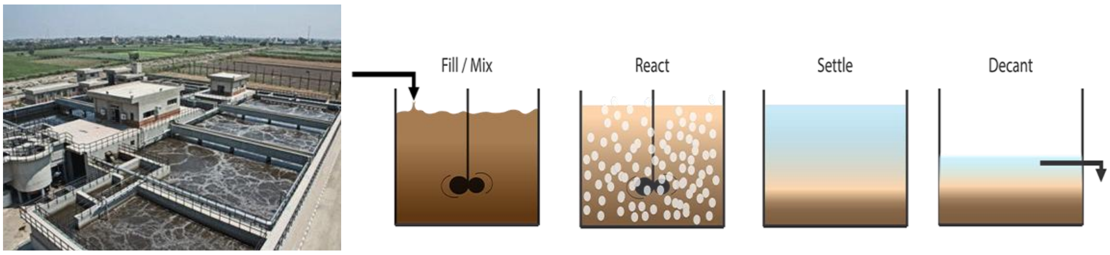

Figure 2: Treatment process in a typical sequence batch reactor treatment plant

Table 4 : Details of Sequential Batch Reactor Treatment technology

Parameter	**STP Technology - SBR (Sequential Batch Reactor)**
Treatment Process	Aerobic suspended growth - biological
"SIZEWISE" Suitability of the process	Suitable for any size, no limitation.
Performance After Secondary Treatment	1. Biological Oxygen Demand (BOD) - 5 mg/lit 2. Chemical Oxygen Demand (COD) - 50 mg/lit 3. Total Suspended Solids (TSS) - 10 mg/lit 4. Ammonic al Nitrogen (NH4-N) - 5 mg/lit 5. Total Nitrogen (TN) - 10 mg/lit 6. Total Phosphorous (TP) - 2 mg/lit 7. Faecal coliforms - 100 MPN/100 (after disinfection)
Additional treatment required	No additional treatment vital to achieve latest outlet norms
Usage of treated effluent	Can be used for non-potable purposes (Gardening, car washing, industrial washings, railways, etc.)
Inlet flow variations	Can handle
Level of automation / energy efficient equipment	Fully automatic with manual over ride
Future Augmentation	Possible
Area Requirements	Approx. Plant Area requirement (m2/MLD) - 400 Additional area required for tertiary treatment (m2/MLD) - 0 Total area (m2/MLD) - 400
Approx. POWER requirement kWh/MLD	130- 150
Overall O&M COST including power Rs./m3	2 - 2.5

Table 5 : Population projection for designing the project for the various zones of Satna

Year	Population	Zone 1	Sewage	Zone 2	Sewage	Zone 3	Sewage	Total
2011	2,82,977	1,02,932	57,64,192	1,04,869	58,72,664	75,176	42,09,856	1,58,46,712
2017	3,10,000	1,12,762	63,14,672	1,14,883	64,33,448	82,355	46,11,880	1,73,60,000
2032	3,89,000	1,41,498	1,91,02,230	1,44,160	1,94,61,600	1,03,343	1,39,51,305	5,25,15,000

III. METHODOLOGY

The data required for the evaluation of green house gases emissions is collected from various sources. Procedures and protocols for quantifying the emissions were followed as per IPCC 2006 guidelines [5]. The estimation of emissions is carried out for all the three STPs jointly for the population of year 2032 with marks the completion of phase 1 of the proposed project.

3.1 Protocol and Procedure for Evaluating GHGs Emissions

The study is based on GHG protocol and IPCC Guidelines for National Greenhouse Gas Inventories (2006). The Greenhouse Gas (GHG) Protocol, developed by World Resources Institute (WRI) and World Business Council on Sustainable Development (WBCSD), sets the global standard for how to measure, manage, and report greenhouse gas emissions. As per the protocol firstly, the organizational boundary and operational boundary are identified. The organizational boundary includes the STP and the grid from which the electricity is being imported. The operational boundary includes the emissions associated with operation and the treatment process at STP. The operational boundary includes Scope1, Scope2 and Scope3 emissions. In scope 1, three gases i.e. CO2, CH4 and N2O are calculated for STP. CO2 emissions from STP and should not be included in national total emissions as they are considered to be of biogenic origin. Biogenic origin means short cycle or natural sources of atmospheric CO2 which cycles from plants to animals to humans as part of the natural carbon cycle and food chain and does not contribute to global warming. In Scope 2, emissions are calculated from import of electricity and in Scope 3, emission from other indirect emissions can be calculated. In this study, scope 3 emission is not included because of insufficient data, the GHGs emissions from STP are calculated in accordance with the IPCC 2006 Guidelines for National Greenhouse Gas Inventories for calculating GHG emissions from STPs.

