International Journal of Current Engineering and Technology

E-ISSN 2277 – 4106, P-ISSN 2347 – 5161
Available at http://inpressco.com/category/ijcet

*Research Article*

# Life cycle assessment for the upgrade of a wastewater treatment plant from secondary to tertiary treatment

**Ahmed El-Morsy and Mohamed Ayoub***

Public Works Engineering Department, Faculty of Engineering, Tanta University, Tanta, Egypt

Received 08 June 2020, Accepted 07 Aug 2020, Available online 09 Aug 2020, Vol.10, No.4 (July/Aug 2020)

**Abstract**

*A life cycle assessment (LCA) was applied in a recent project of upgrading Tazmant wastewater treatment plant in Egypt from secondary to tertiary treatment, taking into the consideration construction phase of the project as well as operation phase of the tertiary treatment. The LCA studies were carried out using CML 2001 impact assessment methodology. It was revealed that the upgrading of Tazmant wastewater treatment plant reduces the environmental impact by 43% from the acidification potential, 60% from the eutrophication potential, 62.5% the ozone layer depletion potential, 42% of abiotic depletion elements point, and 62.5% of photochemical ozone creation potential viewpoints. In addition, the effect of toxicity potential resulting from the operation of tertiary treatment alone amounts to only 20% of that resulting from secondary treatment, which reflects the positive environmental impact of wastewater recycling in addition to the water-saving gained from water reuse.*

**Keywords:** *Environmental impact, LCA, membrane filtration, tertiary treatment, wastewater*

## 1. Introduction

Increasing urbanization has resulted in an uneven distribution of population, industries, and water in urban areas, which led to imposing unprecedented pressures on the limited water and energy resources supplies as well as the safe disposal of domestic wastewater.

Wastewater treatment technologies contribute to protecting the environment and human health. Despite the environmental costs associated with domestic wastewater treatment, it is becoming difficult to ignore the increased impact of both domestic wastewater and the treatment technology on human health and the environment, where, the poor manner in which domestic wastewater is being treated is leading to the spread of many diseases around the world. Moreover, the direct and indirect emissions from wastewater treatment and the used technology are also playing a significant role in climate change (da Silva and Gouveia, 2020).

Environmental pollution from wastewater disposal is a concern in many countries around the world. Both developed and non-developed countries face serious household wastewater pollution problems affecting water bodies, groundwater and the environment. These technologies had a negative impact on the environment as the environmental burden associated with their use increased rapidly.

On the other hand, countries in the Middle East suffer from water shortages (Al-Ansari, 1998; Rogers and Lydon, 1994; Biswas, 1994) and at least 12 Arab countries have acute water scarcity problems with less than 500 m$^3$ of renewable water resources per capita available (Cherfane and Kim, 2012; Barr *et al.*, 2012). The supply of fresh potable water is vital to life, socioeconomic development, and political stability in the region. Scarcity of water resources in this region represents an extremely important factor in the stability and economic development within the region (Al-Ansari, 1998; Naff, 1993). The largest consumer of water in the Middle East is agriculture which accounts for 66% of demand (Hiniker, 1999). Therefore, the water shortage problem cannot be objectively analyzed nor adequately addressed without a thorough consideration of agriculture in the region (Sadik and Barghouti, 1994; Alanbari *et al.*, 2014).

The use of treated wastewater with a high level of quality that, nowadays, are discharged to the environment after their treatment in municipal sewage plants, needs special attention as a new water resource. However, water reuse should not be viewed as simply as reclamation and reuse of wastewater effluents (Ortiz *et al.*, 2007). Recently, this issue comes in Egypt at the top of the priorities that cause concern at the governmental and public levels, where the technologies used to treat domestic wastewater need continuous updating to reuse treated wastewater. This is known as the tertiary treatment of wastewater so that this is done at the least feasible costs of construction and operation

*Corresponding author's ORCID ID: 0000-0001-9833-7397
DOI: https://doi.org/10.14741/ijcet/v.10.4.10

(Diab, 2017; Gallego-Schmid and Tarpani, 2019; Awad *et al*., 2019; da Silva and Gouveia, 2020).

Disposal of domestic wastewater without sufficient treatment is increasingly concerned in developing countries. The improper design and operating of wastewater treatment plants (WWTPs) may cause severe environmental problems on local and global scales (Sabeen *et al*., 2018; Xiong *et al*., 2018a). Moreover, many developing countries are not served by wastewater treatment plants. Primitive methods are still used to mitigate the direct impacts of untreated wastewater on human health, but many environmental and health impacts are unbeatable. Besides, most wastewater treatment plants in developing countries only include primary (physical treatment) and secondary (biological treatment) stages without tertiary treatment or advanced sludge processing. Decisions about wastewater projects in developing countries are primarily influenced by direct capital and operating costs as long as the design is meeting the local standards, while life cycle cost and life cycle environmental impacts are rarely considered (Awad *et al*., 2019).

