A Thesis on

EVALUATION OF GREEN HOUSE GASES EMISSIONS FROM SEWAGE TREATMENT PLANTS IN DELHI

submitted in partial fulfillment of the requirements for the award of the degree of

MASTER OF TECHNOLOGY

in

ENVIRONMENTAL ENGINEERING

Submitted by

MAYANK MRINAL

(2K13/ENE/19)

Under the esteemed guidance of

Dr. Anubha Mandal
UGC Scientist 'C'(Professor Grade)

Mr. Anunay Gour
Assistant Professor

Ms. Lovleen Gupta
Assistant Professor

DEPARTMENT OF ENVIRONMENTAL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Shahbad Daulatpur, Bawana Road, Delhi – 110042

DEPARTMENT OF ENVIRONMENTAL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly DELHI COLLEGE OF ENGINEERING)
AUCHANDI- BAWANA ROAD , NEW DELHI - 110042

CERTIFICATE

This is to certify that the dissertation entitled "**EVALUATION OF GREEN HOUSE GASES FROM SEWAGE TREATMENT PLANTS IN DELHI"** is authentic work done by **Mr. MAYANK MRINAL** Roll.No.**2K13/ENE/19** under our guidance and supervision towards the partial fulfillment of requirement towards the degree of Masters of Technology in *Environmental Engineering* during the academic year 2014 – 2015 in Department of Environmental Engineering of Delhi Technological University.

Dr. Anubha Mandal	Mr. Anunay Gour	Ms. Lovleen Gupta
(Professor&UGC 'C'Scientist)	(Assistant Professor)	(Assistant Professor)

DECLARATION OF ORIGINALITY

I hereby certify that I am the sole author of this thesis and that no part of this thesis has been published or submitted for publication.

I certify that, to the best of my knowledge, my thesis does not infringe upon anyone's copyright nor violates any proprietary rights and that any ideas, techniques, quotations, or any other material from the work of other people included in my thesis, published or otherwise, are fully acknowledged in accordance with the standard referencing practices.

I declare that this is a true copy of my thesis, including any final revisions, as approved by my advisor and supervisor, and that this thesis has not been submitted for a higher degree to any other University or Institution.

Mayank Mrinal
2K13/ENE/19

ABSTRACT

Sewage treatment plants are considered as sources of GHGs (greenhouse gases) production mainly methane, carbon dioxide and nitrous oxide which are produced during biological sewage treatment process and off-site electricity production which is a major source of CO_2 generation. Reducing the green house gases from the sewage treatment plants is a major concern. The day to day increase in the global temperature is an alarming situation and the most prominent cause of which is increase in the emission of green house gases.

In this study, it has been attempted to evaluate the emissions of green house gases from some of the major sewage treatment plants of Delhi. It has been observed that the indirect GHGs emission because of the generation of power at off-site is much more than the direct on-site GHGs emission as a result of sewage treatment by the Activated Sludge Process. The power consumption of the concerned plants are obtained the respective plants. The total power consumption of Okhla, Keshopur and Yamuna Vihar sewage treatment plants are obtained by the addition of the BSES electricity bills for each month(January-2014 to December-2014) provided by the engineers at the respective plants. The power consumption includes the power consumed by all phases i.e. the six phases of Okhla plant, three phases of Keshopur plant and two phases of Yamuna Vihar plant. The Keshopur STP has the highest GHGs emissions of 18640 tCO_2/yr and emissions from Yamuna Vihar sewage treatment plant is lowest at 4159 tCO_2/yr. Although the plants are centralized and well managed but in case of power failure there is no back up. The highest emissions from Keshopur STP is due to more power consumption for operating various operational units as compared to other sewage treatment plants. All the calculations are done based on IPCC 2006 guidelines. The direct GHGs from all the four STPs are same as the MCF factor value for all the activated sludge process based treatment plants is same as provided by Delhi Jal Board and by the respective treatment plants.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my advisor **Dr.Anubha Mandal**, UGC 'C'Scientist , Department of Environmental Engineering, DTU for her advice, guidance, support and continuous encouragement throughout this period. I am grateful to to **Mr.Anunay Gour**, Assistant Professor, Department of Environmental Engineering, DTU and **Ms. Lovleen Gupta**, Assistant Professor, Department of Environmental Engineering for their constructive criticism and guidance which helped me to overcome many difficulties during the study.

I would take this opportunity to record my special thanks to **Dr. Ashok Kumar Gupta**, Head of Environmental Engineering Department, DTU for his great help in completing the project successfully.

I would also like to thank **Dr. Chhemendra Sharma** who is a senior scientist in the Radio & Atmospheric Sciences Division of the National Physical Laboratory, New Delhi for devoting his time in discussing ideas with me and giving his invaluable feedback.

The support received from the staff members at Delhi Jal Board and Delhi Pollution Control Committee Office is thankfully acknowledged.

I wish to expresses my deepest appreciation particularly to **Mr. S.K. Goel**, Senior Environmental Engineer, DPCC; **Ms. Sanjam Chima**, Consultant(P.R.),Delhi Jal Board; **Mr. P.R. Nigam**, Executive Engineer, Yamuna Vihar STP; **Mr. Ravindra Singh**, Assistant Engineer, Okhla STP; **Mr. Suraj Kumar**, Plant Manager, Rithala STP and **Mr. T.P. Singh**, Assistant Engineer, Keshopur STP for their valuable assistance in providing the necessary data.

I am also thankful to my family members and friends for their inspiration and support for completion of this thesis.

Mayank Mrinal
2K13/ENE/19

TABLE OF CONTENTS

NOMENCLATURE

GHGs	Greenhouse gases
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
BOD	Biochemical Oxygen Demand
WWTPs	Wastewater Treatment Plants
CH_4	Methane
N_2O	Nitrous oxide
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
WRI	World Resources Institute
MCF	Methane Correction Factor
DJB	Delhi Jal Board
DPCC	Delhi Pollution Control Committee
tCO_{2e}	Carbon dioxide equivalent emissions in tones

LIST OF TABLES

LIST OF FIGURES

CHAPTER-1

INTRODUCTION

A general introduction about the research which was carried out as part of completion of the project is briefly described in this chapter. In this study, it has been attempted to quantify the emissions of green house gases from some of the major sewage treatment plants of Delhi. The chapter also includes the objectives and the importance of the project.

1.1 Estimation of GHGs Emissions

The increase in the emissions of green house gases in recent years has adversely affected the global temperature because of their effects on environment. The greenhouse gases generation, mainly carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) from anthropogenic sources are the main cause for global warming and climate change. Thus the need to identify and quantify all the sources is obvious for planning strategies to minimize and regulate the rate of emission of GHGs which adversely affects the atmosphere.

The release of methane and nitrous oxide during the treatment of sewage in the sewage treatment plants and carbon dioxide emissions due to power requirement for operating the plant, the sewage treatment plants are source for GHGs emission.Various international protocols have restricted the emissions of green house gases and have imposed penalties in case of non-abidance. Hence, it becomes necessary to estimate the generation of GHGs from STPs before designing and implementing any strategy for its mitigation.

The Kyoto protocol to the United Nations Framework Convention on Climate Change (UNFCCC) which was adopted in 1997 in Kyoto, Japan to reduce greenhouse gas emissions. Also, the UNFCCC which is an international environmental agreement aims to achieve stabilization of green house gases concentrations in the atmosphere at a such level that could prevent harmful anthropogenic intrusion into the climate system.
The characteristics and the type of treatment process of the sewage determines the amount of GHGs to be produced.

1.2 Objective of the Project

In this study, the data from various sources including the sewage treatment plants have been collected for the more accurate and appropriate estimation of GHGs emissions and the objective of the project are:

- To evaluate the direct GHGs namely CH_4, N_2O and CO_2 emissions from the four major sewage treatment plants in Delhi namely :
  - a.) Okhla Sewage Treatment Plant,
  - b.) Rithala Sewage Treatment Plant,
  - c.) Keshopur Sewage Treatment Plant and
  - d.) Yamuna Vihar Sewage Treatment Plant.
- To quantify the indirect emissions of green house gases as result of electricity consumption by concerned sewage treatment plants.

CHAPTER-2
LITERATURE REVIEW

CHAPTER-2
LITERATURE REVIEW

In the last few years, GHGs emissions from wastewater treatment processes and operations have become a significant concern and are increasingly being measured and assessed while determining the long term sustainability of a treatment scheme.

2.1 Sources of Green House Gases

According to Monteith et al.[1] the increasing concentration of GHGs in the atmosphere have led to further studies of GHGs estimation and its source. Waste water is received by wastewater treatment plant and produces treated water by the use of different processes such as aerobic treatment, anaerobic treatment etc. Liquid treatment processes, solids treatment processes, and the combustion of biogas and fossil fuels results in the emission of on-site green house gases. Off-site energy production, and off-site chemical production results in production of off-site greenhouse gases. Scanlan et al.[2] found that the GHGs emissions from wastewater treatment processes and operations in recent years have become a significant concern and thus are increasingly measured and also assessed while determining the long term sustainability of a treatment system. El-Fadel and Massoud[3] suggested the anthropogenic activities have increased atmospheric concentrations of greenhouse gases during the last 100 years. That is why, the identification and quantification of all sources, both natural and anthropogenic, is needed for developing strategies to control and reduce the rate of increase of the GHGs emissions into the atmosphere. Baede et al.[4] investigated that the planet surface when striked by the incoming solar radiation and when some part of this energy gets reflected from the surface as infrared radiation. Clouds and the atmosphere too radiate infrared radiation (IR). Part of this radiation is absorbed by GHGs and that results in increase in kinetic energy of the molecules.

According to IPCC [5] the atmospheric heat retention capacity is simulated due to increased concentrations of GHGs and thus cause GHGs to behave like a blanket which keeps heat inside atmosphere. Thus, the net temperature of the earth gets increased. Different sources of wastewater generation are domestic, commercial and industrial sources. Household used water is called domestic wastewater and industrial wastewater is collected from industrial operations only, whereas municipal wastewater is a combination of household, commercial and non-hazardous industrial wastewaters. The treatment process of wastewater can be on-site (uncollected) or sewered to a centralized plant (collected). In developed countries, the most common methods of treatment processes are centralized aerobic treatment processes and lagoons for both domestic and industrial wastewaters. Centralized aerobic wastewater treatment methods are subdivided as preliminary or/and primary, secondary and tertiary treatment processes. Physical barriers move out larger solids particle from the wastewater through preliminary and primary treatment, while in secondary treatment, organic-matters are biodegraded by microbial oxidation. Generally, it may consist of aerobic stabilization ponds, trickling filters, activated sludge processes, rotating biological contractors or/and anaerobic reactors, lagoons. Tertiary treatment is implied to further treat or remove the pathogens, remaining contaminants and nutrients such as nitrogen and phosphorus compounds. This may include maturation ponds, biological processes, advanced filtration, carbon adsorption, ion exchange, and disinfection with chlorine or other disinfecting compounds such as ozone or ultraviolet light. 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. The various pathways for treatment of wastewater is shown in Figure 2.1.

