



ENVIRONMENTAL ASSESSMENT OF A WASTEWATER TREATMENT PLANT USING LIFE CYCLE ASSESSMENT (LCA) APPROACH: CASE OF AIN TAOUJDATE MOROCCO

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ABSTRACT

A life cycle assessment (LCA) was carried out to evaluate the environmental impact of a wastewater treatment plant (natural lagoon) located in Ain-Taoujdate city in Morocco. ReCiPe midpoint 2014 (H) method was used to assess the impact using ACV4E software. The study aims to analyze the ecological footprint of the plant, by identifying and comparing between the different phases of the life cycle. Construction and operation phases were assessed, only the decommissioning phase was not included. The LCA results of Ain Taoujdate WWTP showed discharges and emissions phase had a considerable impact on the first scenario, then the second scenario which was carried out as a fictitious aerated lagoon plant showed the operation phase with electricity as main source, was predominated over the other impacts. This shows that the last scenario would be suitable, if renewable energies are used as an alternative source, since aerated lagoons are known for their high purification performance compared to natural lagoon.

Key words: WWTP, life cycle assessment, ReCiPe method, environmental impacts

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1. INTRODUCTION

In many developing countries, the establishment of an extensive sewerage network and reliable wastewater treatment is a challenge. Indeed, Morocco had a sanitation rate of only 13% in 2004, there for Moroccan authorities approved the following year the National Sanitation Program (PNA), which has three objectives for 2020 and 2030: to reach a global network connection level of 80% in 2020 and 90% in 2030, to reduce domestic pollution by 80% in 2020 and 90% in 2030, to treat and reuse 100% of collected wastewater in 2030. [1]

Since the launch of the program, Morocco has created 140 wastewater treatment plants, which natural lagoon (NL) is the most widely used system. Thanks to the availability of land and the climatic conditions favored by the country's geographical situation, which have led to adopt it as the best suited technical solution to the economic and climatic context. NL represents more than 82% of the WWTPs built and 56% of the volume of wastewater treated [2]. Aerated lagoon (AL) represents 2% of the WWTPs, activated sludge 12%, bacterial beds 2% and the algal channel around 2%.

On global level, WWTPs are considered source of GHG emissions, surface, groundwater pollution, and odor problems. It is therefore necessary to assess its impact on the environment, through life cycle assessment (LCA), in order to find solutions and ways to reuse treated water and sludge with minimal consequences for humans and the environment. Given that the wastewater treatment industry in Morocco does not constitute precedent, but LCA studies on WWTPs can be considered totally new. Therefore, LCA can be used as an effective decision support tool that provides useful information on the advantages and disadvantages of the different possible alternatives in order to make a WWTP more environmentally friendly.

Over the last decade, a considerable number of studies have been carried out worldwide on ecological footprint and energy consumption by WWTPs using LCA approach. Tillman et al [3] first used this approach on a wastewater system, and several studies have been carried out treating municipal water, municipal and industrial WWTPs, and water recycling facilities [4] [5] [6] [7] [8], considering the construction, operation, and decommissioning phase or only part of the system.

However, the assessment is not straightforward due to the intrinsic spatial and temporal variability of WWTP systems [7]. According to Hospido et al [9] and Foley et al [10], the environmental performance of a WWTP is governed by the final disposition of the treated water and sludge, yet the performance of the plant may also be affected by the quality and inflow composition, size of the plant and local climate. The purpose of wastewater treatment plants must go beyond the protection of surface water and human health [11], i.e. minimizing the loss of resources, reducing waste generation and allowing nutrient recycling [12] [13] [14] [15].

Life cycle assessment (LCA), which is in accordance with the international standards (ISO 14040 and 14044), is an environmental assessment method capable of quantifying the impacts over the entire life cycle of a system, from the extraction of raw materials through the operation phase to the end of life (dismantling). This approach is organized in four stages: goal and scope definition, life cycle impact inventory, life cycle assessment and interpretation. Thanks to its multi-criteria approach, it makes possible to identify the main sources of environmental impacts and thus avoid pollution transfers from one impact category to another or from one stage of the life cycle to another [16].