To identify and evaluate the environmental impacts of products or activities, a systematic and objective tool or method, including all stages of its lifecycle and all possible impacts, is needed. Life Cycle Assessment (LCA) was initially developed for manufactured products or materials, but the conceptual approach has been adapted to assess the environmental effects of processes such as wastewater treatment (Bravo and Ferrer, 2011; Büyükkamacı and Karaca, 2017). Within the field of wastewater treatment, LCA was first applied in the 1990s (Corominas *et al*., 2013). LCA allows for a better evaluation of wastewater treatment technologies in many different approaches. Owing to its holistic approach, LCA is becoming an increasingly significant decision-making tool in environmental management and it is used as a decision support tool to determine the most appropriate wastewater management strategy. LCA studies on wastewater treatment and reuse applications abound (Bravo and Ferrer, 2011; Alyaseri, 2016; Blanco *et al*., 2016; Opher & Friedler, 2016; Büyükkamacı and Karaca, 2017; Garfí *et al*., 2017 Lazic *et al*., 2017; Raghuvanshi *et al*., 2017).

LCA is structured into four phases: goal and scope definition, inventory of data, environmental impact assessment and interpretation of the results. The International Standards Organization (ISO) has drafted a series of regulations that explain how to perform an LCA (UNE-EN ISO 14040 2006a and UNE-EN ISO 14044 2006b), which were followed to perform this study. The aim of this study is to evaluate the environmental performance of an upgraded wastewater treatment plant (WWTP) in Egypt from secondary to tertiary treatment with the aim of reusing treated wastewater, in order to identify processes that cause significant environmental impacts.

## 2. Methodology

### *2.1. Study area description*

The case studied in this paper is a wastewater treatment and reuse project implemented in Tazmant City, Bani-Sweif Governorate, in Egypt, as demonstrated in Figure (1). The project was implemented in two stages: the first is a secondary wastewater treatment unit has operated since 2003 with a capacity of 62500 $m^3$/d, while the second stage is a tertiary treatment unit with the same capacity, which began to supply recycled water to, surrounding urban area in 2019 for agricultural reuse.

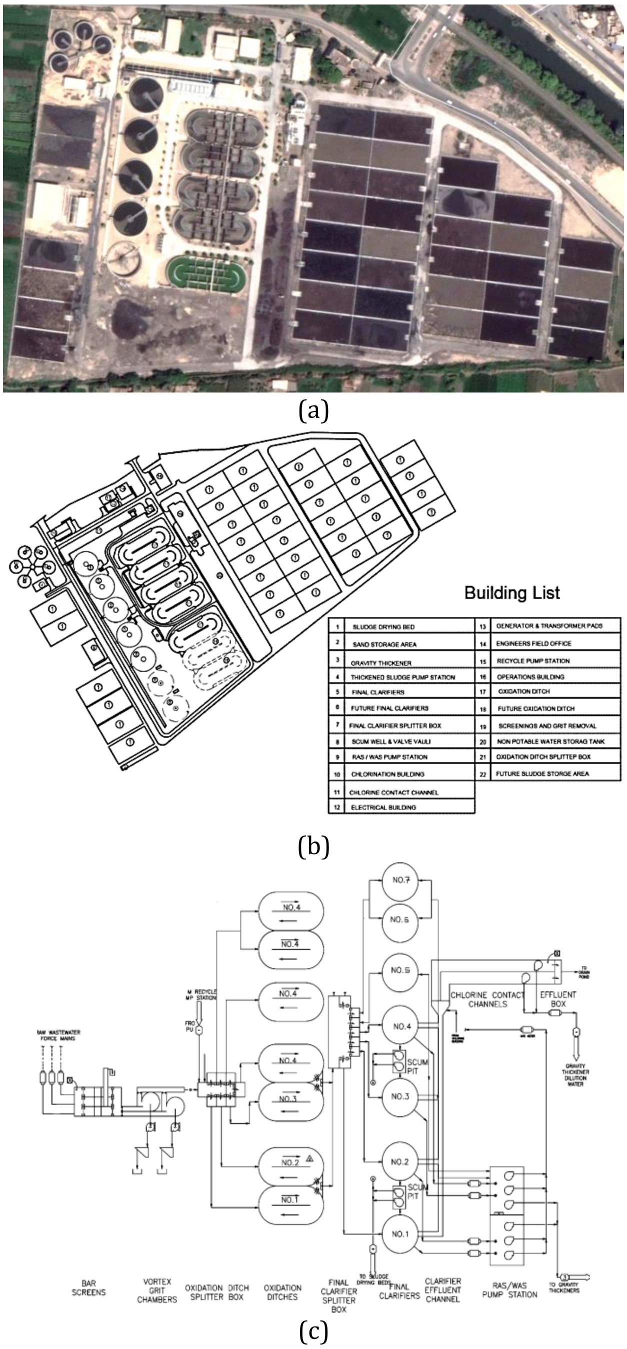


**Fig.1** Tazmant WWTP in (a) an aerial photo adapted from Google Earth, February 2020, (b) a general layout, (c) a flow chart

The preliminary treatment begins with the entry of raw wastewater into the screens and the grit removal chamber. Subsequently, wastewater flows to the primary sedimentation tanks followed by oxidation ditches (activated sludge system) and final sedimentation tanks to be secondary treated. The secondary treated wastewater enters to membrane filters followed by chlorination tank for disinfection to be tertiary treated for reuse (Metcalf and Eddy, 2003).

