Life Cycle Inventory of the most representative municipal wastewater treatment technologies of Latin-America and the Caribbean

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Abstract

In Latin America and the Caribbean, normally, the wastewater is discharged with a partial treatment or without treatment to the water bodies, generating important pollution and health problems. The proposed conventional solution is the treatment of wastewater prior to its discharge, reducing the associated environmental impacts. However , wastewater treatment technologies generate collateral environmental impacts associated with the use of resources and energy, and the production of emissions and biosolids. According to this, the selection of wastewater systems is a key issue in the environmentally responsible making-decision process. It is necessary to select the environmentally best technological options for wastewater treatment addressing the problem with a holistic approach; taking into account all the vectors involved (water, air, soil), all relevant environmental impact categories (global warming, eutrophication, ozone layer depletion, photo-oxidant formation and toxicity, among others) and a broad time framework. This can be achieved with the Life Cycle Assessment, which is a comprehensive methodology that consists of the following steps: 1) defining goal and scope, 2) generation of life cycle inventory, 3) impact assessment and 4) interpretation. This paper presents a preliminary Life Cycle Inventory for wastewater treatment systems in Latin America and the Caribbean. The compendium of air emissions, water discharges and waste were calculated with the use of a computational tool (simulator) designed specifically for this project and, in some cases, complemented with direct information from wastewater treatment plants.

Keywords: Life Cycle Assessment; wastewater treatment plants; environmental impacts.

Introduction

Wastewater treatment has become an important issue due to the pollution associated if the wastewater is not treated. Nowadays, investments in Latin America represents millions of dollars with the aim of installing new wastewater treatment plants (WWTP) to ensure the mitigation of pollution effects and avoiding health damage caused by untreated wastewater.

It is assumed that any kind of technology use for treating wastewater will avoid the environmental pollution to a great extent; however, it is necessary to consider a proper assessment and a systematic evaluation of wastewater treatment technologies, to identify improvement areas and also support the process of making environmentally responsible decisions.

The Life Cycle Assessment (LCA) 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 impacts associated (Tillman et al., 1998; Lundin et al., 2000; Gallego et al., 2008; Hospido et al., 2004; Hospido et al., 2008, among others).

The LCA studies the environmental aspects and the potential impacts through the life of a product or service, from the extraction or raw materials, the production, the use and the final disposal. That means, developing an inventory of relevant inputs and outputs of the system (inventory analysis), assessing their potential impacts (impact assessment) and interpreting the results, in relation with the proposed objectives (interpretation).

In this paper, a preliminary Life Cycle Inventory (LCI) of the most representative wastewater treatment technologies of Latin-America and Caribbean is presented. It is important to note that this LCI is the main input to assess the environmental impacts associated to the wastewater treatment technologies, according to the Life Cycle Assessment approach.

LCI is the more time consuming and data demanding stage in life cycle assessment, as it is an iterative step in which the data must be analyzed, reviewed and if necessary, corrected. The quality of the results depends principally of the LCI; for this reason. it is recommended that the estimations in the inventory may be gathered considering several approaches.

This study is part of the project "Reducing greenhouse gas emissions from wastewater treatment in Latin America and the Caribbean, to adopt more sustainable processes and technologies" developed by the Institute of Engineering at UNAM and sponsored by the International Development Research Center (IDRC) of Canada.

Methods

In order to determine the most important environmental impacts categories of the complete wastewater treatment life cycle, it is necessary to obtain all the inputs and output of each one of the subsystem showed in Figure 1.

