A comparative life cycle assessment of a wastewater treatment technology considering two inflow scales.

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Abstract A Life Cycle Assessment (LCA) is carried out for two wastewater treatment plants (WWTP) of activated sludge technology with different scales of inflow: 12 l/s and 1437 l/s (small and big WWTP, respectively), in order to determine if several small WWTP are environmentally preferably to one big WWTP to treat an equivalent inflow. The functional unit is the quantity of inflow treated by the big WWTP during 20 years. For both systems the energy consumption, raw material, emissions to air, solid wastes and water discharges were quantified for each one of the life cycle stages: equipment fabrication and transport, construction and operation of the plants. The results suggest that the installation of one big WWTP is better in environmental terms that several small WWTP for all the impact categories analyzed. The operation presents the highest impact due, principally, to the use of electricity by the aeration system.

1 Introduction

Existing water systems were initially designed for hygiene and sanitation reasons; however, given the need to achieve long-term sustainability, the objectives of urban water systems need to go beyond the protection of public health and receiving bodies. It is necessary to reduce the impacts to natural resources, to optimize the use of energy and water, reduce waste generation and allow nutrients recycling in plants [1]

In the countries of Latin America and the Caribbean (LAC), growing population pressure on water supply has exceeded, in most cases the ability of governments to achieve planned urban growth and forced to deal with priority water services and sewage, so that, the treatment of wastewater and solid waste disposal has lagged [2].

Based on the foregoing, it is imperative to develop and implement new solutions, fill the gaps of existing infrastructure for wastewater management, with new administrative and technological systems that should consider the limitations and conditions of the region, offering innovation and adaptation disclaiming conventional solutions [3].

One of the questions to which decisions makers reach and face, when designing plants, is about the desirability of designing a single plant that treats a large volume or several plants that treat small flows which together are as large flow.

According to the last, it is necessary to assess in an objective way the environmental implications derived from the wastewater treatment management systems, considering their scale.

The Life Cycle Assessment (LCA) is an objective and systematic tool, which has been applied to the evaluation of wastewater treatment systems [1], [4], [5].

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 LCA is developed for assessing the environmental implications of two scenarios of wastewater treatment plants with activated sludge technology considering two different scales of inflow: 12 l/s (small WWTP) and 1437 l/s (big WWTP), in order to determine if several small WWTP are environmentally preferably to one big WWTP when an equivalent inflow is treated.

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 Engineering Institute at UNAM and sponsored by the International Development Research Center (IDRC).

2 Goal and scope definition

2.1 Scenarios description

In this paper two scenarios of wastewater treatment are analyzed according to their scales of operation: 1) a Big Wastewater Treatment Plant (Big WWTP) which treats 1437 l/s and 2) a group of 120 Wastewater Treatment Plants (Small WWTP) which treat 12 l/s each one.

Data related with the equipment fabrication, transport, construction and operation are obtained from real wastewater treatment plants in Mexico City. In order to facilitate the comparability, the water quality of the influent and effluent are taken from the Big WWTP for both scenarios.

2.2 Functional unit

Considering that the mail function of a Wastewater Treatment Plant (WWTP) is the treatment of an influent, (with the objective of reduce the organic load, nutrients and suspended solids) the Functional Unit (FU) of this study is the quantity of inflow treated by a Big WWTP during 20 years (average lifetime of a WWTP), added up to 906344640 m3.

This FU is in line with the reported by [6]. The UF set is taken as the reference for all inputs and outputs calculations of two systems analyzed: a single system treating 906344640 m3 in 20 years and 120 treating 7568640 m3 in 20 years.

2.3 System description

This study considers the subsystems of: equipment fabrication, transport of equipment, construction and operation, according to the Fig. 1, for each one of the two scenarios of WWTP analyzed.

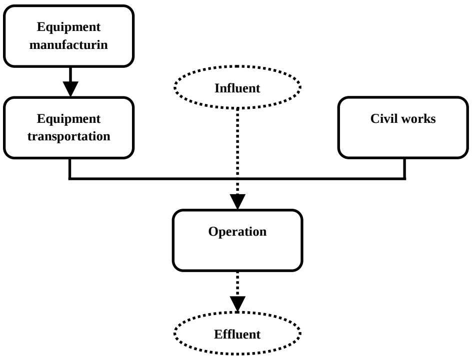

Fig.1: Systems description

3 Life cycle inventory

In order to calculate the Life Cycle Inventory (LCI) all the inputs and outputs of each one of the subsystems are considered. To complement the missing information it was used Ecobilan, DEAM database, associated to the TEAM software.