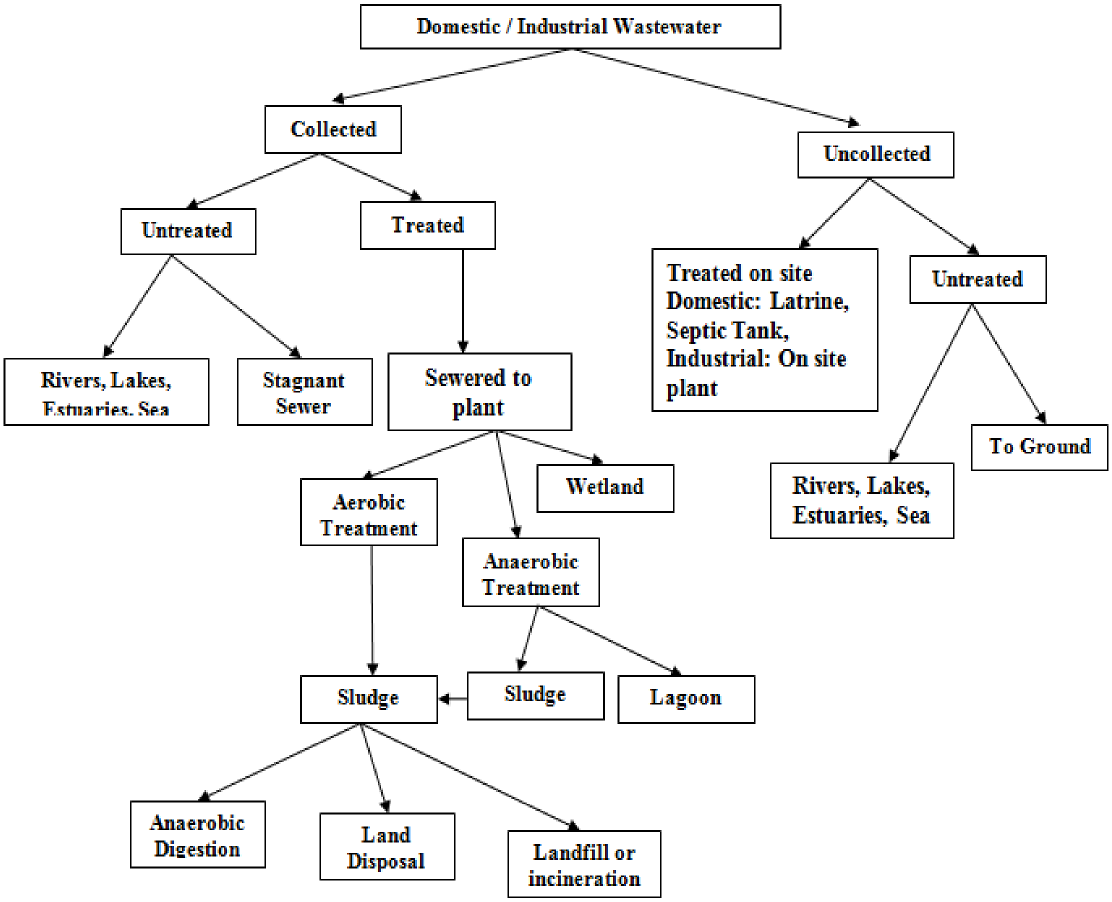

Figure-2.1 Various Pathways for Wastewater Treatment[5].

According to U.S. EPA[6] the larger minor sources of GHGs emissions are wastewater treatment plants (WWTPs). Both directly and indirectly during the treatment processes these plants produce the three important GHGs namely carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The gaseous byproducts such as CO_2, CH_4, and N_2O results in direct emissions and the indirect emissions are caused due to the use of energy and ancillary activities.

Shaw et al.[7] found that the aerobic treatment plants because of using considerable amounts of power emit a significant quantity of greenhouse gases. Direct emissions occur during the treatment process through gaseous byproducts such as CO_2, CH_4, and N_2O, while indirect emissions occur during the use of energy and ancillary activities.

Oennerth et al.[8], Ingildsen et al.[9], Devisscher et al.[10],Olsson et al.[11] have suggested that the increasing demands on effluent quality at lower operational costs have promoted the development of new technologies and the implementation of control concepts to improve the overall performance of wastewater treatment plants (WWTP). Full-scale applications have shown the feasibility of automatic control in aeration systems, chemical dosage and recycle flows

Zhao et al.[12],Spanjers et al., [13],Corominas et al.[14],Stare et al.[15], Flores-Alsina et al.[16],Machado et al., [17] have studied the comparison of the performance of different control strategies and to evaluate them before full-scale implementation by dynamic simulation. Gujer and Erni [18], Lessard and Beck [19], Jeppsson et al.[20] have introduced plant-wide operation to take into account the interactions between the processes. Bridle et al.[21] proposed to re-think the traditional engineering approaches by adding this new dimension due to the increasing interest for greenhouse gas (GHG)emissions from wastewater treatment. Hence, to prevent or minimize GHG emissions generation in WWTP and evaluate different operation schemes new tools are needed.

According to Bani Shahabadi et al,[22] some mathematical tools have been developed by the scientific community to estimate and evaluate the generation of GHG in WWTP. But, these methods are not suitable appear for evaluating WWTP control strategies as they are based on steady state calculations, viz. empirical approaches and comprehensive models.
Energy source can be considered as off-site or upstream emission because it occurs outside of the treatment plant. The consumption of alkalinity is also considered as off-site CO_2 emission source .

Cakir and Stenstrom [23] indicated that the anaerobic treatment has been used to treat sludges and medium to high strength wastewaters (2,000 to 20,000 mg/L COD). Also, wastewater is usually stabilized by using three steps such as hydrolysis, acid fermentation, and methanogenesis in anaerobic treatment process. Many of the estimations focus technology and do not take into consideration every aspect.As for example, the study of the contribution of aerobic degradation of carbonaceous biochemical oxygen demand to green house gases emissions.von Schulthess and Gujer [24],Hiatt and Grady [25] and Foley et al.[26] have quantified the N_2O emissions in aerobic-anoxic activated sludge plants. Batstone et al.[27] and Greenfield and Batstone [28] have evaluated methane (CH_4) and carbon dioxide (CO_2)emissions under anaerobic conditions.

2.2 Types of GHGs Emissions and Global Warming Potential

GHGs emissions from STPs are generally classified mainly as direct emissions and indirect emissions. Direct emissions are on-site emissions at the plant while the off-site emissions are indirect. Both directly and indirectly gases in the atmosphere contribute to the greenhouse effect. When the gas itself absorbs radiation it causes direct effects.

When a gas affects atmospheric processes or when a gas changes the lifetimes of other gases, chemical transformations of the substance produce other greenhouse gases it is indirect effect.

The GWP is generally used to compare the radiative effects of different gases. It means that, GWP of a GHG is the ratio of the heat trapped by one unit mass of the gas compared to one unit mass of CO_2 over a certain time period, generally 100 years[5].

Table 1. Global Warming Potential of GHGs

Gas	**Chemical Name**	**GWP**
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous oxide	N_20	298

Source: IPCC FAR,2007

The GWP factors for a 100 year period are given in Table 2.1 which means that over a time period of 100 years one tonne of methane (CH_4) will contribute the warming effect equivalent to 25 tonnes of CO_2.

Sahely et al.[29] suggested that CO_2 is generated due the oxidation of organic material during wastewater treatment and also because of combustion of fossil fuel on-site for heating.The CO_2 emissions from fossil fuel produced for wastewater treatment processes and combustion of these fuels in boilers is included by IPCC within Energy sector.

Diagger et al.[30] indicated that the alkalinity consumption which results in conversion of inorganic carbon to carbon dioxide is considered as the other main source of off-site CO_2 production. The classification of GHGs emissions from wastewater treatment plants can be into three different sources, namely energy, liquid process emissions and emissions from biosolids processing .A primary clarifier also removes some biodegradable organic matter by simple sedimentation, which is not stabilized. An increase in the sludge production in primary clarifiers results in less GHGs emissions. Electrical energy is used in wastewater treatment plants in a variety of ways such as for aeration, heating purposes etc. Electricity may be produced from different primary sources such as coal, oil, hydropower, natural gas, etc.

Scheehle and Doorn [31] stated that the decomposition of organic matter under anaerobic condition generally produces methane gas.CH_4 may also be generated by untreated wastewater if anaerobic condition is present there. Organic fraction, level of treatment and estimation method determines the CH_4 emissions rate from wastewater management practices which varies from country to country. Domestic as well as industrial wastewaters can be a source of nitrous oxide emissions.

Some of the industrial wastewaters associated with significant nitrogen loadings are also discharged to the municipal sewers, which are therein mixed with domestic, commercial, and institutional wastewater. Human waste and discharges from kitchen, bath, laundry, etc. are included in the domestic wastewater. This type of wastewater can have collection system as an on-site or decentralized wastewater treatment system such as a septic tank system, or can also have centralized wastewater treatment system.

According to Barton and Atwater[32] and Schulthess and Gujer[33],the biological nutrient removal processes are potential source of N_2O apart from solid waste and wastewater sludge incineration which contribute to the increase in atmospheric N_2O, but also biological nutrient removal processes are potential. Thomsen and Lyck [34] identified that N_2O can be produced both by nitrification and denitrification during biological wastewater treatment processes of the nitrogen present in the form of urea, ammonia and proteins. In aerobic process these are converted to nitrates by nitrification.In anaerobic biological conversion of nitrates into dinitrogen gas (N_2) by denitrification takes place. The intermediated product of both processes is nitrous oxide.