The aim of this study is to assess the environmental impact of the Ain-Taoujdate WWTP (LN) and to identify the critical source of these impacts, then a life cycle assessment scenario will be carried out for a (theoretical) aerated lagoon (AL) type, in order to compare between

the two scenarios, to consider which scenario has the least impact on the environment and to choose the most efficient process.

The results obtained can be used as a reference in future WWTPs projects to determine the most environmentally friendly system considering technical, economic and geographical parameters.

2. MATERIALS AND METHODS

2.1. Brief Description of the Wastewater Treatment Plant

The city of Ain Taoujdate has natural lagoon type wastewater treatment plant. This plant is built on a total area of about 11 (ha) to treat influent of 1 500 m³/d, for (20 000 p.e.). It has been operational since 2004. Today the approximate average flow measured for the year 2019 is 2829 m³/d for a population of 42373 p.e., this increase is due to several factors such as increase in population and industrial activities.

The treated water is discharged into Ben Kezza river and the dried sludge is disposed at the public dump, the plant includes:

Pumping station: 3 pumps including one backup pump with a nominal power of 15 Kw, and a total flow rate of 59l/s;

Pre-treatment operations, including a stilling basin, a decanting channel equipped with an inclined screen, an electromagnetic flow meter, and a venturi channel;

Two flow distributors (FD1&FD2), circular in shape (Diameter = 4m), one for anaerobic basins and one for facultative basins; (not included in the inventory, works as gravitational flow)

Four anaerobic Ponds (AP1, AP2, AP3, AP4) with a useful volume of 2,300 m³ and a useful height of 3m;

Two facultative ponds (FP1&FP2) with a volume of 16,500 m³ and a useful height of 1.5 m;

The plant is also equipped with a sludge drying bed of Four units with a total surface area of 960 m², Figure 1.

2.2. Life Cycle Assessment

ACV4E [17] is the software used in this study to carry out the life cycle analysis. It was developed by Irstea (Institut national de recherche en sciences et technologies pour l'environnement et l'agriculture - France) in collaboration with ONEMA (Office National de l'eau et des milieux aquatiques - France) [18].

LCA is an internationally recognized and standardized approach to assess the potential environmental impacts of products and services throughout their life cycle [19]. The general LCA framework is defined according to international standards [ISO 14040-140444, 2006] [20] and is composed of 4 main stages: 1- goal and scope of the study 2- Life cycle inventory 3- Life cycle assessment 4- Interpretation of results.

1. Functional unit: Treat effluent of one population equivalent for one day, which correspond to 60 gBOD₅/d

2. Goal and scope definition:

- The goal of this LCA study is to evaluate the environmental impact of the plant under study (NL) and to define the critical source of these impacts.
- Carry out a life cycle assessment scenario for a (fictitious) aerated lagoon (LA) type station.

- Compare the two scenarios (natural and aerated lagoon) and then define which scenario has the least impact on the environment and choose the most efficient process.

This study will be limited to the construction and operation phase (Figure.1) and will not include city's sewerage network. The end-of-life stage or decommissioning phase of the plant also has not been included in the inventory since its environmental contribution is generally quite negligible compared to the overall environmental contribution of the plant [3] [4] [5] [6] [7].

3. Life cycle assessment

Impact assessment is a crucial step in quantifying the environmental impacts. The goal is to convert LCA data into potential impacts associated with products and processes. There are several methods for characterizing impacts, which evolve as knowledge about environmental mechanisms advances. The multi-criteria method chosen in ACV4E is ReCiPe midpoint 2014 (H).