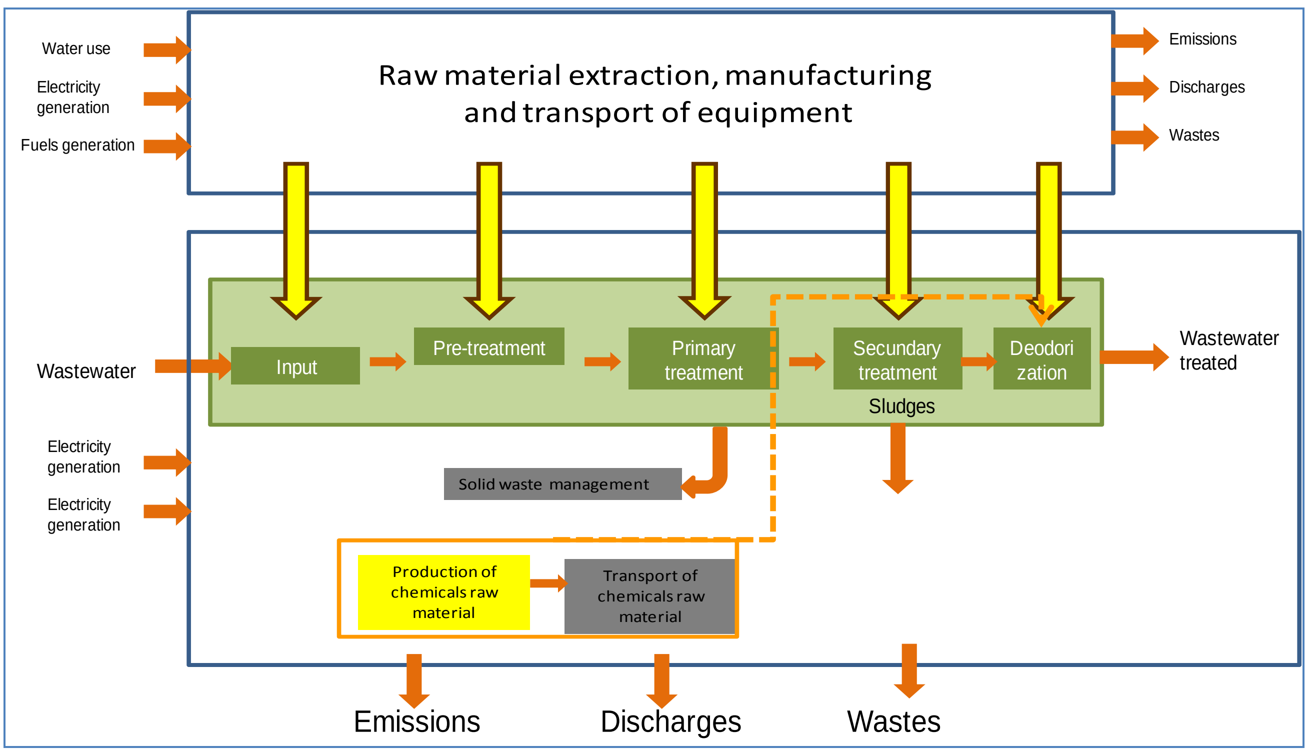

Figure 1. Typical system of wastewater treatment withdifferent input and outputs

Considering that obtaining the data is a difficult process, the Life Cycle Inventory presented in this paper corresponds on the one hand, to the analysis of specific data obtained from four real wastewater treatment plants and on the other hand to the inputs and outputs flows of one representative scenario of wastewater treatment for Latin-America and Caribbean. The characteristics of the systems analyzed are presented in Table 1.

Table 1. Characteristics of the systems analyzed for the generation of the preliminary wastewater treatment life cycle inventory.

System	Abbreviation	Caudal (l/s)	Functional units (base of comparison)	Subsystem considered
Activated sludge (small)	AS1	18	Wastewater treated in 20 years	a) Equipment manufacturing and transport b) Construction c) Operation
Stabilization ponds (small)	SP1	12	Wastewater treated in 20 years	a) Equipment manufacturing and transport b) Construction c) Operation
Activated sludge (big)	AS3	1437	Wastewater treated in 20 years	a) Equipment manufacturing and transport b) Construction c) Operation
Primary treatment (big)	PT3	1344	Wastewater treated in 20 years	a) Equipment manufacturing and transport b) Construction c) Operation
Representative scenario activated sludge (small)	RSAS1	13.3	Wastewater treated in 20 years	Operation

The data related with the operation stage for the AS1, SP1, AS3 and PT3 were obtained directly in the plant facilities, while construction, the equipment fabrication and transport were estimated according to technicalreports. For the case of equipment transport, the fuel consumption was estimated taking into account the distance from Houston, United States and from Guadalajara to Mexico.

For the RSAS1 the data were obtained by means of a computational simulator developed in the Institute of Engineering, as part of this project.

Greenhouse Gases emissions (GHG) were calculated with the IPCC (2006) methodologies.