3.1 Equipment fabrication

Table 1 shows the equipment used over 20 years in each of the two scenarios analyzed. The equipment is defined in terms of a single plant for 20 years. A useful life of 5 years was estimated for each equipment element.

In this subsystem it is considered the steel used in the manufacture of equipment and the power consumption required for it, according to the profile of the United States (DEAM).

Tab.1: Equipment used the scenarios analyzed.

Characteristics	Small WWTP	Big WWTP
Input	20 pumps of 20 HP	28 pumps of 1500 HP
Pre-treatment	Screen	Screen
Primary treatment	12 pumps of 20 HP	24 pumps of 30 HP
Secondary treatment	8 blowers of 20 HP	24 blowers of 900 HP + 16 of 300 HP
	8 pumps of 20 HP	8 pumps of 60 HP
Disinfection	4 compressors	8 compressors
Output	16 pumps of 30 HP	28 pumps of 200 HP

3.2 Transport of equipment

In this Stage it is assumed that equipment is manufactured in a in a border town in southern United States and transported to Mexico City (1500 km). It is considered the diesel generation, according to the DEAM database; fuel use truck performance and the weight of equipment to transport.

3.3 Construction

This subsystem includes the construction with concrete (according to estimates from the volume of the tanks) of canals and pipelines in each of the scenarios analyzed (Table 2). The concrete manufacture was calculated based on DEAM database.

Tab.2: Concrete used in construction of WWTP

Characteristics	Small WWTP (Concrete in t)	Big WWTP (Concrete in t)
Input	15	52
Pre-treatment	35	247
Primary treatment	66	6198
Secondary treatment	159	13399
Disinfection	25	1066
Output	12	376

3.4 Operation

For both scenarios, in the operation stage, physicochemical parameters were taking into account as shown in Table 3. Emissions and landfill leachate data are calculated from [7]. Raw material, chemicals and fuel extraction have been extracted from the DEAM database.

Tab.3: Water characteristics considered for the two scenarios.

	Parameter	Influent	Effluent
Organic Matter (g/m3)	BOD5	103.0625	4.6509
	COD	253.2791	40.34
Nutrients (g/m3)	Nitrates	0.1391	13.29
	Phosphorus	4.6818	4.9555
	Phosphates	14.2982	15.2691
	Nitrites	0.0495	0.2973
	Total Kjeldahl Nitrogen	22.84	5.46
	Phosphorus	6.73	4.91
	Ammonia	14.5	3.82
Heavy metals(g/m3)	Iron	0.6377	0.1455
	Manganese	0.0797	0.0427
	Lead	0.069	0.0689
	Cadmium	0.0105	0.009
	Mercury	0.0014	0.0007
	Arsenic	0.0024	0.0015
	Chrome	0.056	0.056
	Zinc	0.0668	0.0325
	Cupper	0.0289	0.026
Alkali and alkaline earth metals(g/m3)	Total calcium	30.6473	32.9645
	Total magnesium	18.2336	17.6782
	Total sodium	68.3027	75.6264
	Total potassium	14.5918	15.2045
Minerals (g/m3)	Carbonates	226.4936	167.8636
	Boron	0.53	0.5364
Fats and Oils (g/m3)	Fats and Oils	7.8209	2.7591
TSS (g/m3)	Total suspended solids	92.2573	8.1118

4 Results and discussion

The data described above has been used to obtain the potential impacts of the scenarios analyzed according to the model CML 2000 (Table 4). The Life Cycle Impact Assessment (LCIA) was developed with the software: “Tools for Environmental Analysis and Management”: TEAM 4.0.