This method was developed in 2008 by the National Institute for Public Health and the Environment (RIVM), CML, PRé Consultants and the Radboud University of Nijmegen on behalf of the Dutch Ministry of Infrastructure and the Environment, and can be categorized into two main groups: one oriented "potential impacts" (midpoint) and the other oriented "potential damage" (endpoint). The midpoint quantifies the changes in the environment without prejudging their effects, the endpoint quantifies the potential damage (to human health, ecosystems and natural resources).

The environmental impacts (midpoint) assessed by ReCiPe method are:

Global warming, Ozone depletion, Terrestrial acidification, Freshwater eutrophication, Marine eutrophication, Human toxicity, Photochemical oxidant formation, Particulate matter formation, Terrestrial ecotoxicity, Freshwater ecotoxicity, Marine ecotoxicity, Ionizing radiation, Agricultural land occupation, Urban land occupation, Natural land transformation, Water depletion, Metal depletion, Fossil depletion.

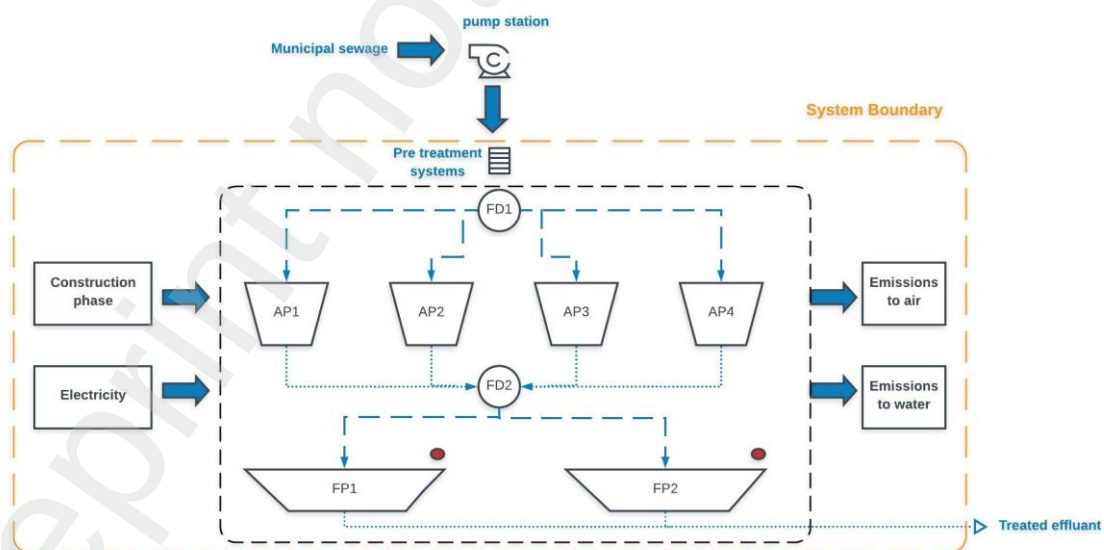


Figure 1. Scope of the LCA of the AinTaoujdate WWTP

2.3. Life Cycle Inventory

Table 1 Construction materials data used on construction phase

Construction materials	Unit	Amount
PVC (Pipe)	ton	1,007
Total mass of geomembrane	ton	38,326
Total mass of geotextile	ton	21,745
Gravel	ton	2005,828
Reinforced concrete	ton	25
Lean concrete	ton	13,200

Table 2 Summary of operation phase life cycle inventory for inputs and outputs of (NL) and (AL) WWTP