Khalil and Rasmussen [35] investigated that due to its higher potential in comparison to CO_2 to absorb infrared radiation which produces heat nitrous oxide is important as a green house gas.The increasing rate of N_20 in the atmosphere is 0.25 to 0.31 % per year. Cicerone et al.[36] and Bliefert and Perraud [37] examined that the formation of stratospheric NO which is mainly produced by N_2O causes destruction of stratospheric ozone. Hanaki et al.[38] stated that the wastewater treatment is a potential source among various anthropogenic sources which produce nitrous oxide. Hong et al.[39] and Debruyn et al.,[40] identified that N_2O emission due to the bacterially mediated denitrification and the transport together with management of municipal wastewater.

Emmerson et al.[41],Vidal et al.[42] and Gallego et al.[43] have done many existing LCA studies of wastewater treatment systems. Almost all of them have examined competing technology configurations, and have consistently identified the strong influence of energy consumption on the overall impact on the environment.

There are studies which have focused more on small and decentralised wastewater systems which consider different issues and scales than those investigated in this study.

Gaterell et al.[44] and Lassaux et al.[45] have examined the relative environmental impacts of different treatment standard by a limited number of studies. The important role of WWTPs in protecting receiving waters from eutrophication have been highlighted by these studies, and it is considered highly beneficial to have hence increased levels of nutrient removal. Yerushalmi et al.[46] has clarified that the liquid treatment process is one of the main on-site sources of GHGs. The biodegradable organic matter stabilization and on-site fossil fuel combustion for energy and heat production is the major cause for emission. Kampschreur, Temmink, Kleerebezem, Jetten, & van Loosdrecht [47] have studied and examined that the main processes used in WWTP for the removal of nitrogen are aerobic ammonium oxidation in combination with aerobic nitrate oxidation which is also called nitrification and denitrification. There are different processes in WWTP that can produce N_2O,namely denitrification, nitrification and chemical reactions.

According to CEA India [48] the emission reductions from CDM projects in the power sector are calculated based on the net electricity generated by the project, and the difference between the emission factors (in tCO_2/MWh) of the baseline and the project activity. The baseline emission factor reflects the carbon intensity of the displaced grid electricity. This baseline emission factor can be derived from the data provided in the CO_2 Database. The annual data columns in the database provide the following: net generation in GWH of the station, absolute carbon dioxide emissions in metric tonnes, and specific carbon dioxide emissions in tCO_2/MWH, for the five fiscal years 2009-10 to 2013-14.

2.3 Emission of GHGs from Unit Operations

The gravity in the primary clarifiers settles the heavier suspended solids and thereafter these settled solids are removed. The various unit processes of municipal wastewater treatment plant are shown in Table 2.2. The biodegradable organic matter which is not stabilized by simple sedimentation is also removed by primary clarifier. (Metcalf and Eddy, 2010).

Table 2.2: Various Unit processes of the municipal wastewater treatment plant (Metcalf and Eddy,2010)

Treatment Process	**Unit Operation**	**Removed Contaminants**	**Equipments**	**Significance**
Preliminary Treatment	Mechanical Bar screens and continuation Gravitational bar screening Floatation	Debris rags and grit Suspended solids Heavier inorganic particles	Bar screen Fine particle sieving Grit chamber Pre aeration Grease wall Scraping chamber	To avoid clogging of equipment
Primary Treatment	Sedimentation Coagulation Floatation	A portion of the suspended solids and organic matter Colloidal substances with the help of coagulants	Primary clarifier Sedimentation tank	To remove most of the suspended solids
Secondary Treatment	Biological	Organic matter	Aeration tank Trickling Filter	To remove all organic matter by micro-organisms

According to Czepiel et al.[49], the increasing sludge production in primary clarifiers results in less green house gases emissions .It is estimated that amount of N_2O emissions from the surface of the primary settling tank to be almost negligible. Activated sludge process, biological aerated filter, trickling filters, rotating biological contractors, and similar other unit operations are aerobic treatment process. Also, aeration is required for biodegradation of organic matter by microorganisms in this type of treatment processes. Therefore, this process leads to higher greenhouse gases emissions because of high energy demands. The carbon in the organic matter is converted to CO_2 when the biodegradable organic matter is stabilized by aerobic treatment. The same amount of organic matter if is stabilized anaerobically, CO_2 and CH_4 are produced. As the GWP of CH_4 is 21 times greater than of CO_2,the aerobic stabilization of organic matter significantly reduces greenhouse gas impact in comparison to anaerobic degradation.

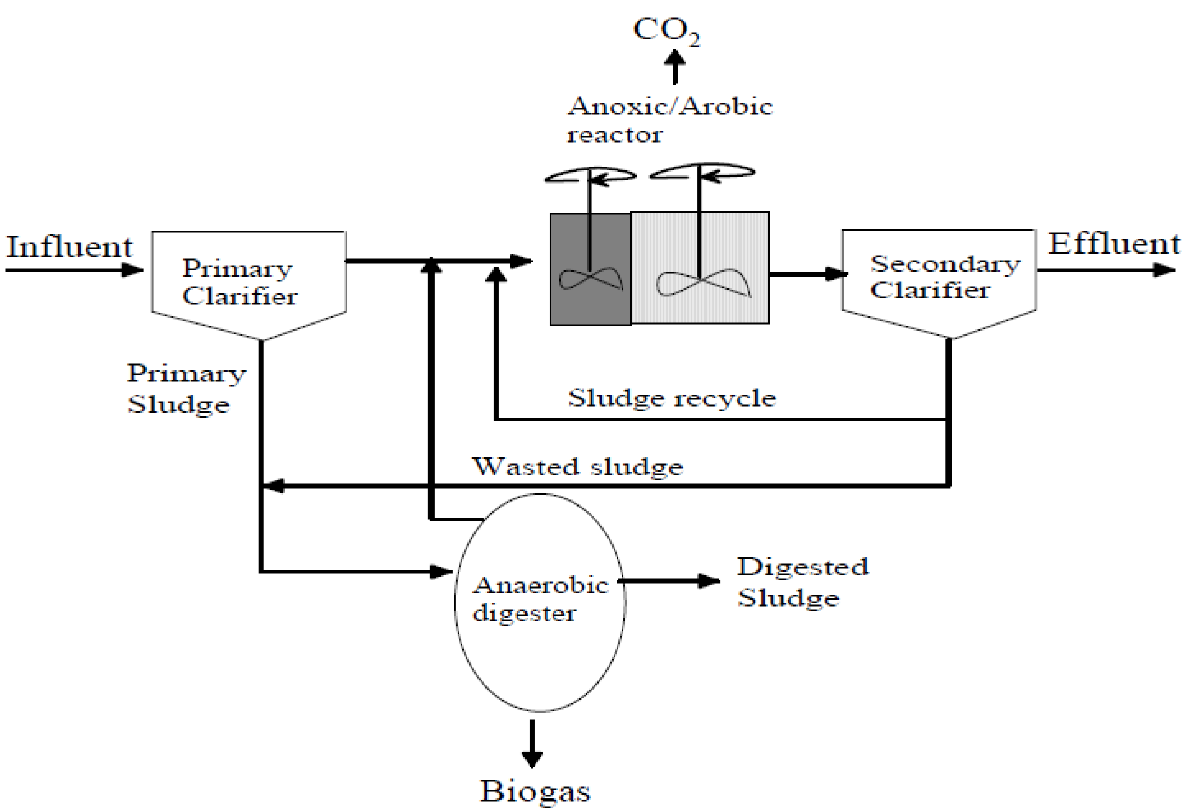

Figure: 2.2 Flow diagram representation of aerobic treatment system with digester[22].

According to Colliver and Stephenson[50],the ammonium ion which is oxidized to nitrate ion using O_2 as electron acceptor in nitrification process. The sequential biological processes such as nitrification and denitrification removes nitrogen which is present in wastewater as ammonium ions Nitrous oxide can be generated during biological wastewater treatment processes. As N_2O has around 300 hundred times effect as compared to CO_2 it is considered an important GHG even if it has low emissions. The source and magnitude of N_2O emissions in WWTPs is relatively difficult to identify . Generally, N_2O emissions depend on The operational parameters of WWTPs and environmental conditions determine N_2O emissions.

Yang et al.,[51] examined that nitrite is considered as an important factor causing N_2O production that reduces the advantages of nitrogen removal via nitrite. $N_2$0 production during nitrogen removal through nitrite is 1.5 times higher than that of nitrogen removal through nitrate .NO_2- is reduced to the intermediates NO and N_2O or N_2 by the bacteria able to carry out complete nitrogen cycle and autotrophic nitrifying bacteria at reduced oxygen level. The biological activity by ammonia oxidizer which is called nitrifier denitrification by the biological activity produces NO and N_2O is shown in figure 2.2 and figure 2.3.

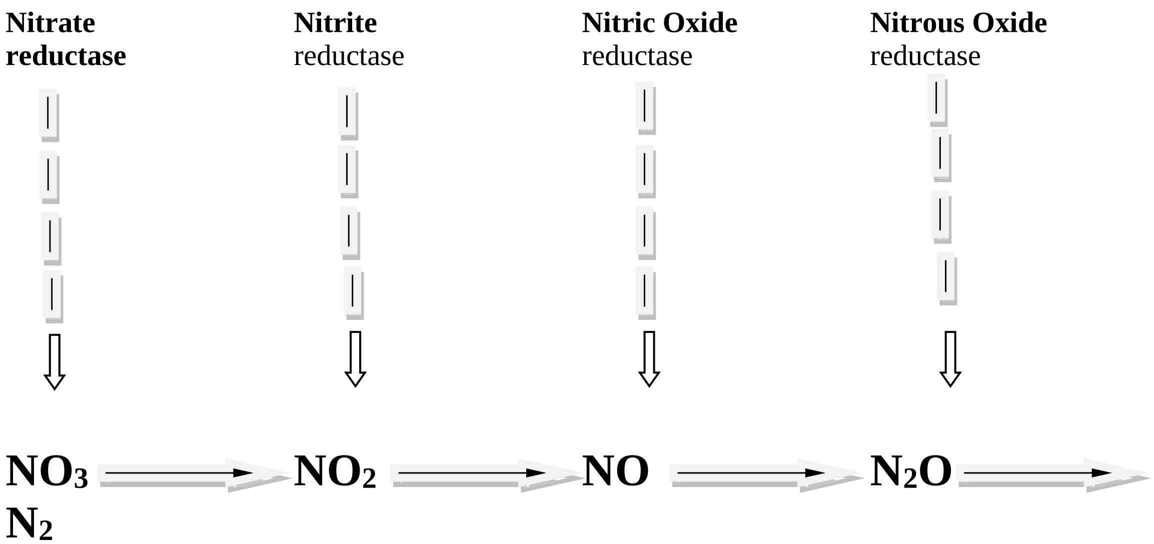

Figure 2.3 - Nitrifier denitrification: hypothetical pathway and enzymes involved[51].