Results of the wastewater characteristics of Tazmant WWTP were collected in the steady-state during the period from October 2019 to January 2020 as appeared in Table (1) for the wastewater characteristics. These data were statistically analyzed to acquire the mean values and standard deviations for each parameter during the data collection period. All analyses were conducted according to Standard Methods for the Examination of Water and Wastewater (Rice *et al.*, 2012).

**Table 1** The wastewater characteristics of Tazmant WWTP

| Parameter | Influent (Raw wastewater) | Effluent (Secondary treated wastewater) | Final effluent (Tertiary treated wastewater) | Limits for irrigation* |
|---|---|---|---|---|
| pH | 7.1± 0.2 | 7.3 ± 0.2 | 7.3 ± 0.2 | 6-9 |
| Temperature (º C) | 26.5 ± 3 | 26.6 ± 3 | 26.6 ± 3 | 35 |
| $BOD_5$ (mg/L) | 237 ± 32 | 18.53 ± 4.5 | 20 ± 1 | 20 |
| COD (mg/L) | 433.15 ± 62 | 71.92 ± 12 | 40 ± 2 | 40 |
| TSS (mg/L) | 289.9 ± 45 | 19.4 ± 2.6 | 10 ± 0.5 | 20 |
| $NO_3$ (mg/L) | - | 0.975 ± 0.1 | - | 10 |
| $PO_4$ (mg/L) | - | 4.29 ± 0.8 | - | - |
| Oil and grease (mg/L) | 22.85 ± 5.2 | 0.55 ± 0.1 | - | 4 |

**Notes:** * Adapted from AbuZeid and Elrawady (2014)

### 2.2. LCA approach (Framework for LCA analysis)

In this study, the LCA studies were carried out using OpenLCA 1.10.1 Software. It has been developed by GreenDelta Company since 2006. The CML 2001 (Institute of Environmental Sciences, Leiden University) impact assessment method was selected to assess the environmental impacts. The required data for the software was obtained from the literature and Eco-invent database, which are integrated into the OpenLCA 1.10.1 software. Seven environmental impact categories were taken into consideration: Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), Ozone Layer Depletion Potential (ODP), Toxicity Potential (TP), Abiotic Depletion Potential (ADP), and Photochemical Ozone Creation Potential (POCP).

OpenLCA 1.10.1 software run on according to created flow diagram and introduced inputs and outputs. The inputs of this study are mainly treated wastewater and energy. Treated wastewater quality shown in Table (1) varies depending on the several factors, such as influent wastewater properties, treatment processes used and operational conditions. The LCA phases are structured in openLCA 1.10.1 Software in accordance with ISO14040 and ISO14044 LCA standards. Figure (2) represents the four stages under the ISO 14040 guidelines (Finkbeiner *et al.*, 2006; Negelah, 2008; Alanbari *et al.*, 2014; Büyükkamacı and Karaca, 2017).

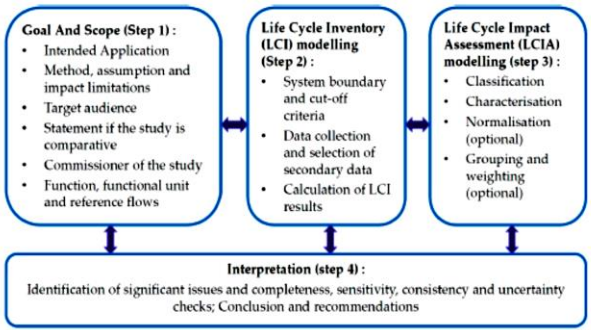


**Fig.2** LCA framework adapted from ISO 14040 (Finkbeiner *et al.*, 2006)

#### 2.2.1. Goal and scope definition

Goal and scope definition is to define how big a part of the product or the process life cycle will be taken in assessment and to what end will the assessment be serving. The criteria serving to system comparison and specific times are described in this step (PRé Consultants, 2010; Krishna *et al.*, 2017).

#### 2.2.2. Inventory analysis (Inventory of data)

In this step, inventory analysis provides a description of material and energy flows within the product system and particularly its interaction with the environment, consumed raw materials, and emissions to the environment (PRé Consultants, 2010; Krishna *et al.*, 2017). The data for a process must be collected in a form, so-called normalizing the process as shown in Figure (3).