			Natural Lagoon	Aerated Lagoon
Sr.No	Parameter	Unit	Operation phase	
Inputs				
1	Electricity	KWh/d	8	360
2	sewage sludge transport	km	10	10
3	Generated sludge	t/y	304.3	396
Outputs				
1	Emissions to air			
1.1	TN	g/d*pe	5,58	0,35
	CH4*	Kg/d*pe	1,23	0.5024
1.2				
1.3	N2O*	Kg/d*pe	0.017	0.0069
1.4	Hg	g/d*pe	3,37E-07	5,54E-05
2	Emissions to water			
2.1	TN	g/d*pe	3	7,5
2.2	TP	g/d*pe	2	2
2.3	Inert-C	g/d*pe	19,17	17,5
2.4	Heavy metals			
	Cadmium	g/d*pe	1,96E-04	3,6E-05
	Mercury	g/d*pe	1,16E-04	1,65E-05
	Nickel	g/d*pe	4,99E-03	1,85E-03
	Lead	g/d*pe	3,92E-03	1,17E-03
	Cobalt	g/d*pe	1,13E-03	2,9E-05
	Arsenic	g/d*pe	8,34E-04	4,68E-04
	Molybdenum	g/d*pe	7,18E-04	8,82E-04
	Zinc	g/d*pe	6,30E-02	2,47E-02
	Barium	g/d*pe	1,02E-02	1,01E-02
	Copper	g/d*pe	2,04E-02	9,72E-03
	Chrome	g/d*pe	8,66E-03	1,96E-03
	Vanadium	g/d*pe	3,24E-04	3,24E-04
3	Emissions to soil**			
3.1	TN	g/d*pe	-	-
3.2	PT	g/d*pe	-	-
3.3	C-Inert	g/d*pe	-	-
3.4	Heavy Metals	g/d*pe	-	-

*source [21]
** For natural lagoon system, there are no emissions to the ground since all ponds are equipped with a geomembrane to ensure it watertight. Emissions to the ground are theoretically nil: sealing clay and a waterproof geotextile have been used in order to avoid any emissions to the ground.

3. RESULTS AND DISCUSSION

The results of the LCA carried out on the WWTP are presented in the following figures:

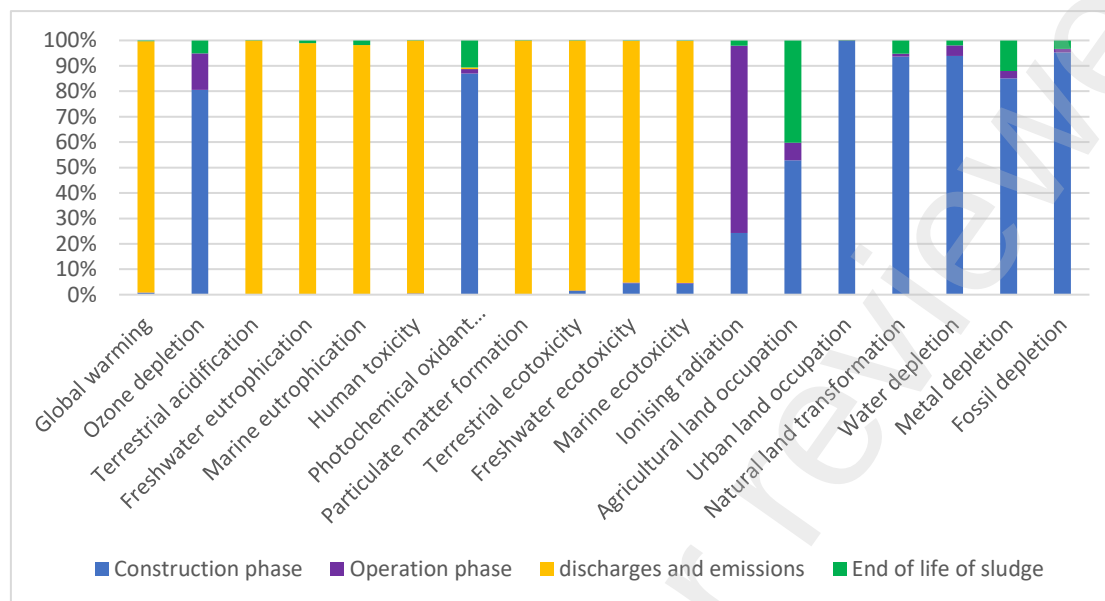


Figure 2(a) LCIA results of first scenario (NL WWTP)