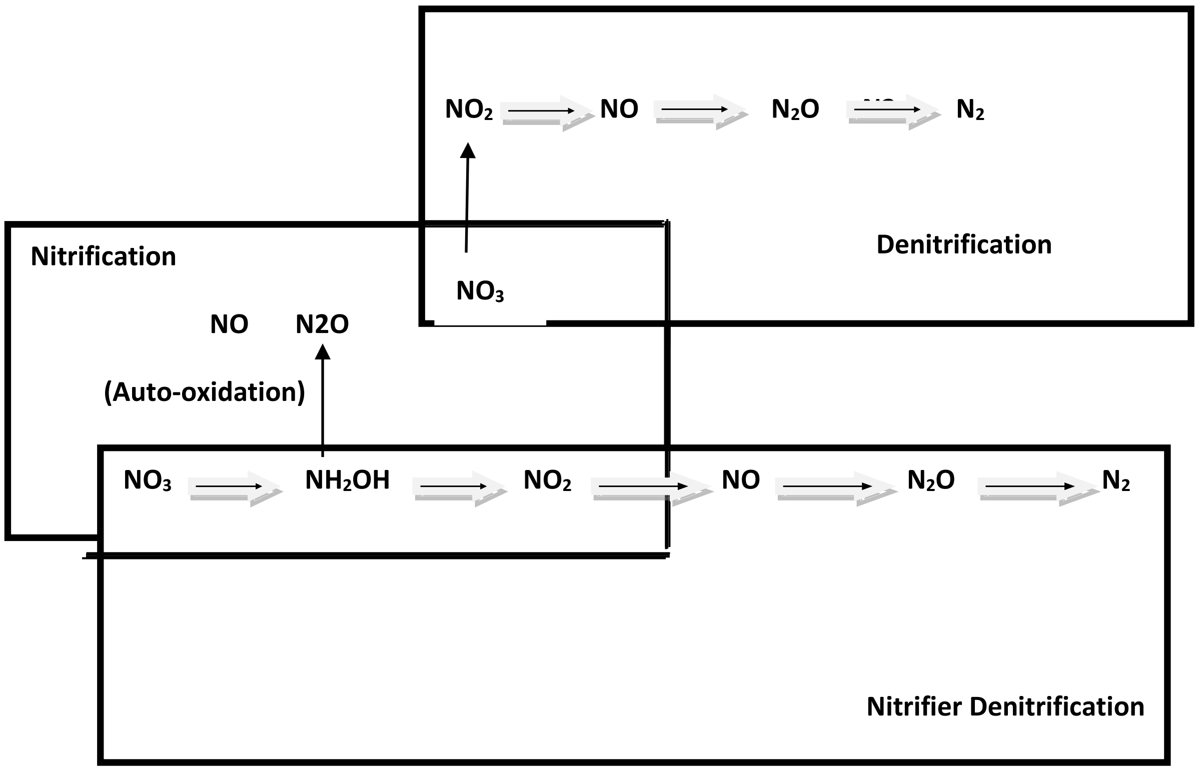

Figure 2.4 - Pathways for nitrous oxide production[51].

2.4 Global Scenario of GHGs Emissions from Waste Water Treatment Plants and Protocol

In year 2000 about nine percent of the total global anthropogenic CH_4 emissions is due to wastewater treatment which is the fifth largest source for methane emissions.

Forty-nine percent of the world's methane emissions from wastewater treatment is due to the combined emissions by India, Indonesia, United States and Indonesia. By 2005 and 2020,the total global CH_4 emissions from wastewater are about to grow by twenty percent. As a source wastewater is the sixth largest contributor to N2O emissions globally, contributing to about 3 % of N2O emissions from all sources. About fifty percent of nitrous oxide emissions in 2000 is caused by India, China, Indonesia and United States. Between 2005 and 2020, global nitrous oxide emissions from wastewater are about to grow by thirteen percent.

Regionally, the highest percentages for methane emissions from wastewater are from Asia mostly from China and India. Countries including Turkey, Bulgaria, Iran,Brazil, Nigeria and Egypt have high emissions in their respective regions. It is expected that the total methane emissions from wastewater handling is to rise by more than forty-five percent .It has been projected by EU that emissions will be lower in 2020 compared to 1990. About forty-five percent increase in the net methane emissions from wastewater handling is expected from 1990 to 2000 with major contribution in the increase from countries from East and South Asia,the Middle East, the Caribbean, and Central and South America. (US EPA, 2006).

According to Corbier et al.[52], the GHG Protocol is an internationally accepted protocol for quantifying GHG emissions. It is a joint initiative by World Business Council for Sustainable Development(WBCSD) and World Resources Institute(WRI) and serves as the premier source of knowledge about corporate GHG accounting and reporting.

The various studied made to evaluate the GHGs emissions from sewage treatment plants follow different protocols and procedures which give an approximate value of the emissions. In this study, an attempt has been made to quantify green house gases emissions based on IPCC 2006 guidelines which is internationally accepted and gives more exact value as compared to other metods.

CHAPTER-3
METHODOLOGY

CHAPTER-3
METHODOLOGY

The data required for the evaluation of green house gases emissions were collected from the respective sewage treatment plants namely Okhla, Rithala, Keshopur and Yamuna Vihar. Also the visits were made to Delhi Jal Board and Delhi Pollution Control Committee for obtaining the values for methane correction factor of the concerned treatment plants and other parameters required for estimating GHGs emissions. Procedures and protocols for quantifying the emissions were followed as per IPCC 2006 guidelines.

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. Hundreds of companies and organizations around the world are using GHG Protocol standards and tools to manage their emissions and become more efficient, resilient, and prosperous organizations. It establishes a comprehensive, global, standardized framework for measuring and managing emissions from private and public sector operations, value chains, products, cities, and policies.

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. CO_2, CH_4 and N_2O are calculated for STP. CO_2 emissions from STP 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.

In Scope 2 emissions are from 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.

Secondly, 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 January 2014 to December 2014.

Thirdly,GHGs emissions from STP are calculated. We have followed IPCC 2006 Guidelines for National Greenhouse Gas Inventories for calculating GHG emissions from STPs.

3.2 Study Area

Following STPs are taken into consideration for evaluation of GHGs Emissions.

3.2.1 Okhla Sewage Treatment Plant:

Okhla STP has 170 MGD capacity with conventional activated sludge process .It has been constructed by Delhi Jal Board in six phases, namely Ph-I 12 MGD , Ph-II 16 MGD, Ph.-III 30 MGD , Ph.-IV 37 MGD, Ph.- V 45 MGD and Ph.-VI 30 MGD for treatment of sewage .It treats sewage generated in ring road catchment area in north Delhi, central Delhi and part of south Delhi. STP is receiving about 110 MGD of sewage. Power failure is a point of concern since it affects the sewage treatment and results in anaerobic decomposition of sewage due non- functioning of surface aerators which supply oxygen and thus results in release of methane gas.DPCC and DJB does the sampling and testing of the effluent and gives the result whether the effluent is meeting the standards or not.

3.2.2 Rithala Sewage Treatment Plant:

Rithala STP has a capacity of approximately 80 MGD and incorporates activated sludge process for sewage treatment. It has been established by Delhi Jal Board and consists of two phases each having 40MGD sewage treatment capacity generated in Rithala-Rohini catchment area in west Delhi. Phase –I of the STP is receiving about 8MGD and Phase –II about 41 MGD of wastewater. Bio-gas produced in Ph.-I as well as in Ph.-II of the plant is used for power generation through gas engines installed under Ph.-II. No stand-by arrangement for running the plant during power cut. Sampling and testing of effluent is done both by DPCC and in the DJB in their laboratory.

3.2.3 Keshopur Sewage Treatment Plant:

The capacity of Keshopur STP is 72 MGD with conventional activated sludge process.It comprises of three phases, namely Ph-I 12 MGD, Ph-II 20 MGD, and Ph.-III 40 MGD for treatment of sewage being received from Keshopur zone catchment area in west Delhi. All the three phases are having activated sludge process for treatment of sewage. Maintenance of all the phases is being done by DJB. STP is receiving a total combined quantity of about 67 MGD of sewage in all the three phases. No stand by arrangement for running the plant during power cut.

3.2.4 Yamuna Vihar Sewage Treatment Plant:

Yamuna Vihar STP has capacity of 20 MGD with conventional activated sludge process .It has been constructed by Delhi Jal Board in two phases. Ph-I 10 MGD and Ph-II 10 MGD for treatment of sewage generated in part of Trans Yamuna area of East Delhi. STP is receiving about 6 MGD of sewage in Ph.-I and 3 MGD in Ph.-II. STP is not fully utilized as there is lack of house sewer connections/sewer lines in the catchment area. There is a diesel generator in case of power failure but is rarely used. Testing and sampling of effluent regularly done by DPCC and DJB. Figure 3.1 shows the flow diagram of sewage treatment plants at Okhla, Keshopur ,Yamuna Vihar and Rithala

Phase-I. Figure 3.2 shows typical flow diagram of sewage treatment plant located at Rithala Phase- II.

Table 3.1 Design Sewage Treatment Capacity and Actual Sewage Flow of the Treatment Plants.

Sewage Treatment Plant	Design Treatment Capacity(MGD)	Actual Sewage Flow(MGD)	Percent Utilization of Plant
Okhla Plant Phase 1st,2nd,3rd,4th,5th&6th	170	110	64.7
Rithala Plant Phase 1st&2nd	80	49	61.2
Keshopur Plant Phase 1st,2nd &3rd	72	67	93.05
Yamuna Vihar Plant Phase 1st&2nd	20	9	45

Data Source: Delhi Jal Board,Respective STPs.

The Table 3.1 shows design sewage treatment capacity and actual sewage flow of the STPs. The Keshopur STP has the highest utilization percentage among all the major four plants. The Yamuna Vihar plant which has the lowest actual sewage flow has also the lowest percent utilization. All the plants are meeting the standards as set by Delhi Pollution Control Committee for the BOD present in the discharge effluent.

