ASSESSMENT OF MUNICIPAL WASTEWATER TREATMENT SYSTEMS USING LIFE CYCLE ASSESSMENT APPROACH

For the partial fulfillment of the Degree

of

Master of Science

in

Environmental Sciences (Environmental Technology)

Submitted
to

Institute of Environment & Sustainable Development
Banaras Hindu University
Varanasi

Submitted
by

Kamala Bind

June, 2017

CERTIFICATE

This is to certify that dissertation work entitled **"Assessment of Municipal Wastewater Treatment Systems Using Life Cycle Assessment Approach"** submitted by **Miss. Kamala Bind** (Enrolment no.379885) has been carried out during the period of January – May (2017) at National Institute of Hydrology, Roorkee, U.K. The report is being submitted in partial fulfillment of degree of Master of Science in Environmental Science (Environmental Technology), Institute of Environment and Sustainable Development, Banaras Hindu University (B.H.U.).

Course Coordinator

Prof. G.S. Singh

Institute of Environment and Sustainable Development (IESD),

Banaras Hindu University, Varanasi

Varanasi-221005

Head of Department

Prof. Kavita Shah

Institute of Environment and Sustainable Development (IESD),

Banaras Hindu University, Varanasi

Varanasi-221005

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the report entitled **"Assessment of Municipal Wastewater Treatment Systems Using Life Cycle Assessment Approach"** in partial fulfillment of the requirement for the degree of Master of Science in Environmental Sciences (Environmental Technology) and submitted to the Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi, India, is an authentic record of my own work carried out during Jan, 2017 to May, 2017 under the supervision of **Er. Omkar Singh, Scientist 'F', NIH, Roorkee**.

The matter presented in this report has not been submitted by me for the award of any other degree of this or other institute.

Kamala Bind

Kamala Bind

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

SUPERVISIOR

ओमकार सिंह

Er. Omkar Singh
Scientist 'F'
Research Management & Outreach Division (RMOD),
National Institute of Hydrology, Roorkee,
Roorkee, India.

5/7/2017

Dr. Dinesh Kumar
Sr-Resource Person,
Research Management & Outreach Division (RMOD),
National Institute of Hydrology, Roorkee,
Roorkee, India.

ACKNOWLEDGEMENTS

Firstly, I would like to express my humble thanks to Prof. **G. S. Singh**, course coordinator, Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi, India, who gave me chance for dissertation from outside of the campus.

I would also like to express my sincere thanks to my supervisor, **Er. Omkar Singh**, **Scientist 'F', National Institute of Hydrology, Roorkee, India**, for the continuous support of my whole dissertation work, for his patience and immense knowledge.

My thanks are due to my co-supervisor **Dr. Dinesh Kumar**, National Institute of Hydrology, Roorkee, India for his support, help and cooperation during dissertation work. He also taught me all the basic things of research.

I am also thankful to **Mr. Brijesh Kumar** P.A., Director, National Institute of Hydrology, Roorkee for his kind support throughout my dissertation work.

I owe special thanks to brother **Mr. Jai Bhagwan** and my sister **Miss. Anita Kumari** for thier support to me.

I am thankful to all my friends (specially mentioned **Deepshikha, Priyanka Verma, Nupur Rai and Neha Kaushik**) for their valuable time and support during my difficult time.

Last but not least, I would like to thank my family members for supporting me throughout my study and my life in general. Special thanks go to my brother **Mr. Umesh Chandra Bind** for his continuous support, guidance, help and encouragement on each stage of my study.

Kamala Bind

ABSTRACT

With increasing environmental concerns and rapid growth of wastewater in domestic as well as in industrial sector, there is an urgent need to treat the wastewater with lower environmental footprints. Different types of treatment technologies are practice to treat large amount of wastewaters. It was found that there is the research gap of appropriate comparison of wastewater treatment technologies, hence this study was undertaken. Present study investigates the performance of four municipal sewage treatment plants (STP) in India based on different technologies. Environmental impacts of selected STPs were calculated and compared through Life Cycle Assessment tool using CML 2 baseline methodology and Eco-invent database. Only operation and maintenance phase of each technology used in secondary treatment was considered during the study. Four impact categories including, energy consumption, Global Warming Potential, Acidification Potential and Eutrophication Potential were considered. During assessment, four technologies of sewage treatment, namely, Constructed Wetland (CW), Activated Sludge Process (ASP), Extended Aeration (EA) and Submerged Aerobic Fixed Film Reactor (SAFF) were selected. Among the selected STPs, the CWs based STP has found in owing negligible energy consumption and negative Global Warming Potential (GWP) due to carbon sequestration capacity of macrophyte (*Canna indica*), than other treatment technologies. SAFF reactor and EA process shows almost similar emission impact for all impact categories. The main contributors of environmental impacts of STPs are emission allied with electricity production required for operation of plant.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

LCA	Life Cycle Assessment/ Life Cycle Analysis
ISO	International Standard Organization
KWh	Kilo Watt Hour
KLD	Kilo Liter per day
MLD	Million Liter per Day
ASP	Activated Sludge Process
SBR	Sequencing Batch Reactor
EA	Extended Aeration
SAFF	Submerged Aerobic Fixed Film Reactor
UASB-FAL	Up-flow Anaerobic Sludge Blanket
CW	Constructed Wetlands
GHG	Green House Gases
GWP	Global Warming Potential
AP	Acidification Potential
EP	Eutrophication Potential
TP	Toxicity Potential
ADP	Abiotic Resource Depletion Potential
ODP	Ozone Depletion Potential

CC	Climate Change
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
TP	Total Phosphorus
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TS	Total Solids
TSS	Total Suspended Solids
TDS	Total Dissolved Solids
GJ	Giga Joules
MJ	Mega Joules

CHAPTER 1

INTRODUCTION

With increasing environmental concerns and rapid growth of wastewater in industry level, there is a high need to treat the wastewater with lower environmental hazards (Shakir et al. 2017, Abdel-Rauof et al. 2012). Untreated wastewater cause health damage, foul smell and also deteriorates environmental health (Shakir et al. 2017).Many developing countries including India, has a several challenge to treat wastewater (Kaur et al. 2012). Untreated wastewater cause health damage, foul smell and also deteriorates environmental health (Agrawal et al. 2010, Oladeji et al. 2016). To overcome this problem, numbers of new wastewater treatment plants which comprises physical, chemical and biological treatment based on advanced technologies, are being installed to make sure the mitigation of pollution effect and avoiding health damage caused by untreated wastewater (Abdel-Rauof et al. 2012). However, different type of treatment technology is being used effectively to reduce large amount of environmental pollution. But, most of these treatment technologies have not been found so encouraging probably due improper assessment and systematic evaluation. So, there is a high demand to utilize the wastewater treatment technology which would enable to reduce environmental concerns.

Wastewater treatment is a process that converts wastewater (water not suitable for most recent use) into an effluent water that can be either reused or return to water cycle with minimal environmental issues. This can be performed with the use of different treatment technologies, some are- ASP (Activated Sludge Process), UASB (Up-flow Anaerobic Sludge Blanket), SBR (Sequencing Batch Reactor), CWs (Constructed Wetlands), EA (Extended Aeration), SAFF (submerged aerobic fixed film reactor), MBBR, trickling filters etc. Every technology has its own pros and cons and has different environmental footprints.

Now a days, the most common tool/ technique to assess the environmental footprints of a process / technology / product is Life Cycle Assessment (LCA) (Jacquemin et al. 2012, Notarnicola et al. 2017). Furthermore, LCA has become most commonly useful tool for assessment and evaluation of environmental aspect with potential impacts of wastewater treatment plants. Computation of environmental impact of wastewater treatment plant would be beneficial in the comparison of treatment technology. Therefore, in the present study, LCA has been used to compare four different treatment technologies of India, namely ASP, EA, SAFF, and CWs.

In sustainability of water resources management, wastewater is being considered more effectively resources rather than waste because it could be used as a source of water for plant nutrients and for energy also (Notarnicola et al. 2017).

Life Cycle Assessment (LCA) is a tool to evaluate the environmental effect of a product or process throughout its entire life cycle, from cradle- to- grave (Notarnicola et al. 2017). Life cycle of any product comprises several stages such as extraction of raw material, manufacturing, transport, packing, storage, use and final disposal of product. Each of this stage requires some inputs, may be in the form of material and energy and may produce some environment deteriorating outputs to the surrounding environment. In wastewater treatment plants LCA is best tool to assess environmental impacts (Jacquemin et al. 2012, Notarnicola et al. 2017). The Life Cycle Assessment is a methodological tool that has been used to assess the environmental impacts associated with wastewater treatment, considering their whole life cycle and taking into account all the environmental impact associated (Tilman et al.1998, Hospido et al. 2008, Notarnicola et al. 2017). The aim of this study to assesses environmental impacts of different selected wastewater treatment technologies.

Environmental Life Cycle Assessment offers a systematic structure, approach, and technique to identify and quantify environmental footprint correlated with the life cycle of products, processes and services, from cradle to grave.

Life cycle Impact Assessment phase (LCIA) should be included within LCA to help in the identification of environmental problems coupled with anthropogenic activities (ISO 14040). To manage environmental problems, we must have knowledge regarding level of environmental problems (Olivier et al. 2002).

1.1 DEFINITION OF LCA

Life cycle assessment (LCA) is a quantitative tool that estimates the environmental impact of a process or product over its life, including raw material extraction, construction, operation, reuse and end-of-life phases (EPA, 2006).

LCA is a technique for assessing the environmental aspects and potential impacts associated with a product, by

- compiling an inventory of relevant inputs and outputs of a product system

- evaluating the potential environmental impacts associated with those inputs and outputs

- interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study. (ISO14040).