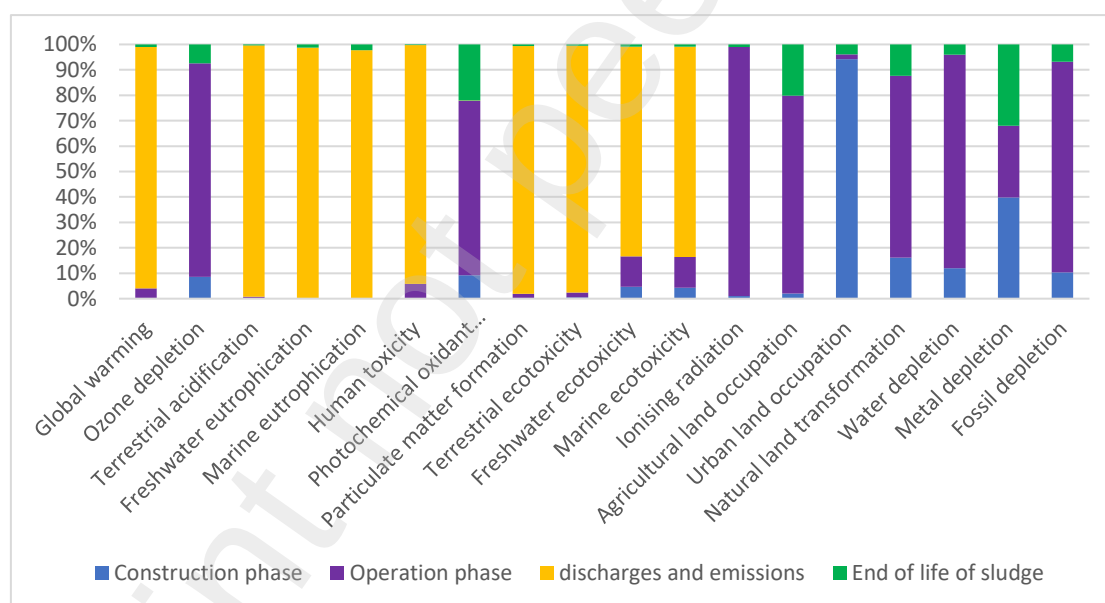


Figure 2(b) LCIA results of second scenario (AL WWTP)

In the next paragraph, we will describe each phase of the performed LCA:

3.1. Construction Phase

In the first scenario (NL), the construction phase is almost dominant and contributes significantly to the following impacts compared to the other phases, Figure 2(a):

Ozone depletion (83%), photochemical oxidant formation (81%), urban land occupation (100%), natural land transformation (89%), water depletion (92%), metal (85%) and fossil depletion (94%).

This domination over these impacts is due to materials construction (gravel, reinforced concrete, geomembrane layer...). Unfortunately, due to the limitation of ACV4E software, it is impossible to distinguish which construction material contributes most to the impact. However, this does not prevent us from raising hypotheses concerning the nature of this contribution to these impacts.

In the second scenario (AL) Figure2(b), it can be seen that the construction phase is less present on all impacts, a presence that is less than 40% (metal depletion), and even more (<12%) on the other impacts (Photochemical oxidant formation, ozone depletion, water depletion). Except on urban land occupation, there is a similarity with the first scenario (NL), which contributes to more than 94% of the global impact.

3.2. Operation Phase

Usually on WWTPs intended for big cities, the operation phase concerns energy consumption and interventions such as maintenance.

Except that, our case study, the natural lagoon is a wastewater treatment process that relies mainly on natural treatment and therefore does not consume energy (8 KWh/d). And this is clearly present in the LCA performed in Figure 2(a), where there is little or almost no evidence of any impact except on ionizing radiation.

In the second scenario, we see that the operation phase has a greater contribution to the following impacts: Ozone depletion (84%), photochemical oxidant formation (69%), ionizing radiation (98%), agricultural land occupation (78%), natural land occupation (72%), water depletion (84%), fossil depletion (83%).