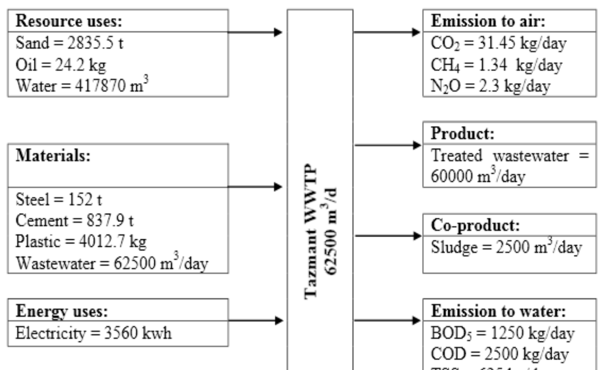


**Fig.3** Inventory analysis of Tazmant WWTP

#### *2.2.3. Impact assessment (Environmental impact assessment)*

There exist a wide variety of impact assessment methods available in OpenLCA 1.10.1 Software. In this study, The CML 2001 method was used to determine the environmental impacts of Tazmant WWTP, so that the upgrading of the treatment plant from secondary to tertiary treatment is evaluated taking into consideration the construction work done to upgrade the plant by adding membrane filters and accessories. Moreover, the function unit was selected to be 1 $m^3$ after secondary as well as tertiary treatment.

#### *2.2.4. Interpretation (Interpretation of the results)*

Interpretation of a life cycle comprises critical review, determination of data sensitivity, and result clarification.

## 3. Results and discussion

The following results are discussed depending on each environmental impact categories. The cases of LCA in the following charts are the treated wastewater after secondary (biological) treatment, the treated wastewater after tertiary treatment (membrane filtration), and the construction work required for upgrading Tazmant WWTP from secondary to tertiary treatment.

### *3.1. Global warming potential*

The global warming potential (GWP) impacts are directly related to the electricity consumption for operating the WWTPs. There is a linear relationship between global warming potential and the consumption of purchased electricity (especially fossil-based electricity) for WWTPs operation. This is mostly recognized to the dominating $CO_2$ emissions during electricity production.

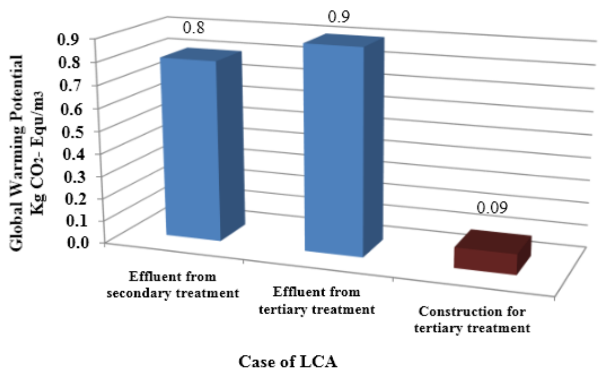


**Fig.4** Global warming potential impact category from each case

Thus, the results of this type of GWP are generally in parallel with the usage of electricity (Zang *et al.*, 2015). It is clear from the Figure (4) that the upgrading of Tazmant WWTP from secondary to tertiary treatment has additional effect on GWP at a slight rate of 12.5% in terms of operation and 11.25% in terms of construction needed to upgrade the WWTP. This is mainly due to the higher energy requirements of the membrane systems for both operations and especially the cleaning phase (Büyükkamacı and Karaca, 2017; Chang *et al.*, 2017).

### *3.2. Acidification potential*

Acidification has local effects on the environment and it is usually associated with atmospheric contamination. Acidification potential (AP) refers to an increase of the hydrogen ion concentration in aquatic commonly caused by the emissions of sulfur dioxide ($SO_2$), ammonia ($NH_3$), and nitrogen oxides ($NO_x$) (Pennington *et al.*, 2004; Goedkoop *et al.* 2009; Zang *et al.*, 2015; Büyükkamacı and Karaca, 2017). It can be noticed from Figure (5) that the tertiary treatment is better than the secondary treatment from the acidification potential point of view, whether in terms of operation or construction required to upgrade Tazmant WWTP. Combination of construction and operation of the tertiary treatment result 0.057 Kg $SO_2$- Equ/$m^3$ i.e. about 57% of the acidification potential impact of the secondary treatment of wastewater. Therefore, upgrading of Tazmant WWTP from secondary to tertiary treatment reduces the environmental impact by 43% from the AP point of view.