Tab.4: Potential impacts obtained in the LCIA

Impact categories	Units	Big WWTP	Small WWTP
AC	t SO2 eq.	3719	8631
AT	t 1,4-DCB eq.	3166	3398
AD	t Sb eq.	4644	10617
EU	t (SO4)3 eq.	157	177
GW	t CO2 eq.	595070	1472545
HT	t 1,4-DCB eq.	102711	234733
PF	t Ethylene eq.	112	287
TT	t 1,4-DCB eq.	1964	3995

Fig. 2 shows the relative performance of the scenarios analyzed. To do so, the LCIA results were indexed using the Big WWTP as baseline and considering 100 as reference for each impact category.

The relative performance of Big WWTP is better than Small WWTP for all the impact categories analyzed. The difference is more than 100% in almost all categories, which is in line with the reported by [5], where the plants of higher capacity -in terms of person equivalents-, present lower impacts.

Aquatic toxicity (AT) and eutrophication (EU) present similar impacts because in the operation stage the same water quality is considered for both scenarios in the influent and effluent.

Eutrophication and aquatic toxicity are the most important impacts categories in wastewater treatment systems, because they constitute the principal function of the treatment and represent relevant benefits to the population and ecosystem healt. However it is necessary to identify potential improvements that support sustainability of the treatments systems.

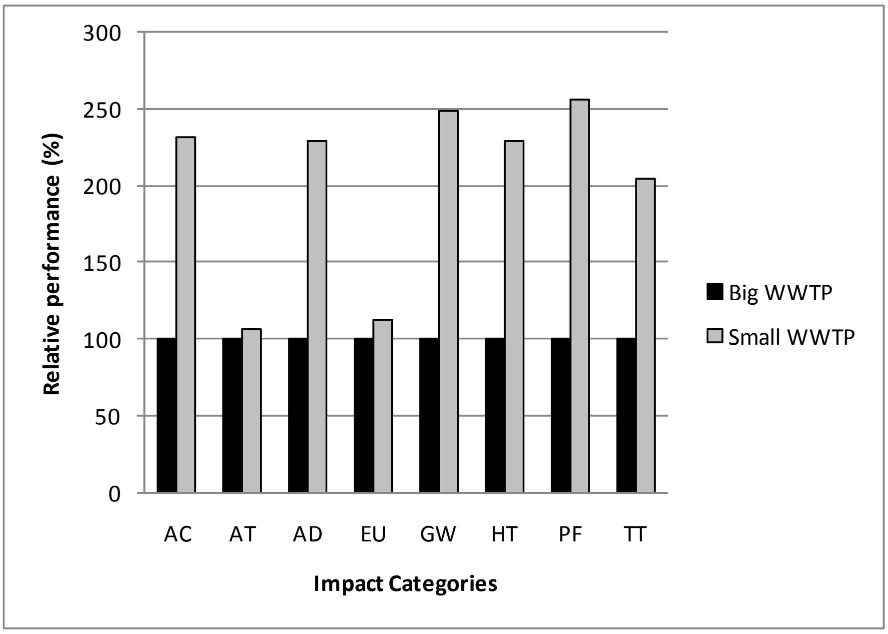

Fig.2: **Relative performance of the scenarios analyzed**

The comparison between the four considered stages: equipment fabrication and transport, construction, operation and landfilling are presented in Fig. 3, where can be observed that the operation presents the highest influence in the global impact in all analyzed categories. This agrees with the reported [4], [5].

Fig. 4 illustrates the relative contributions of all the processes considered in the operation subsystem. Here, the secondary treatment represents the highest impact for almost all categories due to the electricity consumption in the aeration systems, which agrees with the reported [4]. By other hand, Lundin et al [1] state that the electricity demand per functional unit is about four times higher in the small-scale system that they analyzed, which is in line with the results obtained in this study.

Additionally, the input and output pumping present impacts for almost all categories; which is due to the use of electricity, as in the case of the secondary treatment.