This contribution is generally due to the consumption of electricity (theoretically 360KWh/d), which is high compared to the natural lagoon system (scenario 1), and this consumption is due to the continuous injection of oxygen by the air diffusers at the bottom or surface of the ponds Figure. 2(b).

The impact of the operation phase on these impacts can very well be solved by use of green energy, such as photovoltaic panels as a renewable and non-polluting source of energy. In this way, there will be less impact from the WWTP on the affected impacts.

3.3. Discharges and Emissions Phase

Discharges and emissions phase are placed as the first source of potential impact for the two performed LCA, followed by the construction phase of the first scenario (NL) Figure 2(a), and the operation phase for the second scenario (AL) Figure 2. (b), and includes gaseous emissions and emissions to the aquatic environment. It can be seen that the two scenarios share the same contribution to the following impacts: Global warming which is manifested by the contribution of the BOD₅ removal activity in the anaerobic ponds, given that in 2018, Yassine.B et al [21] estimated that the WWTP produced 7920 KgCO_{2e} of methane (CH₄) with an average of 781.74 KgCO_{2e}, and 1662.36 KgCO_{2e} of nitrous oxide (N₂O) in the same year.

Then Terrestrial acidification, (99%) of contribution from both scenarios is directly bound to emissions of SO₂, NO_x and NH₃ to the atmosphere. These pollutants, once emitted, are transported over long distances, interacting with atmospheric components before falling back to ground level causing alteration in acidity of the receiving environments. Marine and freshwater eutrophication are directly impacted by discharges and emissions that are related to nutrients released into water bodies. The impact of human, terrestrial, fresh and marine ecotoxicity are slightly identical for both scenarios, and are mainly related to the disposal of

sludge and effluents containing heavy metals. The ecotoxicity degree depends mainly on the heavy metals released to water and soil.

However, natural or aerated lagoon-based treatment process relies mainly on biological treatment of domestic wastewater, and therefore low concentrations of heavy metals should be expected in the treated water destined for the receiving environment.

3.4. End of Life of Sludge

The end-of-life phase of sludge was assessed as the stage that contributes least and negligibly in the life cycle analysis, except in the first scenario (NL) where the impact on agricultural land occupation is 40% due to sludge. Indeed, their high-water concentration (99%) and the high bacterial populations make it a cultured broth that favors degradation of containing fresh and highly fermentable organic matter [22].

It should be mentioned that the WWTP under study is equipped with four drying beds with a surface area of 920 m², which consists of distributing the sludge to be dewatered on a draining surface (composed of several layers of gravel and sand of varying granulometry), through which the interstitial water flows.

This slight contribution can therefore be explained by the treatment method used, since a lagoon treatment system is mainly intended for small communities, so the wastewater is less loaded compared to big cities, which leads to less sludge production since the ponds are only cleaned every two years.

4. CONCLUSION

The life cycle assessment approach that was conducted in this study is intended to identify the ecological footprint of the WWTP and to propose a scenario for eventual reduction.

The results obtained by ReCiPe mid-point 2014 (H) method showed that "discharges and emissions" phase of the current WWTP made a major contribution to the environmental impacts. The most important potential impacts were global warming, terrestrial acidification, marine and freshwater eutrophication, terrestrial ecotoxicity, freshwater and marine ecotoxicity. This is justified by the microbiological activity coming from the different ponds of the plant. The second simulated scenario showed that a WWTP with aerated lagoon contributes in the same way as a WWTP with natural lagoon type at "discharges and emissions" phase, except at operation phase where the second scenario takes part in a more significant way to the environmental impacts.

This study highlights the importance of opting for renewable energies as an alternative source for wastewater treatment plants, since the second scenario (AL) would be favorable for such situation, since on-site systems are mainly based on electricity and this treatment technique is well known, more efficient in terms of purification efficiency and less productive of greenhouse gases.

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