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ENVIRONMENTAL IMPROVEMENT OF ALEXANDRIA'S WASTEWATER TREATMENT PLANTS USING LIFE CYCLE ASSESSMENT APPROACH

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ABSTRACT

Improving the treatment efficiency of a primary wastewater treatment plant (WWTP), in Alexandria, Egypt, was studied. In order to improve the treatment efficiency of the plant, different improving scenarios were proposed and evaluated. The improvement scenarios are: scenario 1, use of engineered wetland instead of the current treatment system, scenario 2, use of the engineered wetland as a secondary treatment after the existing treatment system and scenario 3, replace the existing treatment system with a secondary WWTP. The scope of this study is to environmentally assess the existing primary WWTP, in addition to assess the possibility of using the engineered wetland for improving the primary WWTP. To evaluate the performance of each treatment system, Life Cycle Assessment (LCA) approach was applied.

Based on the results, the main improvement achieved in all the scenarios is in the category of eutrophication and acidification, as the three scenarios have higher removal efficiency for the nutrients than the current system. Unlike the total reduction in the environmental impact, scenario 3 gave the highest reduction in the category of eutrophication and acidification (25%) followed by scenario 2 (24%) and the lowest reduction achieved by scenario 1 (13%). The analysis revealed that the use of combined system from natural and traditional systems (scenario 2) is the best scenario. However, scenario 3 achieved a very close result.

KEYWORDS: life cycle assessment, wastewater treatment, wetland.

INTRODUCTION

The natural systems for treating wastewater have been proved to be better in terms of its environmental impact as well as the economical feasibility in the long run. However, the performance of such systems is still questionable. So, integrating traditional and natural systems could be desirable to improve the performance of natural systems and to reduce the environmental impact of traditional systems.

As one of the important natural wastewater treatment systems, wetlands have been used in Egypt but in small scale. One of the earliest trials to use Wetland in Egypt was to treat the industrial and domestic wastewater by the application of the parallel Gravel Bed Hydroponic (GBH) reed beds in Ismalia, Egypt (May *et al.,* 1990). Also, the GBH beds were tested at Tenth of Ramadan City by receiving a complex mixture of wastewater from a wide range of industries. The GBH beds were able to remove long chain hydrocarbons and fatty acids, but more recalcitrant compounds, including aromatics such as phthalates, remained. This suggests that GBH beds have applications for industrial wastes but may require a longer residence times or further treatment stages. In the early 1990's, a project for constructing an engineered wetland, at the outlet of Bahr El-Baqar drain, was approved as a collaborative effort between GEF, UNDP and Ministry of State for Environmental Affairs – Egyptian Environmental Affairs Agency (MSEA-EEAA).

To reach the best performance in assisting the environmental systems, a comprehensive analysis has to be carried out. In this context Life Cycle Assessment (LCA) appears to be a very suitable tool to assess the system in a holistic way and to compare the different improvement scenarios. The LCA methodology enables the calculation of environmental burdens in a systematic and scientific way by regarding all the inputs and outputs of a system. Hence, it allows for comparison on environmental grounds (Klöpffer, 1997).

LCA has been widely used for the assessment and the comparison between the different techniques in wastewater treatment field. Tillman *et al.* (1998) and Lassaux *et al.* (2001) used the LCA to assess the change in environmental impacts that may result from the change from centralized wastewater treatment systems to decentralized ones. Almudena *et al.* (2004) evaluated the potential environmental impacts associated with a municipal wastewater treatment plant. Romero (2005) assessed the technology of granular activated carbon (GAC) which is widely used in the industrial wastewater treatment for controlling the emissions of volatile organic compounds. Hazem *et al.* (2001) applied LCA to assess the environmental impacts of six selected investment approaches (developments) which all tackle the problem of sanitary waste being discharged to the environment. One of the hot topics related to the wastewater treatment is the sewage sludge management, in this context the LCA is used for assessing the different options of sludge management. F. J. Dennison *et al.* (1998) studied the management of the sludge resulting from 15 wastewater treatment plants operated by Thames water utilities Ltd. in the UK. Almudena *et al.* (2005) carried out an assessment by using LCA to examine different alternatives of sewage sludge post-treatment: agricultural use of digested sludge, incineration and pyrolysis.