1.2 ADVANTAGES OF USING LCA (Wenzel et al. 2008)

LCA can be used to-

- Quantify and manage environmental aspect of many processes, products, services and operations along different phases of life cycle.
- Identify the significant environmental impacts of processes at all stages of its life cycle.

- Identify opportunities to improve the environmental aspects by implementing eco-design practices to promote improved efficiency, innovation and cost saving of the product.
- Promote demand for products and processes that have fewer adverse environmental impacts.
- Prepare environmental action plans and manage risks.
- Communicate environmental initiatives and respond to stakeholder demands.

1.3 BACKGROUND

A number of efforts have been made to extend LCA methodology, since 1970's. LCA was first applied in 1990s in the field of wastewater treatment (Luis C. et al., 2013). Analysis of papers show variability in the definition of system boundaries and functional unit, the selection of impact assessment methodology and procedure followed during interpretation of result, within the constraints of ISO standards.

In the present time, industrial practices and treatment plants have been adopted that are not sustainable at any level. Increasing consumption of material, energy and water are deteriorating natural resources and their availability and therefore, environmental emissions are increasing (Notarnicola et al. 2017). Thus, environmental footprint of treatment plant is increasing.

1.4 OBJECTIVE

1. Comparison of different wastewater treatment technologies with respect to environmental impacts.
2. Life Cycle Assessment of wastewater treatment technologies.

1.5 QUESTIONNAIRE

Questionnaire utilized during the field survey of four different northern part of our country, India, to gather information related to Wastewater Treatment Plant using different technologies.

Table 1.1: Questionnaire

S. No.	**Parameters**	**Value**
A.	**Basic Information**	
1.	Name and address of STP	
2.	Name of contact person	
3.	Contact detail- Phone No.- e-mail -	
4.	Legal status	
5.	Type of wastewater treated	
6.	Treatment technology	
7.	Type of plant used	
8.	Time of establishment	

9.	Since when working	
10.	Topography	
11.	Source of energy	
12.	Total land area used	
13.	Downstream reuse (Agriculture/ irrigation/ ground water recharge/ other)	
14.	Downstream disposal (river/ open drain/ other)	
B.	**Design detail**	
I.	Primary treatment units	
1.	Screen chamber Type of screen Number of screen Unit size Other details	
2.	Grit chamber Unit size Number of units Hydraulic retention time (HRT) Other detail	
II.	Secondary treatment unit (on the basis of design)	
1.	BOD inlet	

	Outlet	
2.	COD inlet Outlet	
3.	pH inlet outlet	
4.	TKN inlet Outlet	
5.	TP inlet Outlet	
6.	TN inlet Outlet	
7.	TSS inlet Outlet	
8.	Total Coli form inlet Outlet	
9.	Fecal Coli form inlet Outlet	
C.	**Actual performance/ efficiency**	
1.	BOD inlet Outlet	
2.	COD inlet	

	Outlet	
3.	pH inlet outlet	
4.	TKN inlet Outlet	
5.	TP inlet Outlet	
6.	TN inlet Outlet	
7.	TSS inlet Outlet	
8.	Total Coli form inlet Outlet	
9.	Fecal Coli form inlet Outlet	
10.	HRT	
11.	Energy consumption	
D.	**Flow sheet of STP**	

CHAPTER 2

LITERRATURE REVIEW

2.1 SEQUENCING BATCH REACTOR

Inter air SBR, first designed in 1987 for India, such plants have been working in India i.e. Jagjitpur, Haridwar, Botanical Garden Mumbai. SBR can achieve good nutrient removal with minor design changes. In an urban areas where surface water bodies are under stress and cannot take any more nutrient load, SBR is the best possible solution.

Largest SBR in the world is located in United Arab Emirates at flow rates 10MGD, however, SBRs are generally used at flow rates of 5MGD or less.

Sequencing batch reactors are used to treat wastewater in a single batch reactor for the removal of undesirable components and discharge of effluent water, means all the processes of ASP (equalization, aeration, clarification and decantation) can be achieved in a single batch reactor using a timed control sequence. Two or more batch reactors are used in alternate sequence to optimize the performance of the system. This technique has been successfully used to treat municipal sewage as well as industrial wastewater.

2.1.1 Benefits of SBR

- Small land area is needed for establishment of SBR technology based treatment plant in comparison to ASP.

- In SBR technology all processes (i.e. aeration, settling and decantation) took place within a tank. So there is no need of settling tank and sludge recycling system.
- There is no clogging, cleaning and free from common treatment problems.
- It is very easy to control filamentous growth and settling problem in SBR system.
- Treatment efficiency is good as it discharges good quality of treated water for reuse application, having less nitrogen and phosphorous. Thus, this technology has less environmental impacts.
- This does not require secondary clarifier.

2.1.2 Disadvantages

- High level of maintenance is required.

2.2 ACTIVATED SLUDGE PROCESS

Activated sludge process is conventional method used for wastewater treatment. It includes several stages as screens (for removal of large particles before entering the plant), grit chamber (removal of coarse sand and grit) (primary clarifier (settelable suspended solids settled down at the bottom of clarifier, which is periodically removed), aeration tank (oxygen mixed to wastewater for survival of aerobic bacteria that decompose organic matter present in wastewater), secondary clarifier (digested organic sludge settled down and treated effluent discharged, sludge removed from bottom).

2.3 EXTENDED AERATION

Extended Aeration is wastewater treatment technology that are entirely aerobic since the primary settling of the wastewater and the anaerobic digestion of the sludge are omitted. In this technology the power requirement is higher than that of Activated Sludge Systems that's why the operating cost of this system is also higher.

2.4 UP-FLOW ANAEROBIC SLUDGE BLANKET

For wastewater treatment, anaerobic systems have been used since late 19th century. Recent development demonstrated that anaerobic process might be an economically attractive alternative for treatment of different types of industrial wastewaters and in semi tropical areas also for domestic wastewaters.

UASB was developed by Lettinga in Holland in the early 1970's. It differs from other processes by its simplicity of its design and has high loading capacity. It is a combination of physical and biological processes as physical process separates solids and gases from liquid and biological process degrades decomposable organic matter under anaerobic condition. UASB does not require separate settler with sludge return pump and mechanical mixing.

2.5 SUBMERGED AEROBIC FIXED FILM REACTOR

SAFF is a simple and cost- effective method used in secondary treatment of wastewater treatment plant. It is a hybrid reactor in which attached growth and suspended growth take place at once. It works primarily on three stages that are primary settlement, secondary treatment and clarification as conventional system.

Primary settlement:- In this stage settelable solids settled down at the bottom of primary settling tank and removed occasionally like sludge and floating material removed by screening method.

Secondary treatment:-In this stage, organic matter is degraded by living biomass, attached on surface media.

Clarifier:-In this stage, degraded organic matter is settled out and separated from treated effluent.

2.5.1 Benefits:-

- SAFF is more advanced technique used for large residential areas.
- Operation and maintenance cost is very low.
- Liquor treated from primary treatment unit may be reuse.
- It can be operated for big range of MLSS (about 12000-23000 mg/l) unlike conventional treatment.

Most of the studies focus on inventory and impact evaluation phase of different technologies. There are a no. of options available for selection of functional unit in a WWTPs, LCA, such as p.e.-year (person equivalent/ population equivalent-year), volume of sludge production, quantity of removed pollutants, m3 of treated effluent for one year, quantity of inflow treated etc. Among this p.e.-year is most common functional unit used in many study.

There are several software used in LCA that are SimaPro, GaBi6.0, Umberto, Eco- indicator 99, 91/271/EEC UWWTD etc. Characterization methods are used using CML 2 Baseline 2000, Operational Guide to ISO 14040 by Guinee et al. (2001) cited by P.P. Kalbar (2013). Environmental impacts were calculated using methods- ReCiPe 2008, Ecological Footprint, IPCC 2006 GWP 100 year, Eco-invent database, etc.

According to **K. Lopsik, (2013**) WWTPs help in reduction of negative environmental impacts by improvement in effluent quality, but selection of environmentally sound treatment technologies very difficult task. System boundaries include construction and operation phase. He found that impact of one p.e. of CWs is larger than impact of EA system just because of energy used in production of lightweight expanded clay aggregate. CWs dominates in Human Toxicity, Acidification Potential, Ozone Depletion Potential, land use and use of non-renewable resources categories, wherever, EA system dominates in EP and ecotoxicity. Negative impact of CWs is caused by construction phase and hybrid filters made by lightweight expanded clay aggregate. Impact assessment has been carried out by using SimaPro software and ReCiPe assessment methods. Result shows that decrease in average impact of CWs by 22.91% can be achieved by the use of sand and gravel filter.

P.P. Kalbar et al. (2013) used LCA as assessment tool to assess environmental impacts of various wastewater treatment technologies and its comparison. They assumed that all the power generation is from coal- based thermal power plant. The study mainly focuses on O&M phase of WWTPs. ASP, SBR, UASB-FAL and CWs has been chosen on the basis of availability of data and maintenance of record. They concluded that SBR consume more energy in O&M than other technologies and hence high CO2 emission and GWP. It is very difficult to compare the treatment technologies based only on impact category because any technology may perform well in one impact category and poorly in another, e.g. SBR can receive good nutrient removal with minor design changes, hence less EP, but consume more energy than other technologies. According to this paper it is concluded that it is very difficult to compare the treatment technologies based only on impact category because any technology may perform well in one impact category and poorly in another, e.g. SBR can receive good nutrient removal with minor design changes, hence less EP, but consume more energy than other technologies.