IV. DISCUSSION

The paper methodology is based on GHG protocol and IPCC Guidelines for National Greenhouse Gas Inventories (2006) [1]. For the purpose of calculation, values based on the analysis of 106 raw sewage samples in 115 STPs studied by Central Pollution Control Board, average sewage characteristics in terms of the following main parameters Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS) are found to be 185.50 mg/l, 481.00 mg/l and 328.00 mg/l, respectively. [6]

4.1 Calculation for Direct Emissions

The calculations are carried out on the basis of formulas provided in the guidelines for the three major green house gases respectively.

4.2 Calculation of Total Organic Content in wastewater

TOC (kg BOD/cap/yr) = P * BOD * 0.001 * I * 365 = 3,89,000 * 200 * 0.001 * 1 * 365
TOC (kg BOD/cap/yr) = 28,397,000 kg BOD/cap/y -------------------------------------- (1)
Where,
P : Population in inventory year (person)
BOD : 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)

4.3 Estimation of methane emission factor

Methane Emission factor (EFj) (kg CH4/kg BOD) = Bo * MCF = 0.6 * 0.05
Methane Emission factor (EFj) (kg CH4/kg BOD) = 0.03 ----------------------------- (2)
Where,
EFj : Emission Factor, kg CH4 / kg BOD
j : each treatment/discharge pathway or system
Bo : maximum CH4 producing capacity (kg CH4/kg BOD)
MCFj : CH4 correction fraction
(Indicates the degree to which the system is anaerobic).

Table 6 : Parameter Values for Estimating Direct Green House Gases Emissions [4]

Parameter	**Value**	**Source**
Per Capita BOD (g BOD/day)	185.5	CPCB
Population (P)	3,89,000	Satna CDP
Methane Correction Factor	0.05	[7]
Bo, FNPR, FNONCON, FIND-COM	0.6, 0.16, 1.4, 1.25 respectively.	[7]
Ui (Rural, Urban High, Urban Low)	Rural - 0.03, Urban High - 0.66, Urban Low - 0.31 Respectively.	Satna CDP
Tij (Rural, Urban High, Urban Low)	Rural - 0.00, Urban High - 1.00, Urban Low - 1.00 Respectively.	Satna CDP

4.4 **Calculation for methane emissions**

Using the values of Ui and Tij form Table 5, TOC calculated value and Emission factor from equation 1 & 2, we get methane emissions as:

Total CH4 Emissions = [Σi,j (Ui * Ti,j * EFj)](TOW-S)-R
Where,
S = Organic component removed in the form of sludge (kg BOD/yr)
R = Amount of methane recovered in inventory year (kg CH4/yr)
Default values of S and R are taken as zero as per IPCC 2006 guidelines.
Ui = Population Fraction in income group 'i' in the inventory year
Tij = Degree of utilisation of treatment system, j,
for each income group fraction 'i' in the inventory year.

Total CH4 Emissions (kg CH4/yr) = 28,397,000 * 0.03 * 0.33 * 0.66 = 185,545.998 = 185546
Global Warming Potential (GWP) for Methane = 25
(Source: IPCC Fourth Assessment Report (FAR), 2007)
Total CO2et = 185546*25 = 4,638,650 kgCO2e/yr = 5113.23 tCO2e/yr

4.5 Total Nitrogen in the Effluent

Total Nitrogen in the Effluent = (P*Protein*FNPR*FNON-CON*FIND-COM) - N_{SLUDGE}
$N_{EFFLUENT}$ = 3,89,000*0.063*0.16*1.4*1.25 = 6861.96 kg N/year ------------------- (3)
Where:
$N_{EFFLUENT}$ = Total annual amount of nitrogen in the wastewater effluent, kg N/yr
P = Human population
Protein = Annual per capita consumption, average Indian urban default = 0.063 kg/person/yr [8]
FNPR = Fraction of nitrogen in protein, default = 0.16 kg N/kg protein
FNON-CON = Factor for non-consumed protein added to the wastewater
FIND-COM = Factor for industrial and commercial co-discharged protein into sewer system
N_{SLUDGE} = Nitrogen removed with sludge (default = zero) kg N/yr