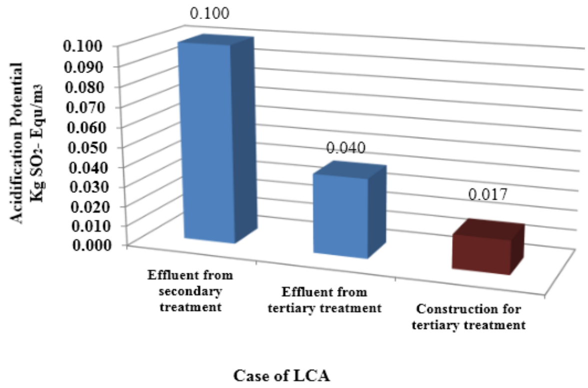


**Fig.5** Acidification potential impact category from each case

### *3.3. Eutrophication potential*

Eutrophication potential (EP) due to the residual nutrients in the effluent has been considered the most relevant environmental issue when performing the environmental evaluation of WWTPs. It is reported that the EP impact category of a WWTP is mostly associated with the emissions to water, mainly due to the phosphorus (P), nitrogen (N) and to a lower extent, degradable organics in wastewater effluent (Zang *et al.*, 2015; Büyükkamacı and Karaca, 2017). Thus, the eutrophication potential impact can be decreased immediately by implementing more sophisticated technology to enhance nutrient removal efficiency (Zang *et al.*, 2015). Figure (6) represents the eutrophication potential of the secondary treatment, tertiary treatment in operation as well as construction stage. Even with the combination of the effects of operation and construction stage in the tertiary treatment, it is noted that its superiority over the secondary treatment of wastewater from the eutrophication potential point of view. Hence, a reduction to about 60% of EP Kg $PO_4$-Equ/m$^3$ can be achieved by upgrading Tazmant WWTP from secondary to tertiary treatment.

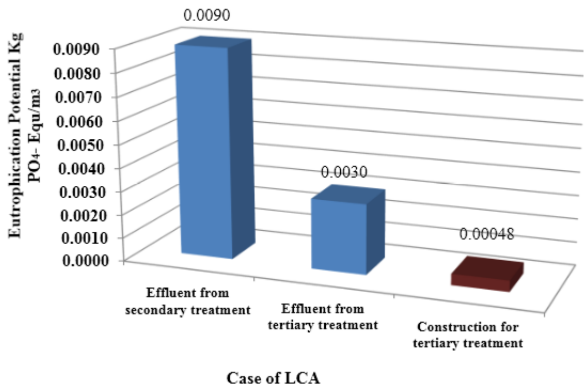


**Fig.6** Eutrophication potential impact category from each case

### *3.4. Ozone layer depletion potential*

The ozone layer depletion (ODPs) is caused by the emission of gases that reduce the ozone layer and depleting substances, such as chlorofluorocarbons and bromo-fluorocarbons, in the stratospheric ozone layer (Itsubo and Inaba 2012). ODPs of the secondary treatment, tertiary treatment in operation as well as construction stage are outlined in Figure (7). It can be noticed that the tertiary treatment of wastewater is lower impact than the secondary treatment from the ODPs point of view by 62.5% of ODPs Kg $R_{11}$-Equ/m$^3$. This result includes the operation and construction phase together for tertiary treatment in Tazmant WWTP.

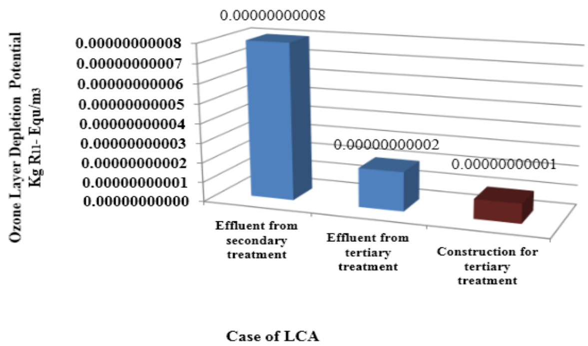


**Fig.7** Ozone layer depletion potential impact category from each case

### *3.5. Toxicity potential*

Toxicity can affect humans, and the environment, such as water, soil. This topic is significant for WWTPs to determine important toxic substances in effluent and thus adopt effective treatment alternatives. For the present study, toxicity potential (TP) was calculated for Tazmant WWTP for the secondary and tertiary treatment. The results of toxicity potentials are given in Figure (8).

From Figure (8), it is noticed that the effect of toxicity potential resulting from the construction stage of the tertiary treatment alone is close to that resulting from the operation of the secondary treatment (about 83% of TP Kg DCB-Equ/m$^3$) in Tazmant WWTP. This indicates the negative environmental impact of the use of conventional building materials (e.g. cement, brick, etc.) on the environment in general. In spite of this, the effect of toxicity potential resulting from the operation of tertiary treatment alone amounts to only 20% TP Kg DCB-Equ/m$^3$ of that resulting from secondary treatment, which reflects the positive environmental impact of wastewater recycling.

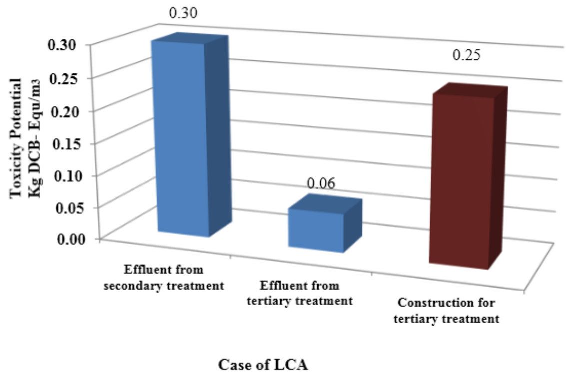


**Fig.8** Toxicity potential impact category from each case

### *3.6. Abiotic depletion elements*

Depletion of the abiotic resource is the reduced availability of the total reserve for the potential resource functions (Van Oers *et al.* 2002). Abiotic resource depletion is grouped as depletion of elements and depletion of fossil fuels.