Houillon, G. and Jolliet, O.(2005) *found* specific ignition in fluidized bed and agricultural spreading are attractive processes from an energy perspective and thermo oxidation processes got global warming balance, after comparison of six wastewater sludge treatment scenarios i.e. agricultural spreading, fluidized bed incineration, incineration in cement kiln, wet oxidation, pyrolysis and land fill. This study was mainly focused on energy and emission contributing to global warming and inattentive to human toxicity, micro pollutant, dioxins etc. functional unit was one ton of dry matter disposed (tDM).

N. Chakraborty et al. (2008) calculated the total possible emission from TPP and compare them with some previous studies and also quantify the measured emission in terms of emission coefficient per Kg of coal utilized and per kWh of electricity generated. IMR 2800 P Flue Gas Analyzer instrument was used to measure the emission rates of direct / indirect GHG emission (CO_2, CO, SO_2 and NO). Methods applied for measurement, calculation, conversion factor and interpretation as per IPCC Guidelines. Unit of measurement was mg/m^3 for all gases except for CO_2, which was measured in percentage of volume. Measurement conducted at 30minutes interval. Factors affecting combustion of coal, quality of coal, burner positioning etc. may result in variation in the emission rates. They generalized that emission rates of direct and indirect GHG obtained from TPP varies on quality of coal mixture, quality of oil, quantity of coal and oil required per unit generation, age and maintenance standard of plant and amount of air fed into furnace.

E. Risch et al. compared CW (2-stage vertical Reed Bed Filter) and conventional activated sludge system, designed as per as French guidelines using LCA and found that vertical Reed Bed Filters has poor efficiency in removing nitrates, organic nitrogen and phosphates, however, it does not require any chemical reagent and only requires lesser energy compared to ASP. ASP applied to obtain stabilized, dry cake sludge after flocculation, coagulation and dewatering. CW is based on 2stage vertical RBF plant designed 3 filters in first stage and 2 in second stages. Only Construction Phase was considered in this study. The study include 18 impact categories i.e, climate change (CC), ozone depletion (OZ), human toxicity (HT), Photochemical oxidant formation (POF), Particulate matter formation (PMF), Ionizing radiation (IR), Terrestrial acidification (TA), Freshwater eutrophication (F-EU), Marine eutrophication (M-EU), Terrestrial ecotoxicity (TET), Freshwater ecotoxicity (FET), Marine ecotoxicity (MET), Agricultural land occupation (ALO), Urban land occupation (ULO), Natural land transformation (NLT), Water depletion (WD), Metal depletion (MD), Fossil depletion (FD). CW is considered to be better than ASP in all categories except EU and ULO.

G. McNamara, et al. (2014) found that energy consumption and sludge application to land are largest contributor to the environmental impact. The main goal of the paper is to assess the environmental costs with variation in size and location. System boundary includes upstream processes such as electricity, natural gas and chemical production. p.e. is considered as functional unit. CML 2001 guidelines are used for LCIA with GaBi 6.0 software.

Güereca Leonor Patricia et.al. Analyzed and compared one big WWTP and several small wastewater treatment scenarios with activated sludge and resulted that one big WWTP generates less impact for all impact categories except eutrophication and aquatic toxicity, in which is almost similar to several small scale WWTP. Aeration system demand more electricity during operation stage in secondary treatment, hence present highest impact. The quantity of inflow treated by big WWTP is considered as functional unit in the study.

P.P. Kalbar et al.(2012) considered construction and O&M only, ignoring dismantling for estimation of environmental impacts using Life cycle approach and found that construction phase contribute only about 1% for impact in comparison to overall impact of plant. The key component of the study is SBR. Energy required for operation of plant and emissions during O&M phase are considered. Contribution of CP compared to overall impact of WWTP is 1.33%for GWP, 0.65% for ADP&0.35%for AP, but its contribution is negligible in EP, FWAT, HT, MAET &TE impact categories. Functional unit considered here is population equivalent per year. SBR requires less land and produce better quality of effluent compared to conventional WWTP. Life Cycle Assessment is best available technique to evaluate environmental impacts of wastewater treatment plants.

Jeff Foley et al., performs quantitative comparison of environmental cost & benefits of WWT Technologies, to identify environmental friendly configuration among 34 different WWT scenarios. Only construction and operation phases of WWTPs are considered. They verified that that anaerobic treatment, with energy recovery, provides better environmental outcomes than "leading edge" aerobic nutrient removal methods. The study helps in getting information for future policy and funding strategies to water authorities and regulatory agencies of the country. The primary function of the study is the removal of contaminants from wastewater followed by secondary function (production of Biosolid and electricity). Mid- point and end-point assessment are considered.

A.P.Machado et. al. (2007) used LCA approach for comparison of WWT technologies for small and decentralized rural communities, focusing on inventory & impact evaluation phase of Constructed Wetlands & Slow Rate Filtration (termed both as energy saving process)and conventional Activated Sludge Process and found that CWs impart major impact in dismantling phase. CWs & SRI have lower CO2 emission & SRI contributed to decrease in GWF. CWs& SRI are much better than ASP because they use less energy & act as Carbon sink and Carbon balance. Functional unit is p. e.-year. SimaPro 7 software was used for environmental impact calculation. Conclusion of this study is that 10% extension of operation lifetime led to 1% decrease in CO2 emission, in CWs and SRI system as well as 5 to 7% decrease in abiotic depletion, respectively. Replacement of steel with HDPE resulted in 1% decrease in CO2 emission and 5% in abiotic depletion in ASP system. This LCA study identifies

CWs and SRI system as suitable technologies in rural areas as these techniques reduce global warming due to carbon sequestration unlike ASP system.

N. Mills, et al. (2014) compared five technologies that are conventional Anaerobic Digestion with CHP, Thermal Hydrolysis Process (THP) Anaerobic digestion(AD) with CHP, THP AD with bio-methane grid injection, THP AD with CHP followed by drying of digested sludge for solid fuel production and THP AD followed by drying, pyrolysis of the digested sludge and use of the both the biogas and the pyrolysis gas in a CHP. Conventionally energy recovered from anaerobic digestion of sewage sludge with biogas use in combined heat and power (CHP) system, though industries are developing a no. of developments that pull out more energy from sludge. The study found that both anaerobic digestion drying option perform well, however displacement of coal by solid fuel was more sustainable solution, followed by pyrolysis and economically & environmentally feasible. The financial and environmental performance can be improved with the use of THP in comparison to conventional AD. Production of biomethane for grid injection is financially attractive method but has worst environmental impacts, but when the electricity grid is decarbonizes, at a point, production of biomethane for grid injection become environmentally beneficial, instead of electricity. Conventional AD (Anaerobic Digestion) perform better than THP (Thermal Hydrolysis Process) & pyrolysis. 6 impact categories are considered in the study, GWP, POCP, EP, AP, ADP element, ADP fossil. Functional unit is dry mass of sludge i. e. Total Dry Solids (TDS). GaBi software is used, which allows a number of different impacts to be analyzed. Main goal of this study was evaluation of relative environmental & economic impacts and impacts of construction and decommissioning are ignored.

S. Renou, et al. (2008) used five LCIA methods that are CML 2000, Eco Indicator 99, EDIP 96, Ecopoints 97 & EPS and constant assessment has been performed for resource depletion, greenhouse effect, eutrophication, acidification and human toxicity. For the sake of stockholders to make them fully confident more work on human and environmental health is required as the present study do not congregate towards similar results. LCA should also be pooled with other tools such as environmental impact assessment, chemical risk analysis, microbial risk analysis etc. to offer a consistent integrated assessment of WWT systems sustainability.

A. Hospido, et al. (2004), follow CML of Leiden University methodology to compute potential impacts related to WWTPs and used SimaPro 5.0 software for inventory assessment. For physicochemical categorization of WWTP with inventory of inputs & outputs related to global process, complete analysis of WWTP was evaluated. A WWTP gives rise to environmental footprints because of energy consumption, chemicals use, emission to surrounding environment and sludge production, post treatment of which has also varied environmental impact. The main objective of this study is to develop a reliable inventory of WWTP, evaluate potential environmental impacts and to identify hot spots associated with the process. Inventory is mainly based on site specific data. Whole WWT Process is divided into five subsystems: pre& primary treatment, secondary treatment, sludge line & gas line, ancillary service and sludge disposal. GWP, ODP, AP, EP, POCP, ADP, HTP and TTP impact categories are considered in the study. In this study two purposeful functional units were defined to consider the fact that the performance of the WWTP generally depends on variability in input data related to different seasons but environmental analysis outcomes confirmed that discrimination is not required as far as the potential impact is concerned. *Variation caused by variability of the data in each season has expelled to be more significant than variation due to seasonability.*

Palmowski,L. and Pinnekamp,J. (2017) investigate organic micro pollutants (OMP) elimination with ozonation, addition of powdered activated carbon (PAC), filtration through granular activated carbon (GAC), which are not fully eliminated in modern WWTP and can potentially harm the aquatic environment. However, further treatment increases the energy demand of WWTPs, that's why, data on energy demand was collected and analysed with OMP elimination process of ten different largo scale municipal wastewater treatment plant. The Application of ultra-filtration and microfiltration process in membrane bioreactor does not achieve high OMP elimination. Nanofiltration and reverse osmosis process show good OMP elimination, Nanofiltration and reverse osmosis process show good OMP elimination, but are not suitable for OMP elimination in inland Result shows that energy demand of ozonation depends on ozone dosages and considerably 2-4 times higher than energy demand of PAC or GAC filtration. GAC are coarser than PAC and used in filters rather than conventional filter material (Abegglen and Siegrist, 2012). Unlike PAC, GAC can be chemically or thermally reactivated after adding fresh GAC to make up the lost during reactivation and reused as filter. There is no typical dosage for GAC, in opposition to ozonation and addition of PAC. The three processes described above have capacity for high elimination of OMP but all are high energy consuming processes.