Findings and discussion

A summary of the most relevant inputs for the analyzed systems are presented in Table 2. The data show the total amounts of energy and raw materials used by m^3 of wastewater treated during 20 years. The results are showed by each one of the subsystems considered: construction, equipment fabrication and operation.

Table.2: Preliminary life cycle inventory of construction, equipment fabrication and operation for the systems analyzed.

Description	Units per m3 of wastewater treated during 20 years	AS1	SP1	AS3	PT3	RSAS1
Construction						
Concrete	g	36.3633	140.5385	23.5030	0.6994	NA
Grave-sand	g	NA	904.8355	NA	NA	NA
Diesel Machinery	kJ	0.6079	46.4868	NA	NA	NA
Diesel transport	l	0.0000	0.0010	NA	NA	NA
Equipment fabrication						
Electricity	kJ	0.1111	0.0317	0.6171	0.0596	NA
Steel	g	1.2627	0.6823	0.3380	0.0403	NA
Diesel fuel	l	0.0007	0.0002	0.0000	0.0000	NA
Operation						
Electricity	kJ	4915.0601	0.3346	3550.4952	200.0019	2316.2280
Chloro (hypochlorite)	g	18.4568	NO	3.6244	NO	86.3443
Lime (CaO)	g	NO	2.1140	NO	NO	NO
Ferric chloride	g	NO	NO	NO	NA	NO
NA=Not available, NO=not applicable						

Table 2 shows that, SP1 is the system with the highest input of concrete, gravel and sand per m^3 of wastewater treated in the considered time frame; this is due to the construction of the ponds. Regarding to the equipment fabrication, AS3 presents the most important electricity demand, which is caused by the high quantity of blowers, pumps and other electrical equipment needed in this mechanized plant.

Of the five systems analyzed, AS1 presents the highest electricity consumption per m3, followed by AS3 and RSAS1 in second and third place respectively. These three systems are based on activated sludge technology, but according to these data, the energetic efficiency is different in the three cases (Table 2).

The hypochlorite is used for disinfection in AS1, AS3 and RSAS1.As in the case of electricity, the consumption of this reagent shows important differences (Table 2).

In Table 3 the wastewater quality of the influent and the effluent are presented for each one of the analyzed systems. It Differences between inflow and outflow BOD_5 can be observed..

The BOD_5 removed is 259 g/m^3 for AS1, 266 g/m^3 for SP1, 98.4 g/m^3 for AS3, 150 g/m^3 for PT3 and 244 g/m^3 for RSAS1; therefore the stabilization ponds (SP1) is the system with highest BOD_5 removed; however, if the analysis in made according to the removal efficiencies (98.7% for AS1, 70% for SP1, 95.5% for AS3, 56% for PT3 and 99.99% for RSAS1), the most effective system is RSAS1, AS1 and AS3, all of them with activated sludge technology, which is the higher electricity consumer.

Table 3: Water characteristics considered for the five systems analyzed.

	Parameter	AS1		SP1		AS3		PT3		RSAS1	
		Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
Organic Matter (g/m3)	BOD5	262.2	3.17	380	114	103.0	4.6	267.4	117.7	244	.005
	COD	647.5	46.82			253.2	40.3	444.2	222.9	557	.022
Nutrients (g/m3)	Nitrates	0.2	20.1					41.05	33.8		
	Phosphorus	8.9	6.69					7.91	5.04		
	Phosphates	27.5	20.4								
	Nitrites	0.16	0.08								
	Total Kjeldahl Nitrogen			64.9	39.3	22.8	5.4			43	31
	Phosphorus			12.9	9.7	6.7	4.9			9	6
	Ammonia					14.5	3.8				
Heavy metals (g/m3)	Iron	0.43	0.07			0.63	0.14				
	Manganese	0.02	0.01			0.07	0.04				
	Lead	0.08	0.08			0.06	0.06	0.08	0.05		
	Cadmium	0.08	0.08			0.01	0.009	0.008	0.006		
	Mercury	0.0004	0.0004			.001	.0007	0.001	0.0008		
	Arsenic	0.001	0.001			.002	.001	0.006	0.005		
	Chrome	0.05	0.05			0.056	0.056	0.16	0.04		
	Zinc	0.18	0.05			0.066	0.032	0.23	0.12		
	Cupper	0.04	0.04			0.028	0.026	0.08	0.04		
Alkali and alkaline earth metals(g/m3)	Total calcium					30.6	32.9				
	Total magnesium					18.2	17.6				
	Total sodium					68.3	75.6				
	Total potassium					14.5	15.2				
Minerals (g/m3)	Carbonates					226.4	167.8				
	Boron					0.53	0.53				
Fats and Oils (g/m3)	Fats and Oils	38.6	5.6			7.82	2.75	52.8	14.4		
TSS (g/m3)	Total suspended solids	92.25	8.11	243	100	92.2	8.11	274.5	100.1	265	90
Surfactants agents	Surfactants agents	9.3	0.18								