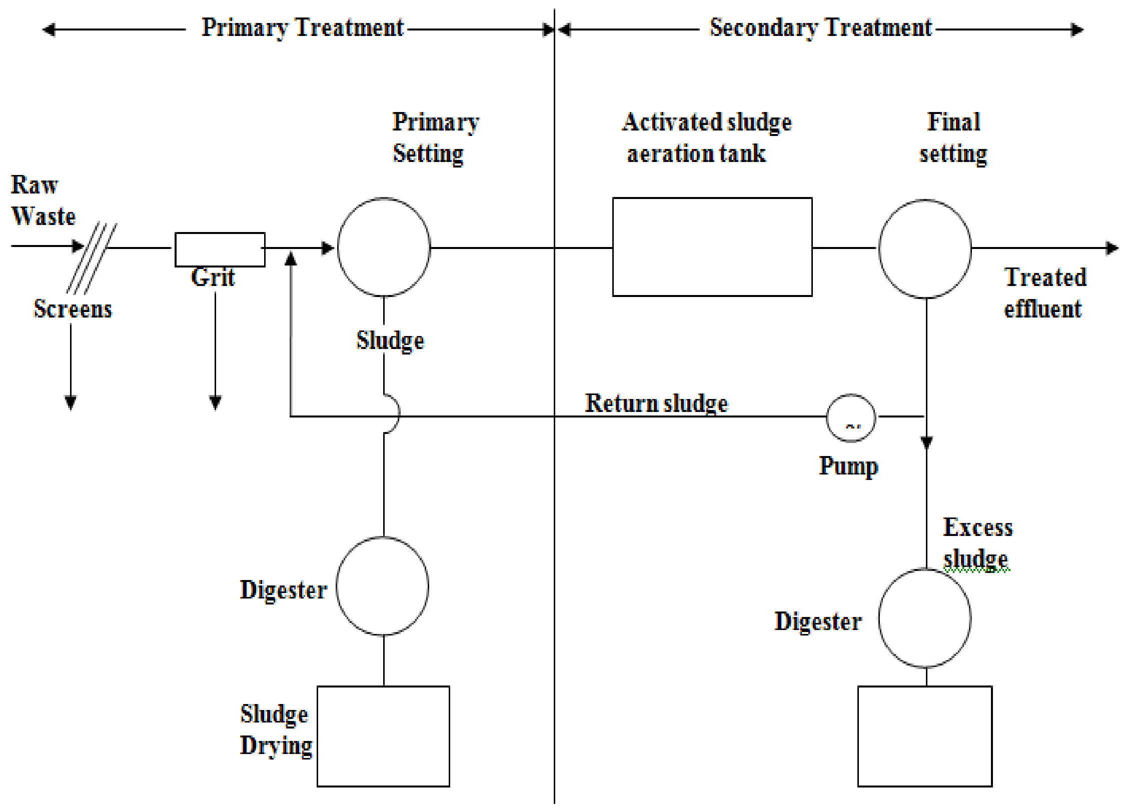

Figure- 3.1 Flow Diagram of Sewage Treatment Plants at Okhla, Keshopur ,Yamuna Vihar and Rithala Phase-I.

In the sewage treatment plant, the activated sludge process is a biological process that involves air or oxygen being introduced into a mixture of screened, and primary treated sewage combined with organisms to develop a biological floc which reduces the organic content of the sewage. The combination of wastewater and biological mass is commonly known as mixed liquor. In all activated sludge plants, once the wastewater has received sufficient treatment, excess mixed liquor is discharged into settling tanks and the treated supernatant is run off to undergo further treatment before discharge. Part of the settled material, the sludge, is returned to the head of the aeration system to re-seed the new wastewater entering the tank. This fraction of the floc is called return activated sludge.

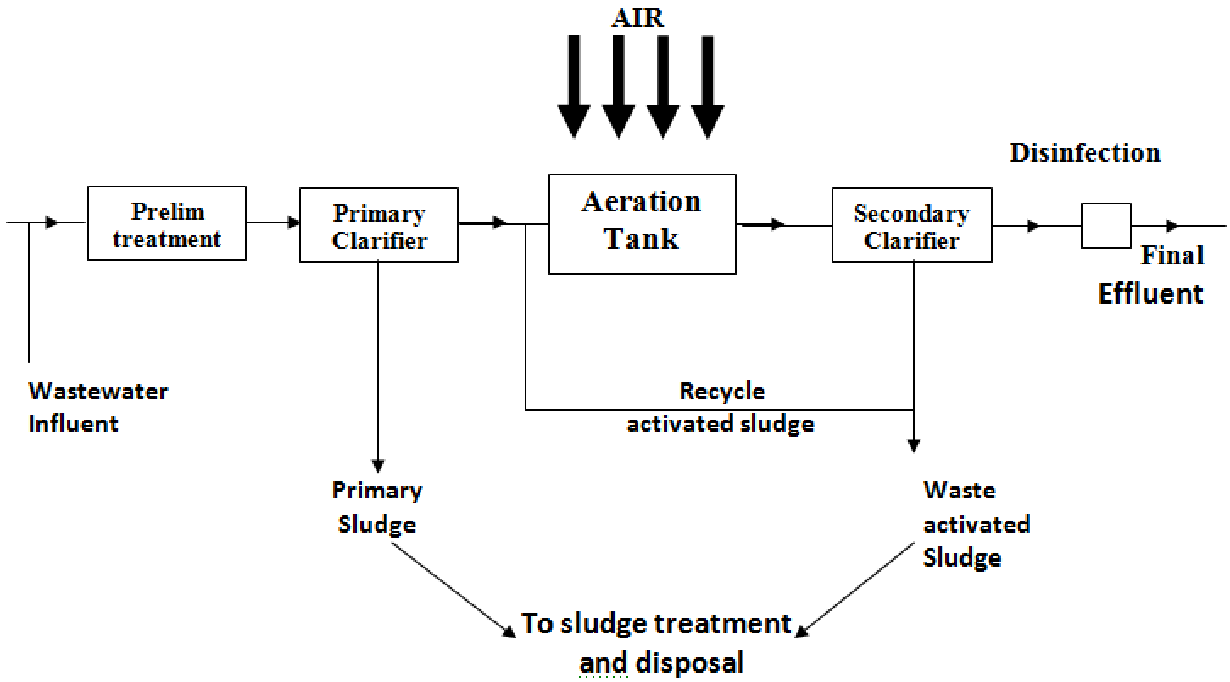

Figure 3.2 – Typical Flow Diagram of Sewage Treatment Plant located at Rithala Phase-II.

Tertiary treatment including chlorination is carried out at Rithala Phase-II STP apart from other treatment processes including preliminary,primary and secondary treatment. The treated effluent is discharged into the Najafgarh drain which is finally discharged into Yamuna river. The water after disinfection is used by the plant for various use including for the purpose of drinking.

3.3 Equations for Evaluating GHGs Emissions as per IPCC 2006 Guidelines

3.3.1 Total CH_4 Emissions from Domestic Wastewater is given by:

$$\left[\sum_{i,j}(U_i * T_{i,j} * EF_j)\right](TOW-S)-R$$

Where:

CH_4 Emissions = CH_4 emissions in inventory year, kg CH_4/yr
TOW = total organics in wastewater in inventory year, kg BOD/yr
S = organic component removed as sludge, kg BOD/yr
U_i = fraction of population in income group *i* in inventory year.
$T_{i,j}$ = degree of utilisation of treatment/discharge pathway or system, *j*, for each income group fraction *i* in inventory year
i = income group: rural, urban high income and urban low income
j = each treatment/discharge pathway or system
EF_j = emission factor, kg CH_4 / kg BOD
R = amount of CH_4 recovered in inventory year, kg CH_4/yr

3.3.2 Total Organics in Wastewater

TOW (kg BOD/cap/yr) = P * BOD * 0.001 * I * 365

Where:

TOW = total organics in wastewater in inventory year, kg BOD/yr
P = country population in inventory year, (person)
BOD = country-specific 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.)

3.3.3 Methane emission factor

CH_4 Emission Factor for each domestic wastewater Treatment/Discharge Pathway System:

$$EF_j = B_o * MCF_j$$

Where:

EF_j = emission factor, kg CH_4/kg BOD

j = each treatment/discharge pathway or system

Bo = maximum CH_4 producing capacity, kg CH_4/kg BOD

MCF_j= methane correction factor (fraction)

3.3.4 N_2O Emissions from wastewater effluent

$$N_2O\ Emissions = N_{EFFLUENT} * EF_{EFFLUENT} * 44/28$$

Where:

N_2O emissions = N_2O emissions in inventory year, kg N_2O/yr

$N_{EFFLUENT}$ = nitrogen in the effluent discharged, kg N/yr

$EF_{EFFLUENT}$ = emission factor for N_2O emissions from discharged wastewater, kg N_2O-N/kg N

The factor 44/28 is the conversion of kg N_2O-N into kg N_2O.

3.3.5 Total Nitrogen in the Effluent

$$N_{EFFLUENT} = (P * Protein * F_{NPR} * F_{NON\text{-}CON} * F_{IND\text{-}COM}) - N_{SLUDGE}$$

Where:

$N_{EFFLUENT}$ = total annual amount of nitrogen in the wastewater effluent, kg N/yr

P = human population

Protein = annual per capita protein consumption, kg/person/yr

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

$F_{NON\text{-}CON}$ = factor for non-consumed protein added to the wastewater

$F_{IND\text{-}COM}$ = factor for industrial and commercial co-discharged protein into the sewer system

N_{SLUDGE} = nitrogen removed with sludge (default = zero), kg N/yr

CHAPTER-4

RESULTS AND DISCUSSIONS

CHAPTER-4

RESULTS AND DISCUSSION

4.1 Calculation of Total Organics in Wastewater

TOW (kg BOD/cap/yr) = P * BOD * 0.001 * I * 365

Where:

TOW = total organics in wastewater in inventory year, kg BOD/yr
P = country population in inventory year, (person)
BOD = country-specific 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.)