Chen et. al. (2011) present low carbon assessment for WWT by CWs as ecological engineering and analysis of inputs- outputs is applied for direct and indirect GHG emission associated with WWTPs. During construction period, constructed wetland needs inputs such as substrate, plants and pipes; these will lead to GHG emission. Result shows that the highest flexes of NO_2 were observed in the vertical subsurface flow constructed wetlands while highest CH_4 fluxes were observed in the free water surface wetland and ratio of GWP factor is 1:21:310 for CO_2:CH_4:N_2O. The LRCW is designed for 20yrs and its treatment capacity is 200m^3. GHG emission of LRCW is ¼ of Cyclic Activated Sludge System (CASS) for the treatment of per m^3 wastewater and is about one half for the removal of one kg of BOD or COD. Hence it is suggested that CWs is low carbon WWT technology and should be promoted to achieve it.

Giovanni De Feo , et al. compared environmental impacts of two on-site small-scale activated sludge total oxidation systems in linear low-density polyethylene (LLDPE) and vibrated reinforced concrete (VRC)of treatment capacity 5,10,20 and 30 equivalent inhabitants, using LCA methodology. The main goal of this study was the evaluation of frequency of construction, operation and disposal phases on the total impact calculated with three methods: Ecological Footprint, ReCiPe 2008 and IPCC 2007 100 years. Results show that use phase was the most significant phase, which contributed about 80% of total impacts followed by construction phase contributing less than 25% for both systems for all impact assessment methods. The plant designed in LLDPE was more eco-friendly than that in VRC that was always more impactful even each phase of life cycle.

Steven E. and Williams, P.E. recognized that attached growth processes are more energy efficient than suspended growth processes in wastewater treatment e.g. Rotating Biological Contractor (RBC- attached growth process) is nearly two times more efficient than Activated Sludge (AS- suspended growth process) or in the other words, require nearly 50% of energy of ASP, but air driven RBC require 30% more energy than ASP. The selected plants have similar flow, discharge permit and both are well operated and data from these plants was supplemented by data of mechanically driven RBC.AS plants are able to reduce power and can be controlled by mixed liquor dissolved oxygen , that allows energy consumption to be reduced during period of low loading, but RBC do not tender this flexibility.

D. Godin, et al. introduce the term net environmental benefit approach for the assessment of the potential impacts associated with discharging wastewater, with or without treatment besides assessing potential impacts of WWTPs life cycle using LCA methodology. NEB approach allows more clear definition of main function of the WWTP in comparison to standard LCA showing trade=off between avoided impact due to WWT and generated impact by WWTP's life cycle.

NEB results and LCA standard results are compared for a small municipal WWTPs and similar result was found for impact categories containing only impacts generated by the WWTP's life cycle itself but differ in those categories where wastewater treatment environmental benefit is accounted for. Thus NEB is more suitable approach to assess environmental life cycle of any WWTPs.

Türkera and Yakar assesses the performance of Hybrid Constructed Wetland-Microbial Fuel Cell (HCW-MFC)for Boron removal and bioelectric production and achieved 63.4% Boron removal for Wastewater containing an average 12.3mg/L inflow of Boron concentration. This wetland system was also able to remove 47.5% nitrate and 19.1% nitrite from wastewater. They found that dehydrogenase and urease activities were strongly correlated with bioelectric production, suggesting that that these enzymes might play important role in bioelectric production with HCW- MFC.

J. Edwards et al. (2017) evaluated the environmental impact of anaerobic co-digestion (AcoD) using LCA and compared it against the current waste management system. AcoD has less environmental impact than the current waste service, for all categories except human toxicity, although it needs collection and pretreatment of food waste separately. Sensitivity analysis indicated that AcoD's GWP decreased by 24.5% with improved household food waste arrangement.

CHAPTER 3

METHODOLOGY

As a part of ISO14000 series of standards, ISO in 2000 has come out with the following standards regarding LCA:

ISO 14040: Environmental Management- LCA- Principal and Framework.

ISO 14041: Environmental Management- LCA-Inventory Analysis.

ISO 14042: Environmental Management-LCA-Impact Assessment.

ISO14043: Environmental Management-LCA- Interpretation.

The goal of LCA in wastewater treatment is to assess material and energy inputs, input of energy in different phases of treatment, emissions during operation and maintenance phase as well as construction and demolition phase. Overall, assess the environmental footprints of wastewater treatment plants. Energy consumption depends on plant sizing and technology used in treatment plants. The impact assessment phase involves category definition, classification of the inventory input and output data, characterization and valuation.

To assess different technologies, it is necessary to bring all technologies on a common platform so that following assumptions are made in this study for technology comparison:-

- It is assumed that power used in operation of plant is generated from coal based thermal power plant.
- Energy consumption for pumping of sewer is not considered.
- Only operation and maintenance phases of secondary treatment are considered except transportation, construction and demolition phase.
- Energy consumption in aeration is major cause of GWP and other impacts.
- Sludge treatment and tertiary treatment are not considered.

3.1 GOAL AND SCOPE DEFINITION

The goal of this study is assessment of environmental impact of selected Wastewater treatment plants and comparison of treatment technologies by using LCA tool. This study focuses on operation and maintenance phase of wastewater treatment plants because construction phase accounts for about 1% of impact to the total impacts of WWTPs (P.P. Kalbar et. al. 2013).

3.1.1 System Boundary

System boundary of WWTPs should be decided thoughtfully because it has large effect on result (Tilman et. al.).in the present study, pumping of sewage is not considered, only energy consumption during operation and maintenance is considered along with output impact categories i.e. GHG, GWP, EP and AP