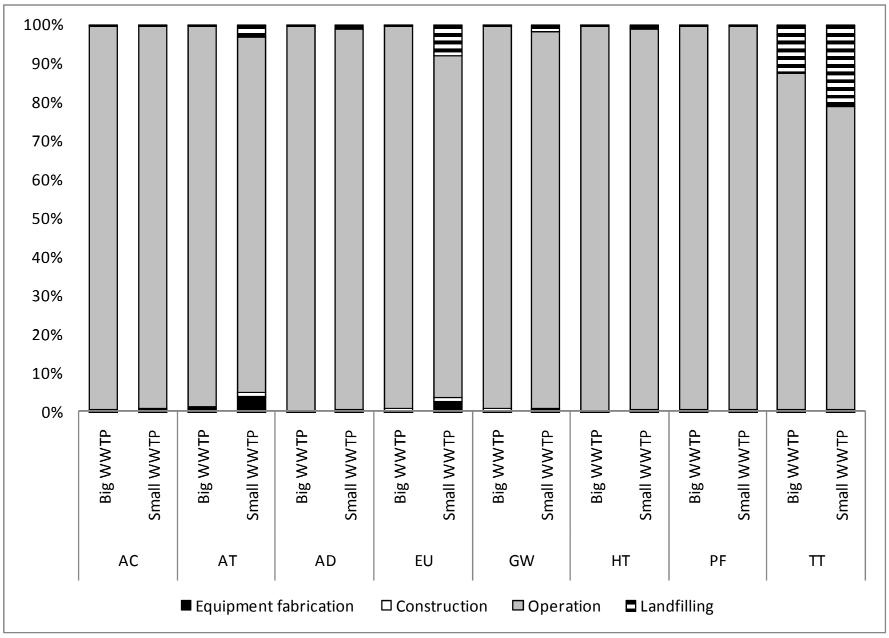

Fig.3: **Relative contribution of each subsystem considered to the total impact**

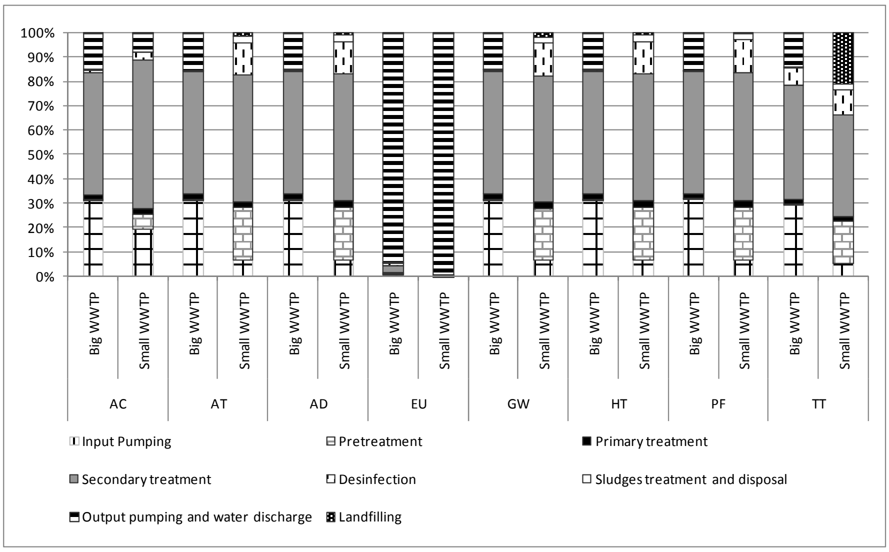

Fig.4: **Relative contributions of all the processes considered in the operation subsystem**

5 Conclusions

Two scenarios of wastewater treatment with activated sludge technology were analyzed comparing two scales of operation: one big WWTP and several small WWTP.

The scenario of several small WWTP generates highest impacts for all the impact categories analyzed, but in eutrophication and aquatic toxicity, the impacts are almost equivalents.

Operation is the stage with most environmental impact due to the secondary treatment in which the aeration systems demand more electricity.

Input and output pumping generate impacts due to the use of electricity as in the case of the aeration.

The use of alternative electricity resources represent a potential improvement to the treatment technology with activated sludge technology in the scenarios analyzed.

The results suggest that the installation of one big WWTP is better, in environmental terms that several small WWTP for all the impact categories analyzed. However, in order to extrapolate the results obtained to other locations, special attention should be taken to wastewater transport, electricity mix and sludge management.

This study is part of a research project in which the most representative wastewater treatment technologies for Latin America are being evaluated to propose the most appropriate technologies for the region; considering technical, economical, environmental and social aspects.

6 Acknowledgements

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