4.6 **Calculation of N2O Emissions from the Sewage Treatment Plant**

Net N2O Emission = $N_{EFFLUENT}$*$EF_{EFFLUENT}$*44/28 = 6861.96*.0005*1.57------------from(3)
Net N2O Emission = 5.38 kg N2O/year
Where:

$EF_{EFFLUENT}$ = Emission factor for N2O from discharged wastewater (kg N2O-N/kg N)
The factor 44/28 is the conversion of kg N2O-N into kg N2O.

GWP for N2O = 298 (IPCC FAR,2007)
Total CO2e Emission = 5.38*298 kgCO2e/yr = 1603.24 kgCO2e/yr
Total CO2e Emission = 1.76 tCO2/yr (approx.)

Hence, Total Direct GHGs Emissions (CH4 & N2O) = 5113.23 + 1.76 = 5114.99 tCO2/yr
Total Direct GHGs Emissions = 5115 tCO2/yr

4.8 Calculation for Indirect GHGs Emissions

For the calculation if indirect emissions, approx. power requirement in kWh/MLD = 130-150. The emission factor is available from Central Electricity Authority. Total Indirect GHGs Emissions = 1760 tCO2/yr.

Table 7 : Indirect Green House Gas Emissions due to power consumption

Plant	Power Consumption (MWH/Yr.)	Emission Factor (Tco2/M WH)	Total CO2 Equivalent Emission (T CO2e/Yr)
STP 1	0.14 MWH*15 MLD*365 = 766.5	0.82	628.53
STP 2	0.14 MWH*16 MLD*365 = 817.6	0.82	670.43
STP 3	0.14 MWH*11 MLD*365 = 562.1	0.82	460.84
Total CO2 Equivalent Emission (T CO2e/Yr)			1,759.8 = 1,760

V. RESULT

Calculated Direct GHGs Emission are 5115 tCO2/yr and the Indirect GHGs Emissions are 1760 tCO2/yr. Hence, **Total GHGs Emissions = 6875 tCO2/yr**. The study shows that approximately 1/4thions are due to electricity consumption of the treatment plants i.e. indirect source and the rest is due to the treatment process followed in the sequence batch reactor. The percentage break-up of emissions is shown in Fig. 3.

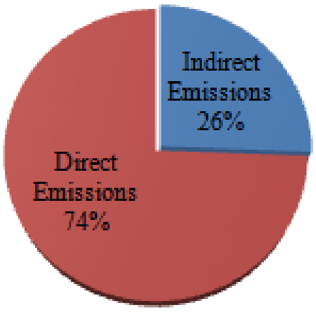

Figure 3: Percentage breakup of source of GHG Emissions

4.9 Control and GHG Emission Reduction Strategies

Greenhouse gases are produced in municipal biological wastewater treatment plant due to three major reasons that are:

1. Using large amounts of energy from electrical and natural gas utilities to operate the plant,
2. Inherently producing CO2 in cause of organic matter oxidation, which is lost to the atmosphere, and
3. Generating excess microorganisms (biomass) that must be disposed off.

The nitrous oxide is emitted as a by-product during nitrification and de-nitrification processes, when ammonia is present in the effluent. There are two significant steps that can be used to reduce the GHGs production in the STPs. The first is the effective conversion of waste activated sludge to biogas in an anaerobic digester and the other is the conversion of biogas to energy. When a STP uses biogas to generate heat and electricity, it reduces the use of non-renewable energy and the mass of residual sludge.

VI. CONCLUSION

The GHGs emissions from the three STPs combined is 6875 tCO2e/yr. The result indicates that the amount of direct green house gases emissions were significantly higher than the indirect emissions. The sewage treatment plants which have been studied are the major treatment plants which combined together will treat more than 75% of the total sewage generated in Satna. Other than Emission reduction strategies discussed, a great fraction of emissions can be reduced by reducing the power consumption for various miscellaneous activities.

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