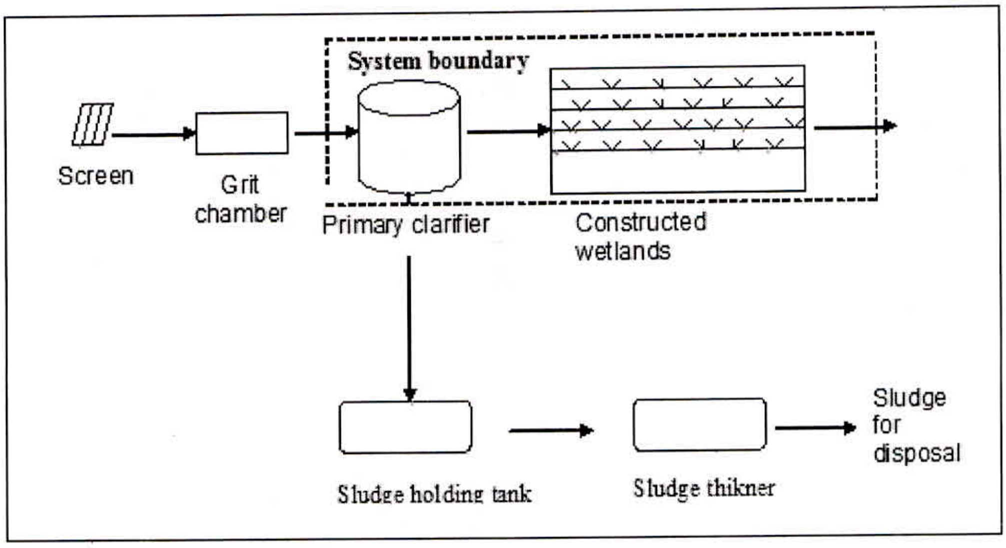

Figure3.1: System Boundary of Constructed Wetland system

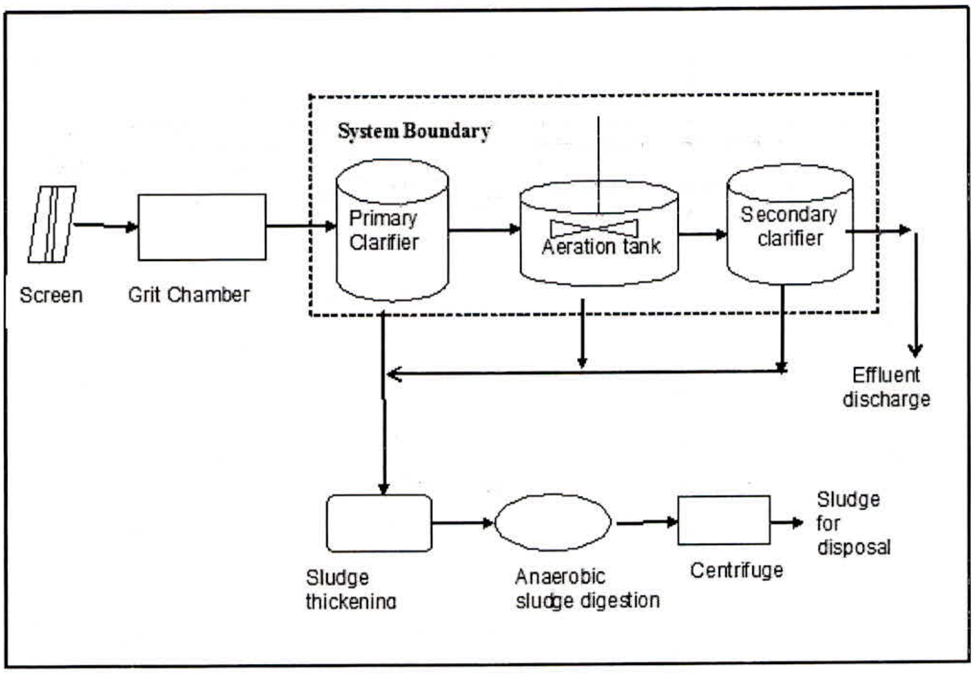

Figure3.2: System Boundary of Activated Sludge Process

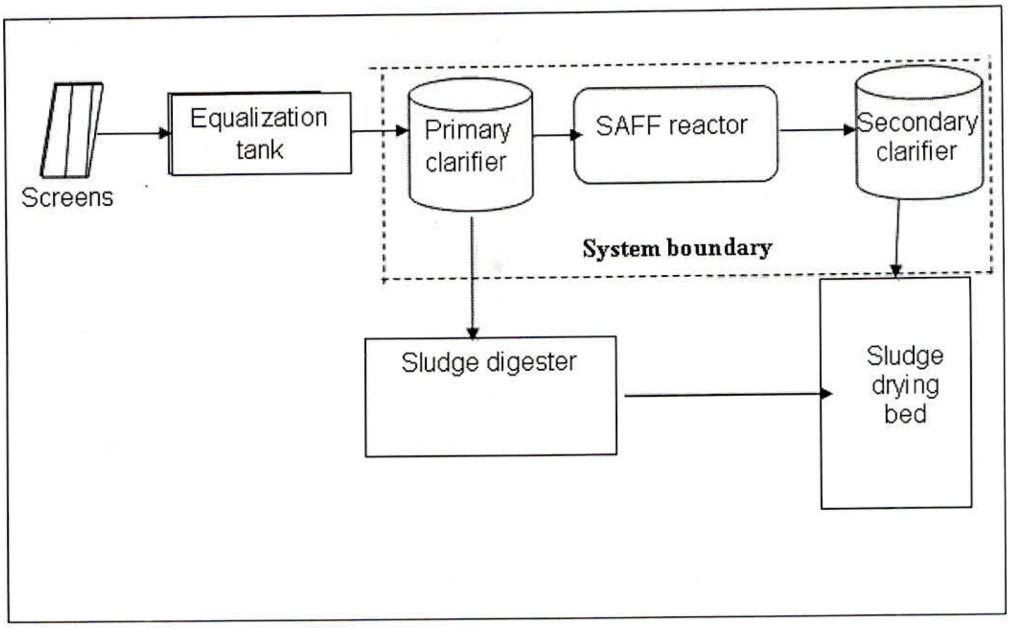

Figure 3.3: System Boundary of SAFF reactor

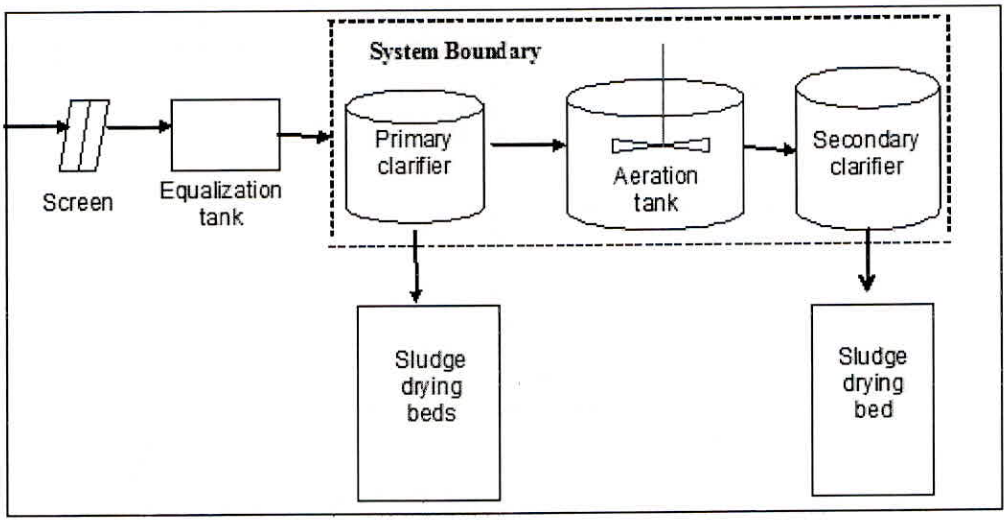

Figure3.4: System Boundary of Extended Aeration process

excluding sludge treatment and disposal. System boundaries of all the plants are shown in figure.3.1, 3.2, 3.3 & 3.4 for CWs, ASP, SAFF and EA respectively.

3.1.2 Functional Unit

In general functional unit is nothing but is the base for treatment technology comparison of WWTPs. To compare different things there must be a basic unit, e.g. functional unit chosen for this study is person equivalent (p.e.) for a period of one year. This is more common functional unit used in LCA studies. 1 p.e represents 50 g of BOD load per day used by Arceivala and Asolekar (2007) in India and cited by P.P. Kalbar (2013).

3.2 INVENTORY ANALYSIS

Life cycle analysis is the second step of life cycle assessment. It is longest and more time consuming stage of LCA. All the data are collected from each treatment plant to estimate inputs and output emission of plant. In this stage, data collected from selected plants must be analyzed, reviewed and corrected, if necessary, according to our objectives. So that, the quality of result depends chiefly on LCI which is generated on the basis of site visits to WWTPs.

Energy is required for operation of plant along with chemicals that are required for disinfection, coagulation, pH balance etc. Chemical production is excluded in this study because of absence of Indian database on production of chemicals. According to energy conservation law, the amount of energy required for operation and maintenance of plant will release in the form of emissions. To estimate the emissions from per unit of energy generation is necessary to complete the emission inventory. In this study it is suppose that all the energy generation is from coal based thermal power plant.

3.2.1 Study Sites

The study area consists of different regions (Jaipur, Dharmshala, Nagrota) across the country. Wastewater treatment plants having different treatment technology and treatment capacity of each plant is shown in **Table 3.1**. Plants were selected on the basis of data availability and treatment efficiency.

Table 3.1 Name of wastewater treatment technologies, its location and capacity considered under study.

S. No.	Study Area	Wastewater Treatment Technology	Capacity
1.	Jaipur	Constructed wetlands	40KLD
2.	Nagrota, H.P.	Sequencing batch reactor	1.30MLD
3.	Dharmshala	Extended aeration	5.15MLD
4.	Jaipur	Activated Sludge Process	27MLD

Figure 3.5: Pictures of STP, Jaipur, Rajasthan. (a, b, c, d & e) different view of aeration and flocs removal process, (f)overflow of effluent from secondary settling tank

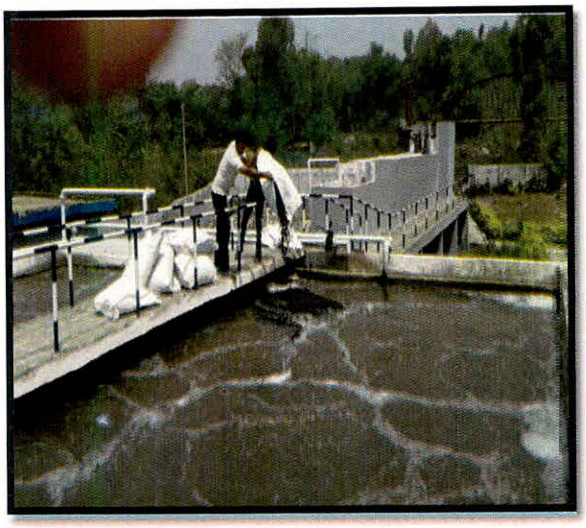

Figure 3.6: Picture showing addition of submerged media in SAFF reactor of STP Nagrota, Himachal Pradesh to provide surface for bacterial growth.

Figure 3.7: Pictures of Constructed Wetland, Jaipur, Rajasthan. (a) and (b) newly constructed wetlands, (c) working and maintained constructed wetland