TOW (kg BOD/cap/yr) = P * BOD * 0.001 * I * 365
Population of Delhi = 16787941
Per capita BOD(gBOD/day) = 46.8

Hence, TOW = 16787941*46.8*0.001*1.25*365

= 358464510.2 kg BOD/cap/yr--------------(1)

4.2 Estimation of methane emission factor

CH_4 Emission Factor for each domestic wastewater Treatment/Discharge Pathway System:

EFj = Bo * MCFj

Where:

EFj = emission factor, kg CH_4/kg BOD

j = each treatment/discharge pathway or system

Bo = maximum CH_4 producing capacity, kg CH_4/kg BOD

MCFj= methane correction factor (fraction)

Maximum methane producing capacity (Bo)(kg CH_4/ kg BOD) =0.6

Methane correction factor (MCFj) = 0.001(See Appendix-II, Table A.4)

Hence, Emission factor(EFj)(kg CH_4/kg BOD) = 0.6*0.001 =0.0006----------------(2)

4.3 Calculation for methane emissions

Type of treatment or discharge is Aerobic.

Fraction of Population income group (Ui) fraction for Delhi is as follows:

Rural=0.07

Urban High=0.66

Urban Low=0.27

Average total=0.333

Degree of utilization of treatment, discharge pathway or method (Tij) for each income group:

Rural=0.00

Urban High=0.95

Urban Low=0.99

Average Total= 0.65

Table 4.1 Urbanization and Degree of utilization of treatment

	Income Group		
	Rural	Urban High	Urban Low
Urbanization(Ui)	0.07	0.66	0.27
Tij	0.00	0.95	0.99

Source: DPCC

The country-specific values for Urbanization and degree of utilization of treatment is obtained from Delhi Pollution Control Committee and shown in Table 4.1. Although the default values for these parameters are available by IPCC 2006 guidelines but for more accurate and exact results the data specific for Delhi is taken.

Using the values of Ui and Tij form Table 4.1 and TOW and Emission factor from equation(1)&(2) in the governing equation below, we get methane emissions as:

$$\textbf{Total } CH_4 \textbf{ Emissions} = \left[\sum_{i,j}(U_i * T_{i,j} * EF_j)\right](TOW-S)-R$$

Net CH_4 Emissions(kg CH_4/yr) = 358464510.2*0.0006*0.65*0.333

= 46553.78.

GWP for Methane = 25 (Source: IPCC FAR,2007)

Total CO_2et = 46.55378*25=**1164 tCO_2e/yr** (approx.)

4.4 Calculation of N_20 Emissions from the Sewage Treatment Plant

The governing equation for the estimation of methane from domestic waste water is as follows:

$$N_2O \text{ Emissions} = N_{EFFLUENT} * EF_{EFFLUENT} * 44/28$$

Where:

N_2O emissions = N_2O emissions in inventory year, kg N_2O/yr

$N_{EFFLUENT}$ = nitrogen in the effluent, kg N/yr

$EF_{EFFLUENT}$ = emission factor for N_2O emissions from discharged to wastewater, kg N_2O-N/kg N

The factor 44/28 is the conversion of kg N_2O-N into kg N_2O.

4.5 Total Nitrogen in the Effluent

$$N_{EFFLUENT} = (P * Protein * F_{NPR} * F_{NON\text{-}CON} * F_{IND\text{-}COM}) - N_{SLUDGE}$$

Where:

$N_{EFFLUENT}$ = total annual amount of nitrogen in the wastewater effluent, kg N/yr

P = human population

Protein = annual per capita protein consumption, kg/person/yr

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

$F_{NON\text{-}CON}$ = factor for non-consumed protein added to the wastewater

$F_{IND\text{-}COM}$ = factor for industrial and commercial co-discharged protein into the sewer system

N_{SLUDGE} = nitrogen removed with sludge (default = zero), kg N/yr

Total Nitrogen in the Effluent =16787941*0.056*0.16*1.4*1.25

= 263234.9 kg N/year ---------------------(3)

Net N_2O Emission = 263234.9*.0005*1.57-------------from(3)

= **206.6 kg N_2O/year**

GWP for N_2O = 298 (IPCC FAR,2007)

Total CO_2e Emission = 61566.8 kgCO_2e/yr = **62tCO_2/yr**(approx.)

Hence, Total Direct GHGs Emissions(CH_4&N_2O) = (Total CH_4+Total N_20)Emissions

= **1164+62=1226tCO_2/yr**

4.6 Methane Emissions

a.) Net CH_4 Emissions (kg CH_4/yr) from four STPs combined = 186216

b.) Net CH_4 Emissions (tCO_2e/yr) from four STPs combined = 4656

4.7 Nitrous Dioxide Emissions

a.) Net N_20 Emissions (kg N_20/yr) from four STPs combined = 828

b.) Net N_20 Emissions (tCO_2e/yr) from four STPs combined = 248

The individual methane emissions and nitrous dioxide emissions from all the four STPs are same and the net emissions from all the four STPs are obtained by the addition of emissions by each sewage treatment plants. The methane emissions from each treatment plants is same because of the same MCF values which was provided by the Delhi Jal Board.

4.8 Indirect GHGs Emissions

a.) Emissions from Okhla STP(tCO_2e/yr) = 14240

b.) Emissions from Rithala STP(tCO_2e/yr) = 10560

c.) Emissions from Keshopur STP(tCO_2e/yr) = 17413

d.) Emissions from Yamuna Vihar STP(tCO_2e/yr) = 2933

Table 8. Summary of Power Consumption and Methane Correction Factor of Plants.

Plants	Power Consumption(MWH/yr)	MCF
Okhla Sewage Treatment Plant	17365	0.001
Rithala Sewage Treatment Plant	12878	0.001
Keshopur Sewage Treatment Plant	21236	0.001
Yamuna Vihar Sewage Treatment Plant	3577	0.001

The above the table shows the summarized power consumption of the various concerned STPs. The energy consumption data is obtained from the respective STPs and the Delhi Jal Board Head Office.The power consumption of the Keshopur sewage treatment plant is highest among the four treatment plants. The Keshopur plant(72 MGD) is more efficiently working inspite of the fact that the sewage which is being treated by this plant is less as compared to Okhala and Rithala STP which is 170MGD and 80 MGD repectively.The Methane correction factor which gives an idea about the efficiency of the plant and the extent to which the plant is anaerobic is provided by the respective plants which has approximately the same value. Although all the plants of this study are based on aerobic treatment of sewage but because of their not proper functioning and due to unavailability of power at sometime, the anaerobic degradation of the sewage starts and they start emitting methane.

Table 7. Total CO_2 equivalent indirect emission from the STPs.

Plant	Power Consumption(MWH/Yr.)	Emission Factor (t CO_2/MWH)	Total CO_2 Equivalent Emission(t CO_2e/yr)
Okhla STP	17365	0.82	14240
Rithala STP	12878	0.82	10560
Keshopur STP	21236	0.82	17413
Yamuna Vihar STP	3577	0.82	2933

The emission factor is available from Central Electricity Authority,CO_2 Baseline Database for Indian Power Sector 2014.The power consumption by various components of the plant viz. pumps,surface aerators etc. for the treatment of sewage results in the indirect GHGs emission. CO_2 emissions per unit of electricity is a regional value and varies on yearly basis. The equivalent CO_2 emissions from the plants are obtained by multiplying the yearly power consumption with the emission factor for the concerned year. The carbon content in the coal and the specific coal usage by the thermal power plants producing electricity determines the CO_2 emissions. Central Electricity Authority (CEA) has compiled a database containing the necessary data on CO_2 emissions for all grid-connected power stations in India. The Indian electricity system is divided into two grids, the Integrated Northern, Eastern, Western, and North-Eastern regional grids (NEWNE) and the Southern Grid. Each grid covers several states. As the grids are interconnected, there is inter-state and inter-regional exchange. A small power exchange also takes place with the neighbouring countries Bhutan and Nepal. For each of the two grids, the main emission factors are calculated in accordance with the relevant CDM methodologies. CEA will continue updating the database at the end of each fiscal year.

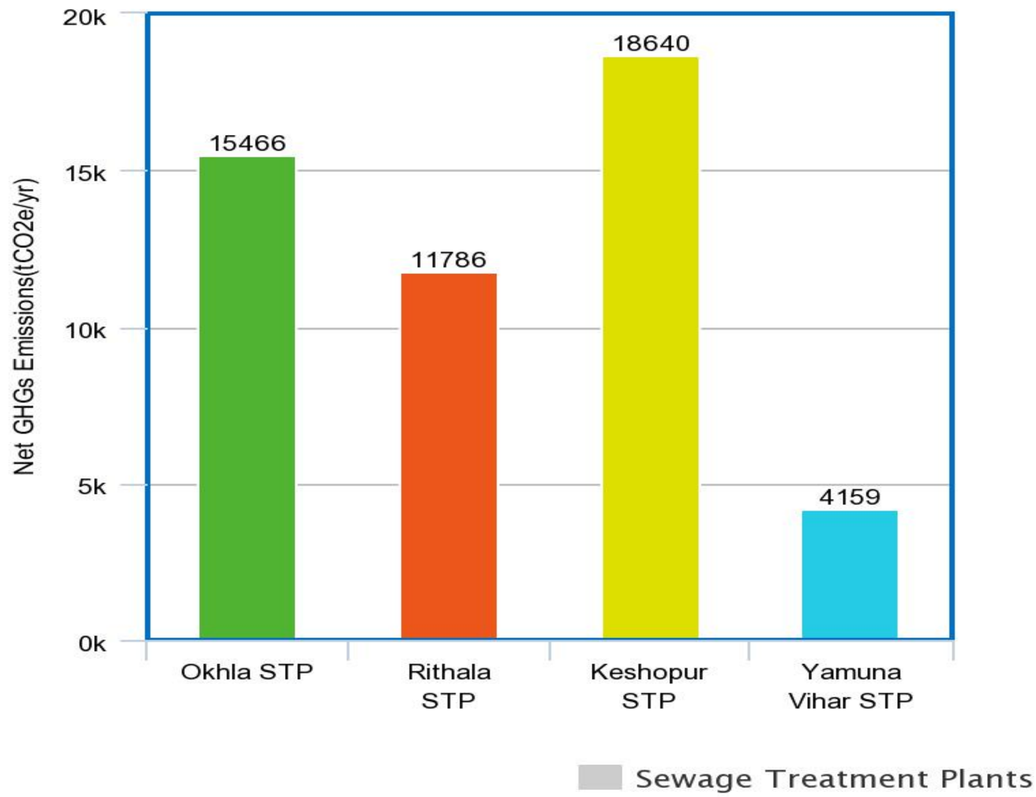

Figure 4.1: Net GHGs Emissions from different STPs

The net green house gases emissions are the sum total of the direct and the indirect emissions from the plants. It is found that Keshopur plant(72MGD) has the highest emissions which is 18640tCO_2/yr and Yamuna Vihar STP has the lowest emission of 4159tCO_2/yr. The lowest emission of Yamuna Vihar STP is primarily because the volume of the sewage being treated at this plant is less as compared to the other plants.Directions by the Delhi Jal Board have been given to Keshopur plant to reduce the power consumption so that the emission of green house gases can be minimized.