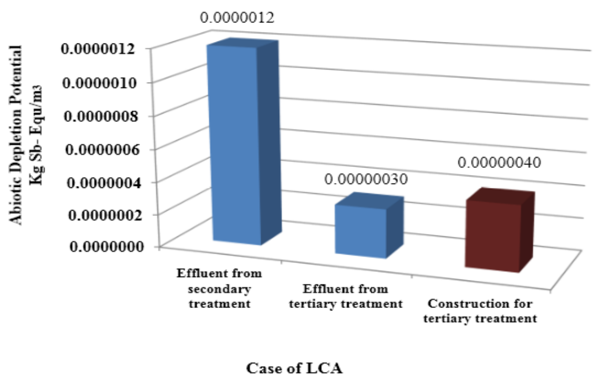


**Fig.9** Abiotic depletion elements impact category from each case

As shown in Figure (9), the highest abiotic depletion elements effect in Tazmant WWTP was $1.2\times10^{-6}$ kg Sb-Equ / m$^3$ from the secondary treatment. While the effect of the tertiary treatment in the construction and operation stage was $4\times10^{-7}$ kg Sb-Equ / m$^3$ and $3\times10^{-7}$ kg Sb-Equ / m$^3$, respectively. Furthermore, the combination of tertiary treatment operation and construction stage has lower effects compared to the secondary treatment only by about 42% of abiotic depletion elements point of view. Therefore, the tertiary treatment of wastewater is less depletion of abiotic resources as well as environmentally friendly.

### *3.7. Photochemical ozone creation potential*

Photochemical ozone creation potential (POCP) has been utilized to characterize compounds as indicated by their ability to form ozone (Andersson-Sköld and Holmberg 2000) and it is ordinarily used in life cycle impact assessment to address the impact category 'photo-oxidant formation' and just gives factors for particular volatile organic compounds and does not consider background concentrations and meteorological conditions (Labouze *et al*. 2004).

As shown in Figure (10), the highest POCP in Tazmant WWTP was 4 gm. Ethene-Equ/m$^3$ from the secondary treatment. While the impact of the tertiary treatment in the construction and operation stage was 0.9 gm. Ethene-Equ/m$^3$ and 0.6 gm. Ethene-Equ/m$^3$, respectively. Moreover, the combination of tertiary treatment operation and construction stage has lower effects compared to the secondary treatment just by about 62.5% of POCP point of view. In this manner, the tertiary treatment of wastewater is less POCP as well as environmentally friendly.

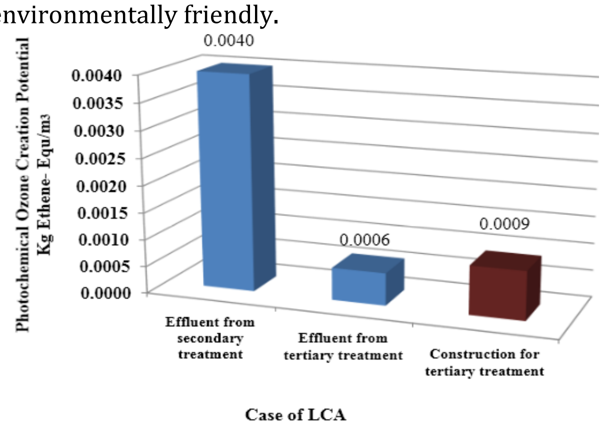


**Fig.10** Photochemical ozone creation potential impact category from each case

## Conclusions

Life cycle assessment (LCA) has been widely used to determine the most suitable wastewater treatment alternatives. The scope of this study is evaluating the environmental performance of upgrading Tazmant WWTP in Egypt from secondary to tertiary treatment with the aim of wastewater recycling, in order to identify processes that cause significant environmental impacts. LCA depends on the functional unit and the system boundaries. Since the functional unit of this study is 1 m$^3$ of treated wastewater. In addition, the LCA studies were carried out via OpenLCA 1.10.1 software and CML 2001 impact assessment methodology to assess the environmental impact.

As a result of the comprehensive LCA analysis of the current study, it was revealed that the life cycle benefited more from tertiary treated wastewater. Furthermore, the tertiary treatment was very beneficial to impact categories due to the water-saving gained from water reuse. According to this study, the following conclusions were obtained:

The upgrading of Tazmant WWTP has additional effect on the global warming potential at a slight rate of 12.5% in terms of operation and 11.25% in terms of construction needed to upgrade the WWTP. This is mainly due to the higher energy requirements of the membrane systems for both operations and especially the cleaning phase.

The tertiary treatment is better than the secondary treatment from the acidification potential point of view, whether in terms of operation or construction required to upgrade Tazmant WWTP. Combination of construction and operation of the tertiary treatment result about 57% of the acidification potential impact of the secondary treatment of wastewater. Therefore, upgrading of Tazmant WWTP from secondary to tertiary treatment reduces the environmental impact by 43% from the acidification potential point of view.

A reduction to about 60% of the eutrophication potential can be achieved by upgrading the Tazmant treatment plant from secondary treatment to the third stage. Despite the combined effects of the operation and construction stage in the tertiary treatment, it is noted that its superiority over the secondary treatment of wastewater from the eutrophication potential point of view.