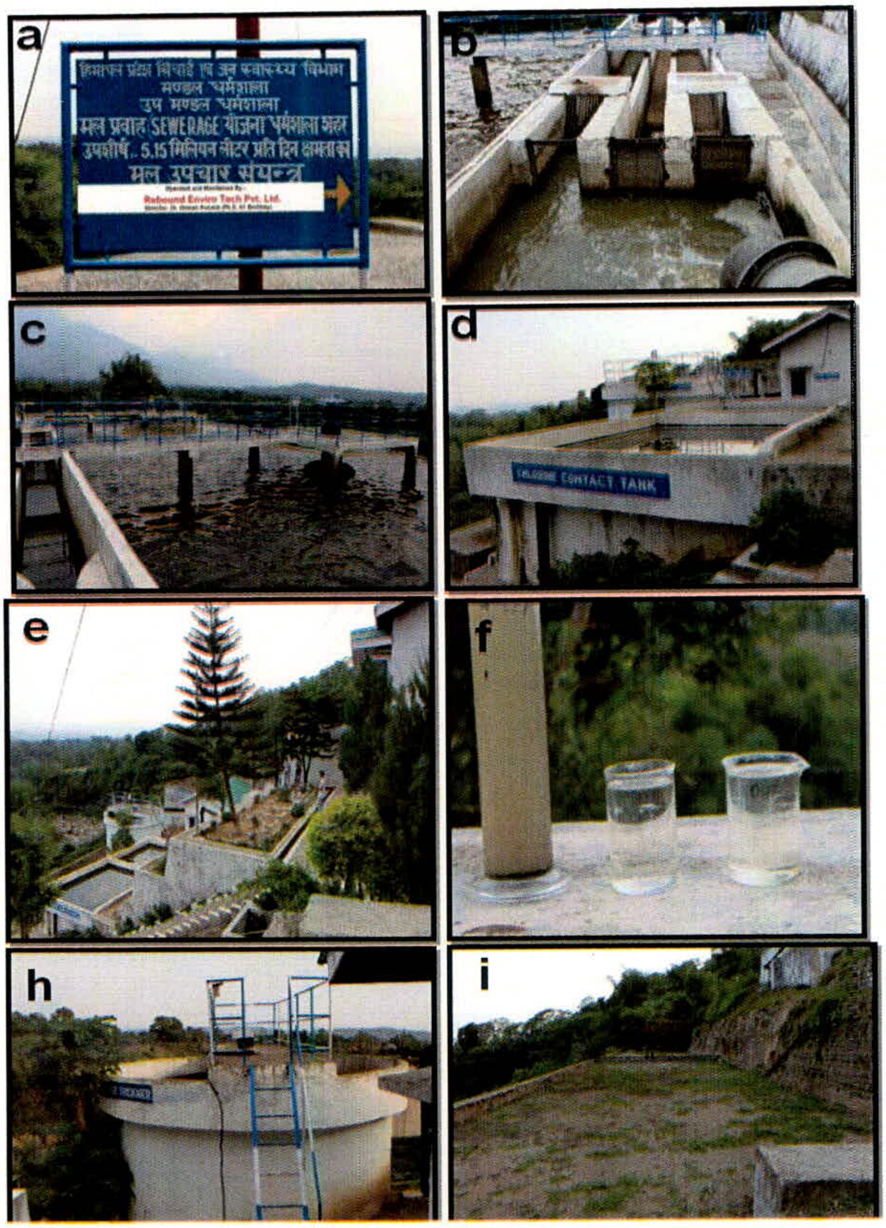

Figure 3.8: Pictures of STP Dharmshala, Himachal Pradesh. (a)main board of STP showing treatment capacity of plant, (b) inlet of influent and screening,(c) aeration tank, (d)& (e) chlorine contact tank, (f) beaker containing treated effluent, (g) discharge of treated effluent into adjoining river, (h) sludge thickner (i) sludge drying bed

3.2.2 Activated Sludge Process

Activated sludge process is a conventional treatment technology for secondary treatment of wastewater in India. So in this study, all the techniques taken into account are compared with ASP. Emission inventory is created by the study of 27 MLD STP at Jaipur North, Jaipur established in 1995. The plant was selected on the basis of availability of data and its consistence performance. ASP plant comprise of all the treatment units such as- screens, primary treatment, aeration tank, secondary settling tank, sludge holding tank etc, has been shown in **figure 3.2.** Energy consumption accounted for 55%, 4% and 28% in aeration, primary treatment and sludge treatment, respectively (P.P. Kalbar et.al. 2013).

3.2.3 Extended Aeration

Plant selected for study is located at Dharmashala, Himachal Pradesh has capacity to treat 5.15 MLD municipal wastewater but its current flow is 2.9 MLD.

Extended aeration is fully aerobic process and referred to as total oxidation process because BOD removal efficiency is high which converts all the primarily treated influent BOD into CO_2.This can accept periodic loading without being upset. This process requires more energy and higher oxygen for operation therefore its running cost is high (Jacqemin et al. 2017).

In this process aerobic digestion of surplus sludge is done and desired quantity of sludge is returned to aeration tank for maintenance of bacterial population.

Sludge does not require any further treatment; it may be taken directly for dewatering and disposal.

3.2.4 Submerged Aerobic Fixed Film Reactor

SAFF is more advance technique for secondary treatment. This process is perfect for big housing and commercial areas. In this study, inventory is made by using the data of 1.30 MLD Sewage Treatment Plant, Nagrota, Himachal Pradesh. The current flow of this plant is 1.30 MLD.

This technique consumes less amount of energy than other technologies (Jacqemin et al. 2017). Man-made media films are used to provide surface for bacterial population. Bacteria use organic matter as food from incoming sewage to convert it into CO_2 and water. Oxygen is provided to bacteria by blower.

3.2.5 Constructed Wetlands

CWs are tertiary treatment unit, followed by secondary treatment unit, ASP at Orient Residency, Patarkar Colony, Mansarovar, Jaipur of treatment capacity 40KLD. The emission inventory summary is given in table 3.1. CWs at Mansarovar, Jaipur uses ***Canna indica*** for treatment of sewage of hospital.

For comparison of treatment technologies it is necessary to have similar platform for all, but three technologies among selected four are used as secondary treatment, except CWs. So conversion of tertiary treatment CWs to an equivalent secondary treatment system is required (P.P. Kalbar et al. 2013).

During calculation of environmental impact of CWs over the life cycle, estimation of carbon sequestration achieved by harvesting *Canna indica* is needed (P.P. Kalbar et al. 2013). In the present study carbon sequestration capacity of the CWs is assumed to be 3.3 kg/ m^2/year, which was used by Dixon et al. (2003) in an LCA study and cited by Kalbar et al. (2012).

Table 3.2: summary of inventory analysis of WWTPs (all the value expressed per p.e.-year)

S.N.	Parameter	Unit	ASP	CWs	EA	SAFF
1.	Energy Consumption	kWh	4.79	0.00	5.10	5.40
2.	CO2 Emission	Kg	11.95	-0.35	12.69	13.48
3.	SO2 Emission	Kg	0.065	0.00	0.069	0.073
4.	NOx Emission	Kg	0.026	0.00	0.027	0.029
5.	CO Emission	Kg	4.35	0.00	4.62	4.91
6.	COD Removal	Kg	26.27	30.22	15.24	11.47
7.	TKN Removal	Kg	0.25	1.03	0.14	0,07
8.	Total Phosphorus Removal	Kg	0.07	0.40	0.07	0.07

3.3 IMPACT ASSESSMENT

This stage of LCA comprises following elements-

3.3.1 Impact category selection

Impact categories are selected on the basis of goal of the study and availability of data. Energy consumption, Global Warming Potential, Acidification Potential and Eutrophication Potential are considered as impact category in this study.

3.3.2 Classification

Classification includes grouping of emissions into impact categories according to their environmental effect.

3.3.3 Characterization phase

Characterization phase is used in aggregation of emissions within each impact categories using characterization factor from eco-invent database, as certain emissions may contribute more than one impact such as NO_x contribute to acidification as well as eutrophication (APMechado et.al.). Characterization factors are taken from eco-invent database for all impact category in this study.

3.3.4 Normalization phase

Normalization phase include calculation of category indicator results relative to reference value. This phase is not considered in this study due to lack of Indian database of normalization factors.

Due to lack of reference value availability in India normalization is not included in this study.

3.4 INTERPRETATION

This is the last phase of LCA in which findings of the inventory analysis and impact assessment phase or goal and definition phase are combined together with the purpose of conclusion and recommendations (ISO 1440).

CHAPTER 4

RESULTS and DISCUSSION

The results of LCA for the assessment of technologies, including ASP, CWs, EA and SAFF technologies are based on the field data analysis of four different WWTPs situated at different location in Northern Part of the country. **Table 3.2** shows life cycle inventory while **Table 4.3**, show life cycle impact for different WWTPs.

4.1 ENERGY CONSUMPTION

The energy consumption for the selected WWTPs are 5.40 kWh/p.e.-year for SAFF, 5.10 kWh/ p.e.-year for EA, 4.79 kWh/ p.e.-year for ASP and 0.00 kWh/p.e.-year for CWs, which is in the range of similar studies carried out, by Kalbar et. al.(2012) reported 15.76 kWh/ p.e.-year and in the other countries; Tillman et al. (1998) reported 46.4 kWh/p.e.-year, Lundin et al. (2000) reported 33 kWh/p.e.-year, Hospido et al. (2008) reported 28.3 kWh/p.e.-year for WWTP having ASP for secondary treatment.

The impact of WWTPs depends on design, operation and maintenance of plant, as it has been already reported by Kalbar et. al. (2012) and Gallege et.al.(2008).

Table 4.1:- Calculation of energy Consumption.

WWTT	Current flow	Current flow (in KLD)	Electricity consumption (in kWh/d)	Electricity consumption unit per p.e. per year	kg of coal burn per-p.e.-year
ASP	27MLD	27000	3500	4.796296	2.262586
CWs	40KLD	40	0	0	0
EA	2.9MLD	2900	400	5.103448	2.407481
SAFF	1.30MLD	1300	190	5.407692	2.551004

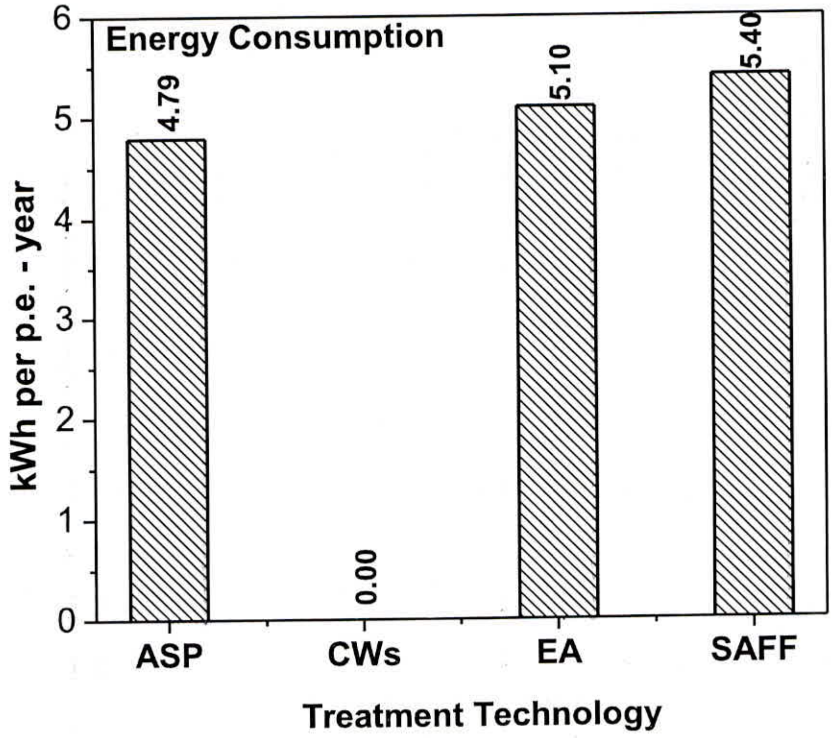

Figure 4.1: Bar diagram showing result of Energy Consumption by different technologies in kWh per p.e.-year