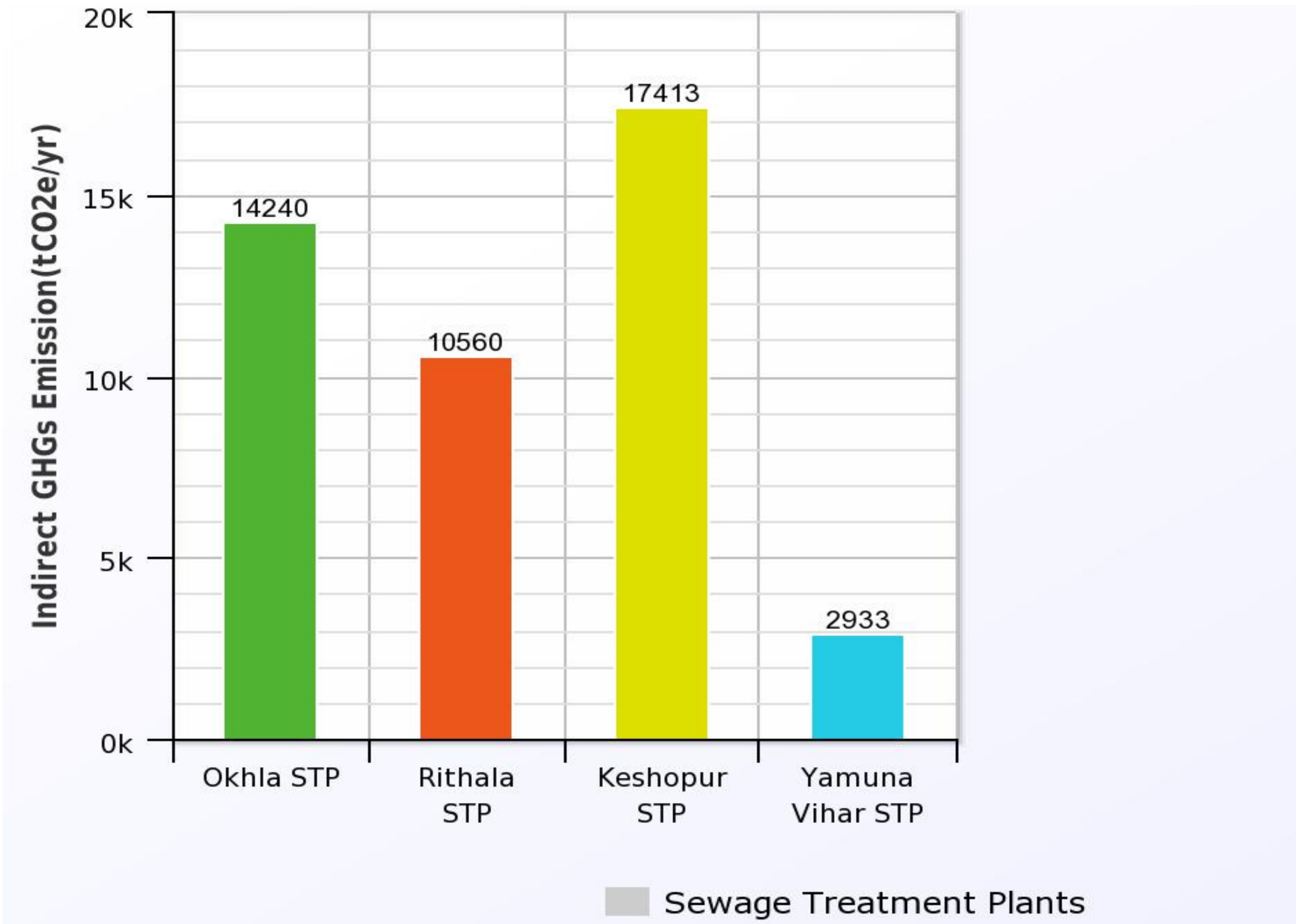

Figure 4.2 : Off-Site GHGs Emissions from STPs

The Off-Site green house gases emissions are the indirect emissions due to consumption of electricity for operating the various units of the plant. It is found that the Yamuna Vihar STP has the lowest indirect GHGs emissions and Keshopur has the highest. The indirect emissions may also be due to various miscellaneous activities including the energy consumption by the staffs at the plant for their personal use. But here we are taking into consideration the energy consumption only for the operation of various treatment units at the plant. The approximate energy consumption of two phases of Rithala sewage treatment plant is obtained from the plant manager due to the unavailability of the electricity bills of few months at the time of visit.

CHAPTER-5

CONCLUSION

CONCLUSION

The direct GHGs emissions from four STPs combined is 4904 tCO_2e/yr while the combined indirect emissions is 45146 tCO_2e/yr. The result indicates that the amounts the indirect green house gases emissions were significantly higher than the direct emissions at all the four STPs.

CH_4 production from all the four plants is assessed as 4656 tCO_2e/yr and 248 t CO_2e/yr as N_2O emissions. The four sewage treatment plants which have been studied are the major treatment plants which combined together treats more than 70 percent of the total sewage generated in Delhi.

The Keshopur plant where the actual flow of the sewage to be treated is less as compared to flow at Okhla plant is producing more indirect emissions. The higher emissions from the Keshopur plant can be reduced by reducing the power consumption for various other miscellaneous activities including the personal use by the staffs at the plant. The emission of direct green house gases from all the plants are same because of the same value for methane correction factor.

Methane 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.

As the anaerobic treatment process does not consume much power as compared to the aerobic process, the use of anaerobic process based treatment plants is more economical and environment friendly.

SCOPE FOR FUTURE STUDY

The indirect GHGs emissions related with construction of infrastructure including the treatment units and various other miscellaneous activities concerned with the sewage treatment plants can be measured in the future study.

The country-specific value for the organic component removed as sludge and the amount of CH_4 recovered in inventory year can be taken for getting more accurate methane emission values from the plant. Some of the plants are recovering the methane produced during the treatment and also the biogas which is again used for the production of electricity and thus reduces the indirect emissions from the plants.

The GHGs emissions related with transportation of various equipments and energy consumption by the man power at the plant can also be taken into account. Also, apart from the domestic sewage treatment plants, the study of those plants which are treating industrial wastewater can be made so that it can be compared that which of the two is producing more emissions.

Also, a comparison can be made between the GHGs emissions from the STPs between two consecutive years to ascertain whether the emissions from plants are reducing or not.

REFERENCES

(1). Monteith, H. D., Sahely, H. R., MacLean, H. L., and Bagley, D. M. (2011). A rational procedure for estimation of greenhouse-gas emissions from municipal wastewater treatment plants. *Water Environment Research*, 77(4), 390-403.

(2). Scanlan, P., Elmendorf, H., Santha, H., and Rowan, J. (2008). How green is your footprint? The impact of greenhouse gas emissions on strategic planning. In Session 12:Climate Change Management, Mitigation, and Adaption. *Proceedings of the Water Environment Federation, Sustainability*, 10, 783-792.

(3). El-Fadel, M., and Massoud, M. (2010). Methane emissions from wastewater management. *Environmental Pollution*, 114(2), 177-185.

(4). Baede, A.P.M., Ahlonsou, E., Ding, Y., and Schimel, D. (2010). The Climate System: An overview in climate change 2001. The scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, The Intergovernmental Panel on Climate Change (IPCC).The Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press,Cambridge, UK. 87-98.

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

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

(7). Shaw, A. R., Third, K. A., and Cooper, S. (2008). The importance of selecting the right greenhouse gas model for sustainable design decisions in wastewater treatment. In session 4: Climate change mitigation at WWTPs. *Proceedings of the Water Environment Federation, sustainability*, 4, 260-263.

(8). Oennerth, T.B., Nielsen, M.K., Stamer, C., (2002). Advanced computer control based on real and software sensors. *Water Science Technology* 33 (1), 237-245.

(9). Ingildsen, P., Jeppsson, U., Olsson, G., (2009). Dissolved oxygen controller based on on-line measurements of ammonium combining feed-forward and feedback. *Water Science Technology* 46(8-9), 454-465.

(10). Devisscher, M., Bogaert, H., Bixio, D., Van de Velde, J., Thoeye, C., (2006). Feasibility of automatic chemicals dosage control: a full scale evaluation. Water Science Technology 45, 4-5. 448-452.

(11). Olsson, G., Nielsen, M.K., Yuan, Z., Lynggaard-Jensen, A., Steyer, J.P. 2010. Instrumentation, Control and Automation in Wastewater Systems. IWA Publishing, London, UK.

(12). Zhao, H., Isaacs, S.H., Soeberg, H., Kummel, M., (2007). An analysis of nitrogen removal and control strategies in an alternating activated-sludge process. *Water Resources* 29 (2), 535-544.

(13). Spanjers, H., Vanrolleghem, P.A., Nguyen, K., Vanhooren, H.,Patry, G.G., 2007. Towards a simulation-benchmark for evaluating respirometry-based control strategies. *Water Sci.Technol.* 37 (12), 219-226.

(14). Corominas, L., Sin, G., Puig, S., Traore, A., Balaguer, M., Colprim, J., Vanrolleghem, P.A., 2006. Model-based evaluation of an online control strategy for SBRs based on OUR and ORP measurements. *Water Sci. Technol*. 53 (4-5), 161-169.

(15). Stare, A., Vrecko, D., Hvala, N., Strmcnik, S., 2007. Comparison of control strategies for nitrogen removal in an activated sludge process in terms of operating costs: a simulation study. *Water Res*. 41 (9), 2004-2014.

(16). Flores-Alsina, X., Sin, G., Rodriguez-Roda, I., Gernaey, K.V., 2008. Multi criteria evaluation of wastewater treatment plant control strategies under uncertainty. *Water Res.* 42 (17), 4485-4497.

(17). Machado, V.C., Gabriel, D., Lafuente, J., Baeza, J.A., 2009. Cost and effluent quality controllers design based on therelative gain array for a nutrient removal WWTP.*Water Res.* 43 (20), 5129-5141.