The tertiary treatment of wastewater is lower impact than the secondary treatment from the ozone layer depletion potential point of view by 62.5%. This result includes the operation and construction phase together for tertiary treatment in Tazmant WWTP.

The effect of toxicity potential (TP) resulting from the construction stage of the tertiary treatment alone is close to that resulting from the operation of the secondary treatment (about 83% of TP Kg DCB-Equ/m$^3$) in Tazmant WWTP. This indicates the negative environmental impact of the use of conventional building materials (e.g. cement, brick, etc.) on the environment in general. In spite of this, the effect of toxicity potential resulting from the operation of tertiary treatment alone amounts to only 20% TP Kg DCB-Equ/m$^3$ of that resulting from secondary treatment, which reflects the positive environmental impact of wastewater recycling.

The combination of tertiary treatment operation and construction stage has lower effects compared to the secondary treatment only by about 42% of abiotic depletion elements point of view. Therefore, the tertiary treatment of wastewater is less depletion of abiotic resources as well as environmentally friendly.

The combination of tertiary treatment operation and construction stage has lower effects compared to the secondary treatment just by about 62.5% of photochemical ozone creation potential (POCP) point of view. In this manner, the tertiary treatment of wastewater is less POCP as well as environmentally friendly.

## References


AbuZeid, K; Elrawady, M. (2014).*Strategic Vision for Treated Wastewater Reuse in Egypt*. Water Resources Management Program, CEDARE.

Alanbari, M. A., Al-Ansari, N., Altaee, S. A., & Knutsson, S. (2014). Application of Simapro7 on Karbala Wastewater Treatment Plant, Iraq. *Journal of Earth Sciences and Geotechnical Engineering, 4*(2), 55-68.

Al-Ansari, N.A., Water Resources in the Arab countries: problems and possible solutions, Water: a looming crisis", *Intern. Conf. on World Water Resources at the beginning of the 21st century*, UNESCO, Paris, 3-6 June 1998.

Alyaseri, I. (2016). Performance of wastewater treatment plants in Iraq: life cycle assessment approach. *IOSR J. Environ. Sci. Toxicol. Food Technol., 10*(8), 29-36.

Andersson-Sköld, Y., & Holmberg, L. (2000). Photochemical ozone creation potentials (POCP) and replacement of solvents in Europe. *Atmospheric Environment, 34*(19), 3159-3169.

Awad, H., Alalm, M. G., & El-Etriby, H. K. (2019). Environmental and cost life cycle assessment of different alternatives for improvement of wastewater treatment plants in developing countries. *Science of the Total Environment, 660*, 57-68.

Barr J., Grego S., Hassan E., Niasse M., Rast W.and Talafré J., Regional challenges, global impacts, in Managing Water under Uncertainty and Risk, UN World Water Development Report 4, Chapter 7, 2012.

Blanco, D., Collado, S., Laca, A., & Díaz, M. (2016). Life cycle assessment of introducing an anaerobic digester in a municipal wastewater treatment plant in Spain. *Water Science and Technology, 73*(4), 835-842.

Bravo, L., & Ferrer, I. (2011). Life Cycle Assessment of an intensive sewage treatment plant in Barcelona (Spain) with focus on energy aspects. *Water Science and Technology, 64*(2), 440-447.

Büyükkamacı, N., & Karaca, G. (2017). Life cycle assessment study on polishing units for use of treated wastewater in agricultural reuse. *Water Science and Technology, 76*(12), 3205-3212.

Chang, H., Liang, H., Qu, F., Liu, B., Yu, H., Du, X., ... & Snyder, S. A. (2017). Hydraulic backwashing for low-pressure membranes in drinking water treatment: A review. *Journal of Membrane Science, 540*, 362-380.

Corominas, L., Foley, J., Guest, J. S., Hospido, A., Larsen, H. F., Morera, S., & Shaw, A. (2013). Life cycle assessment applied to wastewater treatment: state of the art. *Water research, 47*(15), 5480-5492.

da Silva, F. J. G., & Gouveia, R. M. (2020). Global Population Growth and Industrial Impact on the Environment. In *Cleaner Production* (pp. 33-75). Springer, Cham.

Diab, Y. (2017, October). Sustainable and Resilient Cities: Is It an Infrastructure Problem? In *International Conference on Sustainable Infrastructure 2017* (pp. 11-19).

Finkbeiner, M., Inaba, A., Tan, R., Christiansen, K., & Klüppel, H. J. (2006). The new international standards for life cycle assessment: ISO 14040 and ISO 14044. *The international journal of life cycle assessment, 11*(2), 80-85.

Frischknecht, R., Jungbluth, N., Althaus, H. J., Bauer, C., Doka, G., Dones, R. & Loerincik, Y. (2007). Implementation of life cycle impact assessment methods.

Gallego-Schmid, A., & Tarpani, R. R. Z. (2019). Life cycle assessment of wastewater treatment in developing countries: a review. *Water research, 153*, 63-79.