Wastewater treatment results in the emission of all three of the main GHGs: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). However, for wastewater treatment, CO_2 emissions do not need to be considered, in line with GHG accounting standards.

Methane emissions result from the metabolism of organic matter by microorganisms under anaerobic conditions and nitrous oxide emissions occur as a by-product during the conversion of organic nitrogen and ammonium into nitrogen gas, via nitrification and denitrification. These emissions mainly occur in the treatment process, and in the aquatic receiving environment (post discharge).

Table 4 presents the methane and nitrous oxide emissions. CH_4 is generated only in anaerobic conditions, thus, SP1 is the only one system with this GHG emission. N_2O emissions are based in the quantity of nitrogen in the effluent; in this sense, AS3 is the system with the lowest nitrogen load in the outflow (Table 3), however is the system with the highest level of N_2O production because of its large wastewater flow treated.

Table 4. Greenhouse gases emissions of operation stage for the systems analyzed

GHG emissions	Units	AS1	SP1	AS3	PT3	RSAS1
N_2O emissions*	Kg/20 years	NA	2,283	38454	NA	2043
CH_4 emissions	Kg / 20 years	NO	1,449,545	NO	NO	NO
*Indirect emissions generated in the aquatic receiving environment. NA=Not available, NO=not applicable						

Conclusions

According to the results obtained so far, it can be concluded that:

- Stabilization ponds require most raw materials than the other systems in the construction stage.
- Equipment fabrication is the stage with lower demand of material and energy.
- For all the analyzed systems, operation is the stage with highest electricity requirements.
- Activated sludge (small) is the system with more electricity requirements.
- Stabilization ponds is the system with the highest quantity of BOD_5 removed, the lowest electricity consumption and the only system with methane emissions.
- Activated sludge systems present the highest removal efficiencies and the highest electricity consumption.
- It is necessary to obtain precise information about the chemical raw material used during the operation stage.
- It is imperative to obtain all the physico-chemical and biological parameters of the influent and effluent for all the analyzed systems.
- It is necessary to estimates the nitrous oxide emissions for all the analyzed systems
- Research for the development and improve of the emission factors of GHG for wastewater treatment for LAC region is necessary.

- The generation of a Life Cycle Inventory in wastewater treatment is a difficult process due to the lack of information in the sector in Latin-America and the Caribbean.

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References

Gallego, A., Hospido, A., Moreira, M. T., and Feijoo, G. (2008). Environmental performance of wastewater treatment plants for small populations. *Resources Conservation & Recycling* . Obtenido de SciencieDirect.

Hospido, A., Moreira, M. T., & Feijoo, G. (2008). A Comparison of Municipal Wastewater Treatment Plants for Big Centres of Population in Galicia (Spain). *Int J LCA , 13* (1), 57 - 64.

Hospido, A., Moreira, M. T., Fernández-Couto, M., & Feijoo, G. (2004). Environmental Perfromance of a Municipal Wastewater Treatment Plants. *Int J LCA , 9* (4), 261 – 27.

IPCC, 2006. Directrices del IPCC del 2006 para los inventarios nacionales de gases de efecto invernadero. Capítulo 6: Tratamiento y eliminación de aguas residuales.

Lundin M, Bengtsson M, Molander S (2000): Life Cycle Assessment of wastewater systems: Influence of system boundaries and scale on calculated environmental loads. Environmental Science Technology 34 (1) 180–186.

Tillman A-M, Svingby M, Lundström H (1998): Life Cycle Assessment of municipal waste water systems. Int. J. LCA 3 (3) 145–157.