4.2 GLOBAL WARMING POTENTIAL

It is reported in many papers that higher the energy consumption higher will be the CO_2 emission, hence higher the Global Warming Potential. In this study, the global warming potential for the selected plants are 88.66 kg of CO_2 eq., -0.35 kg of CO_2 eq., 94.15 kg of CO_2eq.and 100.03 kg of CO_2 eq. for ASP, CWs, EA and SAFF respectively. The GWP is calculated with time horizon of 100 years, using baseline method outlined in Guinee et al. (2001). CWs have lesser CO_2 emission, hence negative GWP than ASP, EA and SAFF, because CWs act as

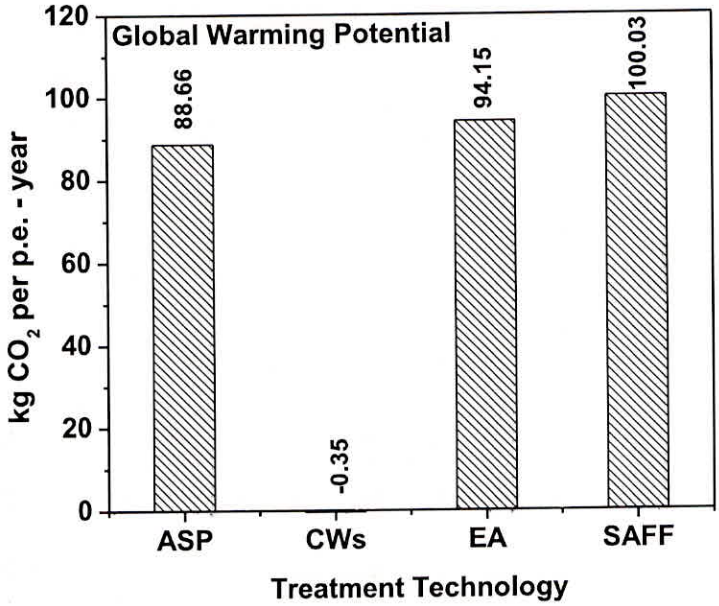

Figure 4.2: Bar diagram showing result of Global Warming Potential of selected treatment technologies in g CO_2 per p. e.-year

carbon sink (Dixon et al. (2003) and Machado et al. (2007) and bulk quantity of CO_2 sequestration during wastewater treatment. Negative GWP shows that this technique can mitigate global warming.

Table 4.2:- Calculation of Global Warming Potential.

			GHG Emission								
Gases	Emission factor equivalent	emission factor per Kg	ASP kg of coal burn per-p. e.-year (2.26kg)	CWs coal burn per-p. e.-year in kg(1.13)	EA coal burn per-p. e.-year in kg (2.40)	SAFF coal burn per-p. e.-year in kg (2.55)	characterization factor	ASP	CWs	EA	SAFF
CO2	5.29-Kg	5.29	11.9554	-0.35	12.696	13.4895	1	11.9554	-0.35	12.696	13.49
CO	5.78e-3Kg	1.92667	4.354267	0	4.624	4.913					
CH4	5.78e-4Kg	1.445	3.2657	0	3.468	3.68475	21	68.5797	0	72.828	77.38
NOX	0.0116-Kg	0.0116	0.026216	0	0.02784	0.02958	310	8.12696	0	8.6304	9.1698
SO2	0.0289-Kg	0.0289	0.065314	0	0.06936	0.073695					
							Total=	88.6621	-0.35	94.1544	100.04

Table 4.3: Result of the Life Cycle Assessment of wastewater treatment technologies (all the value expressed per p.e.-year)

Impact Category	Unit	ASP	CWs	EA	SAFF
Energy Consumption	kWh	4.79	0.00	5.10	5.40
Global Warming Potential	KgCO_2 eq.	88.66	-0.35	94.15	100.03
Acidification Potential	Kg SO_2 eq.	0.65	0.00	0.69	0.73
Eutrophication Potential	Kg PO_4 eq.	0.91	2.34	0.62	0.51

4.3 ACIDIFICATION POTENTIAL

Electricity used for operation of plant is generated from coal combustion, which emits SO_2 and NO_x in atmosphere, causing acidification and abiotic resource depletion. SAFF has highest acidification potential (0.7364kg SO_2 eq.) followed by EA (0.693 kg SO_2 eq.), ASP (0.652 kg SO_2 eq.) and CWs (0.00 kg SO_2 eq.).

Acidification Potential is caused by emission of acidifying substances causing worst impacts on water bodies, buildings, soil, vegetation, human being etc. (Adelowo et al. 2016, Notarnicola et al. 2012). This is caused due to greater amount of electricity generation from coal based thermal power plants which contributes greater amount of SOx and NOx emission.

Table 4.4:- Calculation of acidification potential.

			1kg of coal produce 0.0289 kg of SO2							
Calculation of Acidification Potential.										
								Acidification potential		
Acid producer	SO2 emitted from 1Kg of coal (0.0289-kg)	ASP kg of coal burn per-p. e.-year (2.26kg)	CWs coal burn in kg(1.13)	EA coal burn in kg (2.40)	SAFF coal burn in kg (2.55)	Acidification Potential equivalent (in kg SO2-eq./kg)	ASP	CWs	EA	SAFF
SO2	0.0289	0.065314	0	0.06936	0.073695	1	0.065314	0	0.06936	0.073695
NH3	0.054332	0.12279	0	0.130397	0.138547	1.88	0.230846	0	0.245146	0.260468
HCl	0.025432	0.057476	0	0.061037	0.064852	0.88	0.050579	0	0.053712	0.057069
N2O	0.02023	0.04572	0	0.048552	0.051587	0.7	0.032004	0	0.033986	0.036111
NOx	0.02023	0.04572	0	0.048552	0.051587	0.7	0.032004	0	0.033986	0.036111
NO	0.030923	0.069886	0	0.074215	0.078854	1.07	0.074778	0	0.07941	0.084373
HF	0.04624	0.104502	0	0.110976	0.117912	1.6	0.167204	0	0.177562	0.188659
Total	0.226287						0.652729	0	0.693163	0.736486

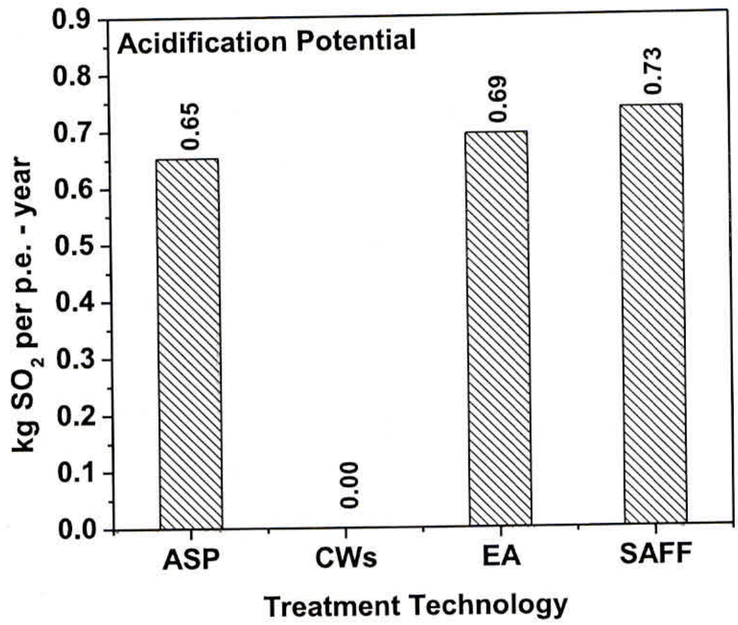

Figure 4.3: Bar diagram showing result of Acidification Potential of selected plant in kg SO_2 per p. e.-year

4.4 EUTROPHICATION POTENTIAL

Eutrophication is caused by phosphorous and nitrogen emission to water resulting in formation of algal blooms due to nutrient enrichment. SAFF (0.51 kg PO_4eq.) has lowest EP because of efficient nutrient removal capacity, hence better effluent quality. CWs have highest EP (2.35 kg PO_4eq.) because of plants used for treatment, which have nutrient recycling capacity, so nutrient removal is negligible in comparison to SAFF and EA.EP calculated of ASP and EA is 0.91 kg PO_4eq. and 0.62kg PO_4eq. Respectively.