Garfí, M., Flores, L., & Ferrer, I. (2017). Life cycle assessment of wastewater treatment systems for small communities: activated sludge, constructed wetlands and high rate algal ponds. *Journal of Cleaner Production, 161*, 211-219.

Goedkoop, M., Heijungs, R., Huijbregts, M., De Schryver, A., Struijs, J., & Van Zelm, R. (2009). ReCiPe 2008. *A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level, 1*, 1-126.

Hiniker, M. Sustainable Solutions to Water Conflicts in the Jordan Valley, Geneva: Green Cross International, 1999.

Itsubo, N., & Inaba, A. (2012). Characterization and damage evaluation methods. *LIME 2 Life-cycle Impact Assessment Method Based on Endpoint Modeling Chapter II.*

Krishna, I. M., Manickam, V., Shah, A., & Davergave, N. (2017). *Environmental management: science and engineering for industry*. Butterworth-Heinemann.

Lazic, A., Baresel, C., Kerchove, A., & Dahlgren, L. (2017). Holistic wastewater reuse solutions–evaluation of treatment efficiency, environmental impacts and costs. *Int. J. Water Wastewater Treat, 3*(1).

Metcalf & Eddy, Burton, F. L., Stensel, H. D., & Tchobanoglous, G. (2003). *Wastewater engineering: treatment and reuse*. McGraw Hill.

Naff, T., Conflict and water use in the Middle East, , in Roger, R. and Lydon, P. (Ed.), Water in the Arab Word: Perspectives and Prognoses, Harvard University, 253-284,1993.

Negelah S. (2008). *A Life Cycle Assessment of Sewage Sludge Treatment Options*. Msc, thesis, Aalborg University, Denmark.

Opher, T., & Friedler, E. (2016). Comparative LCA of decentralized wastewater treatment alternatives for non-potable urban reuse. *Journal of environmental management, 182*, 464-476.

Ortiz, M., Raluy, R. G., & Serra, L. (2007). Life cycle assessment of water treatment technologies: wastewater and water-reuse in a small town. *Desalination, 204*(1-3), 121-131.

Pennington, D. W., Potting, J., Finnveden, G., Lindeijer, E., Jolliet, O., Rydberg, T., & Rebitzer, G. (2004). Life cycle assessment Part 2: Current impact assessment practice. *Environment international, 30*(5), 721-739.

PRé Consultants, Introduction to LCA with SimaPro 7, 2010. http://www. environmental-xpert.com/software/pre/pre.htm

Raghuvanshi, S., Bhakar, V., Sowmya, C., & Sangwan, K. S. (2017). Waste water treatment plant life cycle assessment: treatment process to reuse of water. *Procedia CIRP, 61*, 761-766.

Rice, E. W., Baird, R. B., Eaton, A. D., & Clesceri, L. S. (2012). Standard methods for the examination of water and wastewater. *American Public Health Association, Washington, DC, 541*.

Rogers P. and Lydon P. (eds.), "Water in the Arab World", Massachusetts, USA: Harvard University Press, 1994.

Sabeen, A.H., Noor, Z.Z., Ngadi, N., Almuraisy, S., Raheem, A.B. (2018). Quantification of environmental impacts of domestic wastewater treatment using life cycle assessment: a review. *J. Clean. Prod. 190*, 221–233.

Sadik A.K. and Barghouti S., The water problems of the Arab world: Management of scarce water resources, In P. Rogers and P. Lydon (eds.), "Water in the Arab World", Massachusetts, USA: Harvard University Press. 4-37, 1994.

UNE-EN ISO 14040 (2006a). *Gestión ambiental, Análisis del ciclo de vida y Principios y marco de referencia (Environmental Management, Life Cycle Assessment and Principles and Framework*). Comité técnico AEN/CTN 150 Gestión Medioambiental, AENOR, Madrid.

UNE-EN ISO 14044 (2006b). *Gestión ambiental, Análisis del ciclo de vida y Requisitos y directrices (Environmenta Management, Life Cycle Assessment and Requirements an Guidelines*). Comité técnico AEN/CTN 150 Gestión Medioambiental, AENOR, Madrid.

Van Oers, L., De Koning, A., Guinée, J. B., & Huppes, G. (2002). Abiotic resource depletion in LCA. *Road and Hydraulic Engineering Institute, Ministry of Transport and Water, Amsterdam.*

Xiong, W., Zeng, G., Yang, Z., Zhou, Y., Zhang, C., Cheng, M., Liu, Y., Hu, L., Wan, J., Zhou, C., Xu, R., Li, X. (2018a). Adsorption of tetracycline antibiotics from aqueous solutions on nano composite multi-walled carbon nanotube functionalized MIL-53(Fe) as new adsorbent. *Sci. Total Environ. 627*, 235–244.

Zang, Y., Li, Y., Wang, C., Zhang, W., & Xiong, W. (2015). Towards more accurate life cycle assessment of biological wastewater treatment plants: a review. *Journal of Cleaner Production, 107*, 676-692.