(18). Gujer, W., Erni, P., 1978. The effect of diurnal ammonium load variation on the performance of nitrifying activated sludge processes. Prog. *Water Technol*. 10 (5/6), 391-407.

(19). Lessard, P., Beck, M.B., 1993. Modelling of the activated sludge process: a case of Norwich plant. *Water Res*. 27 (6), 963-978.

(20). Jeppsson, U., Pons, M.N., Nopens, I., Alex, J., Copp, J.B., Gernaey, K.V.,Rosen, C., Steyer, J.P., Vanrolleghem, P.A., 2007. Benchmark simulation model no 2 a general protocol and exploratory case studies. Water Sci. Technol. 56 (8), 287-295.

(21). Bridle, T., Shaw A., Cooper S., Yap K.C., Third K., Domurad M.2008. Estimation of greenhouse gas emissions from wastewater treatment plants. In: Proceedings IWA World Water Congress 2008, Vienna, Austria. September 7-12, 2008.

(22). Shahabadi, B. M., Yerushalmi, L., and Haghighat, F. (2010). Estimation of greenhouse gas generation in wastewater treatment plants - model development and application. *Chemosphere*, 78(9), 1085-1092.

(23). Cakir, F. Y., and M. K. Stenstrom. (2005). Greenhouse gas production: A comparison between aerobic and anaerobic wastewater treatment technology. *Water Research*, 39,(17): 4197-4203.

(24). von Schulthess, R., Gujer, W., 2009. Release of nitrous oxide (N_2O) from denitrifying activated sludge: verification and application of a mathematical model. *Water Res.* 30 (3),521-530.

(25). Hiatt, W.C., Grady Jr., C.P.L., 2008b. Application of the activated sludge model for nitrogen to elevated nitrogen conditions. *Water Environ. Res.* 80, 2134-2144.

(26). Foley, J., de Haas, D., Yuan, Z., Lant, P., 2010. Nitrous oxide generation in full-scale biological nutrient removal wastewater treatment plants. *Water Res.* 44, 831-844.

(27). Batstone, D.J., Keller, J., Angelidaki, I., Kayuznyi, S.V., Pavlostathis, S.G., Rozzi, A., Sanders, W.T.M., Siegrist, H., Vavilin, V.A., 2009. Anaerobic Digestion Model No 1. IWA Publishing, London, UK. IWA STR No 13.

(28). Greenfield, P.F., Batstone, D.J., 2003. Anaerobic digestion: impact of future previous term greenhouse next term gases mitigation policies on methane generation and usage. *Water Sci. Technol.* 52 (1-2), 39-47.

(29). Sahely, H. R. (2006a) .Urban water systems for sustainable cities. PhD. Thesis, University of Toronto, Toronto, ON, Canada.

(30). Diagger, G. T., Peterson, P. R., Witherspoon, J and Allen, E. (2004). Impact of global warming concerns on wastewater treatment plant design and operation. *Adcances in Water and Wastewater Treatment*, 1-19.

(31). Scheehle, E. A. and Doorn, M. R. J. (2001). Improvements to the U.S. Wastewater Methane and Nitrous Oxide Emission Estimates, U.S. Environmental Protection Agency (EPA). Washington, DC.

(32). Barton, P. K., and Atwater, J. W. (2010). Nitrous oxide emissions and the anthropogenic nitrogen in wastewater and solid waste. *Journal of Environmental Engineering*, 128(2),137-150.

(33). Schulthess, R. V. and Gujer, W. (2007). Release of nitrous oxide (N_2O) from denitrifying activated sludge: verification and application of a mathematical model. *Water Research*,30(3), 521-530.

(34) Thomsen, M., and Lyck, E. (2011). Emission of CH_4 and N_2O from wastewater treatment plants (6B). No. 208. Ministry of the Environment. National Environmental Research Institute, Denmark.

(35). Khalil, M. A. K., and Rasmussen, R. A. (2005). The global sources of nitrous oxide. *Journal of Geophysical Research*, 97, 14651–14660.

(36). Cicerone, R. J. (1989). Analysis of sources and sinks of atmospheric nitrous oxide (N_2O). *Journal of Geophysical Research*, 94(D15), 18, 265-271.

(37). Bliefert, C., and Perraud, R. (2010). Environmental chemistry, air, water, soils, waste. De Boeck, Paris, 181-183.

(38). Hanaki, K., Nakamura, and Matsuo, T. (2006). Nitrous oxide production in nitrogen removal process treating domestic sewage from combined sewer system. *Adcances in Water and Wastewater Treatment Technology*, 153-164.

(39.) Hong, Z., Hanaki, K., and Matsuo, T. (2007). Greenhouse gas- N_2O production during denitrification in wastewater treatment plant. *Water Science Technology*, 28(7), 203–207.

(40). Debruyn, W., Lissens, G., Van Rensbergen, J., and Wevers, M. (2004). Nitrous oxide emissions from waste water. *Environmental Monitoring and Assessment*, 31(1-2), 159-165.

(41). Emmerson, R. H. C., Morse, G. K., Lester, J. N., and Edge, D. R., 2008. The Life-Cycle Analysis of Small-Scale Sewage Treatment Processes. *Journal of Chartered Institution of Water & Environmental Management* **9** (3), 317-325.

(42). Vidal, N., Poch, M., Marti, E., and Rodriguez-Roda, I., 2012. Evaluation of the environmental implications to include structural changes in a wastewater treatment plant. *Journal of Chemical Technology and Biotechnology* **77** (11), 1206-1211.

(43). Gallego, A., Hospido, A., Moreira, M. T., and Feijoo, G., 2009. Environmental performance of wastewater treatment plants for small populations. *Resources Conservation and Recycling* **52** (6), 931-940.

(44). Gaterell, M. R., Griffin, P., and Lester, J. N., 2010. Evaluation of environmental burdens associated with sewage treatment processes using life cycle assessment techniques. *Environmental Technology* **26** (3), 231-249.

(45). Lassaux, S., Renzoni, R., and Germain, A., (2012). Life Cycle Assessment of Water from the Pumping Station to the Wastewater Treatment Plant. *International Journal of Life Cycle Assessment* **12** (2), 118-126.

(46). Yerushalmi, L., Haghighat, F., and Shahabadi, M. B. (2011). Contribution of onsite and offsite processes to greenhouse (GHG) gas emissions by wastewater treatment plants *World Academy of Science, Engineering and Technology*, 54, 618-622.

(47). Kampschreur, M. J., Temmink, H., Kleerebezem, R., Jetten, M. S. M., and van Loosdrecht, M. C. M. (2009). Nitrous oxide emission during wastewater treatment. *Water Research*, 43(17), 4093-4103.

(48). CEA (2014). Central Electricity Authority, Ministry of Power, Govt of India, CO_2 Baseline Database for Indian Power Sector.

(49). Czepiel, P., Crill, P., and Harriss, R. (2009). Nitrous oxide emissions from municipal wastewater treatment. *Environmental Science & Technology*, 29(9), 2352-2356.

(50). Burgess, J. E., Colliver, B. B., Stuetz, R. M., Stephenson, T. (2010). Dinitrogen oxide production by a mixed culture of nitrifying bacteria during ammonia shock loading and aeration failure. *Journal of Industrial Microbiology and Biotechnology*, 29 (6), 309–313.

(51). Yang, Q., Liu, X., Peng, C., Wang, S., Sun, H., and Peng, Y. (2011). N_2O production during nitrogen removal via nitrite from domestic wastewater: Main sources and control method. *Environmental Science and Technology, 43*(24), 9400-9406.

(52). Ranganathan, Corbier, Bhatia (2001). World Resources Institute, World Business Council for Sustainable Development.*The Greenhouse Gas protocol: A Corporate Accounting and Reporting Standard*,2-10.

APPENDIX

APPENDIX

Data Sheet

Table 4. Monthly Power Consumption of Okhla STP(Six Phases) in the year 2014.

Month	Power Consumption(KWH)	Power Consumption (MWH)
January	1739420	1739.42
February	1469160	1469.16
March	1407240	1407.24
April	1516800	1516.80
May	1420780	1420.78
June	1317600	1317.60
July	1490040	1490.04
August	1433090	1433.09
September	1313520	1313.52
October	1418880	1418.88
November	1440000	1440.00
December	1398480	1398.48
Total Consumption	17365010	17365.01

Source: Okhla STP.

Table 5. Monthly Power Consumption of Keshopur STP) in the year 2014.

Month	Power Consumption(KWH)	Power Consumption(MWH)
January	1620500	1620.50
February	1685200	1685.20
March	1623000	1623.00
April	1709900	1709.90
May	1737100	1737.10
June	1762800	1762.80
July	1787200	1787.20
August	1810000	1810.00
September	1837000	1837.00
October	1863700	1863.70
November	1887800	1887.80
December	1912000	1912.00
Total Consumption	21236200	21236.20

The yearly power consumption of Keshopur STP is calculated as 21236 MWH.

Table 6. Monthly Power Consumption of Yamuna Vihar STP in the year 2014

Month	Power Consumption(KWH)	Power Consumption(MWH)
January	257200	257.20
February	287720	287.72
March	259400	259.40
April	285000	285.00
May	247620	247.62
June	269420	269.42
July	303040	303.04
August	329280	329.28
September	322920	322.92
October	351000	351.00
November	332440	332.44
December	331900	331.90
Total Consumption	3576940	3576.94

The yearly power consumption of Yamuna Vihar STP is calculated as 3577 MWH.

The yearly power consumption of Rithala STP 12878 MWH for the year 2014 as confirmed by the plant engineer.

Table A.4 Parameter Values for Estimation of Direct GHGs.

Parameter	Value		Source
Per Capita BOD(gBOD/day)	46.8		DPCC
Population	16787941		Statistical Abstract of Delhi 2014 Report, Govt. of NCT of Delhi
Methane correction factor or each treatment system(MCF_j)	0.001		DJB, Respective Sewage Treatment Plants
B_o, F_{NPR}, $F_{NON\text{-}CON}$, $F_{IND\text{-}COM}$	0.6,0.16,1.4,1.25 respectively.		IPCC 2006
Ui	Rural	0.07	Housing Condition in India NSS Report 2010,MOEF Report 2011
	Urban High	0.66	
	Urban Low	0.27	
Tij	Rural	0.00	Housing Condition in India NSS Report 2010,MOEF Report 2011
	Urban High	0.95	
	Urban Low	0.99	