Table 4.5:- Calculation of Eutrophication potential

Calculation of Eutrophication Potential									
EP= ∑(mi*Epi) in Kg-P-eq.									
mi= mass (in Kg) of inventory flow									
						Eutrophication Potential in p.e.			
Nutrients (in kg)	ASP nutrient removal in kg p. e.	CWs nutrient removal in kg p. e.	EA nutrient removal in kg p. e.	SAFF nutrient removal in kg p. e.	PO_4-eq factor (in kg eq PO_4)	ASP	CWs	EA	SAFF
Total Nitrogen	0.259	1.036	0.148	0.074	0.42	0.10878	0.43512	0.06216	0.03108
Total Phosphorous	0.074	0.407	0.074	0.074	3.07	0.22718	1.24949	0.22718	0.22718
COD	26.27	30.22	15.24	11.47	0.022	0.57794	0.66484	0.33528	0.25234
Total						0.9139	2.34945	0.62462	0.5106

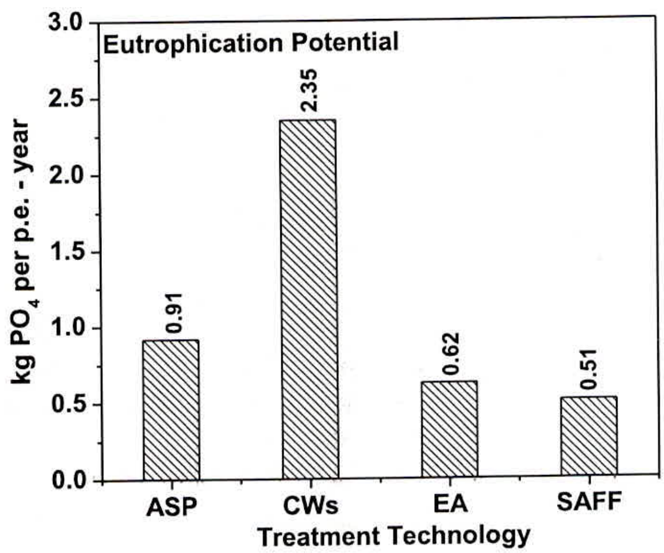

Figure 4.4: Bar diagram showing result of Eutrophication Potential of selected technologies in kg PO_4per p.e.-year

CHAPTER 5

CONCLUSIONS

Environmental impacts of four WWTPs having different treatment technologies were calculated using LCA tool. CW technology was more efficient technology in some impact category i.e. energy consumption, global warming potential and acidification potential as it consumes less amount of energy during wastewater treatment. SAFF consumes more energy than ASP, EA and CWs because SAFF is the process in which attached growth and suspended growth processes take place simultaneously and it has high nutrient removal efficiency having better effluent quality than rest selected processes.

Any technology may be installed anywhere. CWs may be suitable technology as decentralized system for colonies/ small residential areas/ grouping houses/ village of less loading. It might be difficult to install it in large residential areas/ city due to large area requirement, while SAFF reactor require less land and suitable for large residential area, high volume of mixed liquor suspended solids.

After a detailed study of wastewater treatment plants, using different technologies, WWTPs were compared with the help of life cycle assessment, as a result of which constructed wetlands are most environmental friendly in terms of potential impacts.

REFERENCES

1) Abdel-Raouf, N., Al-Homaidan, A.A., Ibraheem, I.B.M. (2012) Microalgae and wastewater treatment. Saudi Journal of Biological Sciences 19(3) pp. 257-275.
2) Agrawal, A., Pandey, R.S., Sharma, B. (2010) Water Pollution with Special Reference to Pesticide Contamination in India. J Water Resource and Protection 2(5), Article ID: 1793, pp. 17.
3) AlmudenaHospido, M., Teresa Moreirai, Mercedes FernfindezCouto andGumersindoFeijoo. (2004), Environmental Performance of Municipal Wastewater Treatment Plant. Int J LCA 9 (4), pp. 261 – 271
4) Arceivala, S.J. and Asolekar, S.R. (2007) Wastewater Treatment for Pollution Control and Reuse (3rd edn). Tata McGraw Hill, New Delhi.
5) Chakraborty, N., Mukherjee, I., Santra, A.K., and Chakraborty, S., Bhattacharya, S., Mitrads, A.P. and Sharma, C. 2008) Measurement of CO2, CO, SO2, & NO Emission from Coal- Based Thermal Power Plant in India. Atmospheric Environment, 42, pp. 1073-1082.
6) Chen, G.Q., Shao, L., Chen, Z.M., Li, Z., Zhang, B., Chen, H., Wu Z. (2011) Low-carbon assessment for ecological wastewater treatment by a constructed wetland in Beijing, Ecological Engineering 37, pp. 622-628.
7) Chen, G.Q., Chen, H., Chen, Z.M., Zhang, B., Shao, L., Guo, S., Zhou, S.Y., Jiang, M.M. (2011a) Low- carbon building assessment and multi-scale input- output analysis. Commun. Nonlinear Sci. Numer. Simul.16, pp. 583-595.
8) Dixon, A., Simon, M., Burkitt, T. (2003) Assessing the environmental impact of two options for small-scale wastewater treatment: Comparing a reed bed and an aerated biological filter using a life cycle approach, Ecological Engineering , 20 (4),pp. 297-308.
9) Foley, J., de Haas D., Hartley, K., Lant, P. (2007)Life cycle assessment of biological nutrient removal wastewater treatment plants. In: Proceedings

of the 3rd International Conference on Life Cycle Management, Zurich, Switzerland, Aug. 27-29,

10)Guinee, J.B., Gorree, M., Heijungs, R., Huppes, G., Kleijn, R., de Koning, A., van Oers, L., Wegener Sleeswijk, A., Suh, W. and Udo de Haes, H. (2001) Handbook on Life Cycle Assessment. Operational Guide to the ISO Standards. Kluwer Academic Publishers, Dordrecht.

11) Hospido, A., Teresa, M.M. and Gumersindo, F (2008) A Comparison of Municipal Wastewater Treatment Plants for Big Centres of Population in Galicia (Spain) Int J LCA. 13(1), pp. 57 – 64.

12)Houillon, G., Jolliet, O. (2005) Life cycle assessment of processes for the treatment of wastewater urban sludge: Energy and global warming analysis. Journal of Cleaner Production 13 (3), pp. 287–299.

13)IPCC Guideline for Greenhouse Inventories 2006

14) International Standard Organization ISO 14040:2006 Environmental Management – Life Cycle Assessment- Principal and Framework 2006.

15)ISO 14040. Environmental management – Life cycle assessment – Principles and framework, ISO 14000 International Standards Compendium (1997). International Organization for Standardization (ISO), Geneva

16)Jacquemin, L., Pontalier, P.Y., Sablayrolles, C. (2012) Life cycle assessment (LCA) applied to the process industry: a review. Int J Life Cycle Assess 17, pp. 1028-1041.

17)Kalbar, P.P., Karmakar, S. Asolekar, S.R. (2013) Assessment of Wastewater Treatment Technologies: Life Cycle Approach Water and Environment Journal 27, pp. 261-268

18)Kalbar, P.P., Karmakar, S., Asolekar, S.R. (2012) Estimation of environmental footprint of municipal wastewater treatment in India; Life Cycle Approach, International conference on environmental science and technology, IPCBEE, vol.30.

19)Kaur, A., Wani, S.P., Singh, A.K., Lal, K. (2012) Wastewater production, treatment and use in India, http://www.ais.unwater.org/ais/pluginfile.php/356/mod_page/content/111/CountryReport_India.pdf.

20)Lopsik, K. (2013) Life cycle assessment of small-scale constructed wetland and extended aeration activated sludge wastewater treatment system. Int. J. Environ. Sci. Technol. 10, pp. 1295–1308.

21)Lundin, M., Bengtsson, M., and Molande, S. (2000) Life Cycle Assessment of Wastewater Systems: Influence of System Boundaries and Scale on Calculated Environmental Loads Environ. Sci. Technol34, pp. 180-186.

22)Machado, A. P, Urbano, L, Brito, A.G, Janknecht, P, Salas, J.J, and Nogueira, R. (2007) Life cycle assessment of wastewater treatment options for small and decentralized communities. Water Science &Technology 56(3), pp. 15–22.

23)McNamara, G., Doherty, E., Clifford, E., Life Cycle Assessment of Wastewater Treatment Plant in Ireland, 2014.

24)Mills, N., Pearce, P., Farrow, J., Thorpe, R.B., Kirkby, N.F. (2014),Environmental & economic life cycle assessment of current & future sewage sludge to energy technologies. Waste Management, 34, pp. 185–195.

25)Notarnicola, B., Sala, S., Anton, A., McLaren, S.J., Saouter, E., Sonesson, U. (2017) The role of life cycle assessment in supporting sustainable agri-food systems: A review of the challenges. J. Cleaner Production 140, pp. 399-409.

26)Oladeji O, Adelowo F. (2016) The Impacts of Human Activities on Ogbomosho Rivers: Causes, Effects and Role of an Individual (Ogbomosho Residents) in Prevention of Water Pollution. Environ Sci Ind J. 12(8), pp. 104.

27)Olivier, B. (2002) Tacit knowledge and environmental management. Long Range Planning 35(3), pp. 291-317.

28)Palmowski,L., Pinnekamp,J. (2017) Energy demand for elimination of organic micropollutants in municipal wastewater treatment plants, Science of The Total Environment (575), pp. 1139–1149.

29)Risch, E., Catherine B., Philippe R., Sylvie G., Alain H. LCA in wastewater treatment-Applicability and limitation of Constructed Wetland Systems; using vertical Reed Bed Filters

30)Renou, S., Thomas, J.S., Aoustin, E., Pons, M.N., (2008) Influence of impact assessment methods in wastewater treatment LCA. Journal of Cleaner Production 16 (10), pp. 1098-1105

31)Shakir, E., Zahraw, Z., Hameed, A., Al-Obaidy, M.J. (2017) Environmental and health risks associated with reuse of wastewater for irrigation. Egyptian Journal of Petroleum. 26, pp. 95-102.

32)Swiss Centre for Life-Cycle Inventories. (2009) Ecoinvent data- base, Dübendorf, Switzerland.

33)Tillman, A.M., Svingby, M. and Lundström, H. (1998) Life Cycle Assessment of Municipal Wastewater Systems. Int. J. Life Cycle Assess., 3 (3), pp. 145–157.

34)Wenzel, H., Larsen H.F., Clauson-Kaas, J., Jacobsen B.N. (2008) Weighing environmental advantages and disadvantages of advanced wastewater treatment of micro-pollutants using environmental life cycle assessment. Wat Sci Tech 57(1), pp. 27-32.

35)Zhang, X.H., Deng, S.H., Jun Wu, Jiang, W.(2010) A sustainability analysis of a municipal sewage treatment ecosystem based on emergy, Ecological Engineering, 36, pp. 685-695.