Due to the unique characteristics of LCA, this tool was used in this research to assess the possible improvement of the primary wastewater treatment plants in Alexandria City in Egypt by using different treatment methods. Alexandria is located in the north of Egypt on the Mediterranean Sea. It is the second most important city in Egypt after Cairo, with a population of about 3.7 millions (AGPP, 2006). It is the main harbour and the most popular summer resort for Egyptians. It is the second most important industrial centre in Egypt; Alexandria hosts nearly 37% of Egypt's industries (large oil refineries; chemical, cement, and metal plants; textile mills; and food processing operations), and nearly 40% of the working sector is employed by the industrial sector (UNDP, 2003). Therefore the wastewater treatment system of Alexandria is under great pressure that affects its performance.

The main goal of this research is to improve the current performance of the primary wastewater treatment plants in Alexandria, hence following are the specific objectives of this research:

1. Analysing the current situation using LCA
2. Suggesting improvement scenarios using natural systems or combination of traditional and natural systems
3. Assessing the improvement scenarios and comparing it with the secondary wastewater treatment plants that already exists in Alexandria
4. Recommending for the decision makers the best scenario

The scope of this research will be limited to assess only one of the primary WWTPs (East WWTP) and one of the Secondary WWTPs (Hanoville WWTP), in addition to assessing the possibility of using engineered wetland for improving the primary WWTP. It is important to mention that the main focus of this research is only the environmental burdens due to its importance; the other aspects like economical and social aspects are not studied. The main functional unit used is the treatment of one cubic meter of wastewater. The operational phase only is considered as it has the most significant environmental impact of the life cycle of WWTPs (Friedrich and Buckley, 2001).

DESCRIPTION OF THE SYSTEMS UNDER STUDY

Alexandria has currently six wastewater treatment plants (WWTP), two of them are primary treatment and four are secondary treatment (Table 1). Hereafter is a brief description of the plants that are in the focus by this research. In addition, a description also for the wetland that will be used for the comparison purposes and for the improvement scenarios is presented.

Table 1. Capacity of the six WWTPs

Plant	Type	Actual capacity (m^3 d^{-1})	Design capacity (m^3 d^{-1})
West WWTP	Primary treatment	450000	607000
East WWTP	Primary treatment	350000	462000
Eskan Mubark WWTP	Secondary treatment	15000	15000
Hanoville WWTP	Secondary treatment	20000	20000
Agamy WWTP	Secondary treatment	210000	210000
Amereya WWTP (under construction)	Secondary treatment	No available data	No available data

East WWTP

In the schematic of the treatment plant (Figure 1), the wastewater is pumped from pump stations out the plant. The wastewater then passes through bar screens to remove the big particles and floating big particles, and then goes to the grit removal chamber to remove the grit before going to the flow split chamber which distributes the flow to the primary sedimentation tanks. The primary sedimentation tanks are the main treatment unit which treats the water with a removal of about 30% in average and up to 50%. The water resulted from the sedimentation tanks then passes through effluent screening facility before discharge into Lake Maryout.

The sludge resulted from the East treatment plant is diluted and then pumped to the west treatment plant to be dewatered. The sludge dewatering unit is located beside the west WWTP. The process of dewatering the sludge begins with mixing the sludge in equalization tanks to homogenize the sludge, then the polymers are added to the sludge for facilitating the settling of the sludge (separation of the sludge from the water), and by the mean of a belt press the sludge is compressed to raise the density from about 3% at the treatment plant to about 28% after the dewatering. The treated sludge is transported to the disposal site where it is been composted and then sold to the farmers to be used as fertilizer.

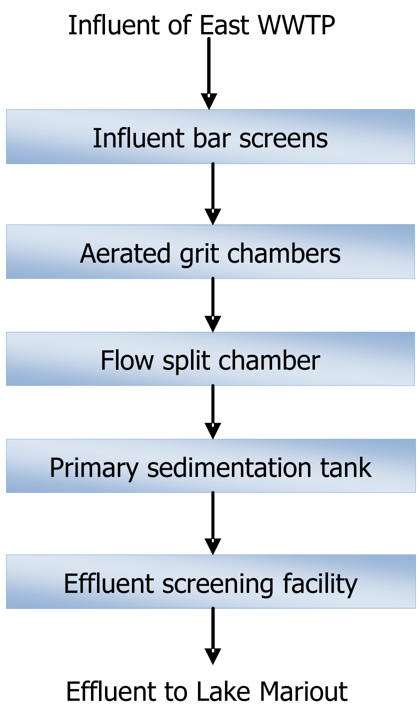

Figure 1. Schematic of the treatment process in the East WWTP

Hanoville WWTP

Hanoville plant (Figure 2) was built to test the best treatment technology that can be appropriate to be used in Alexandria. The plant uses two techniques in the treatment which are sequence batch reactor with extended aeration (10000 m^3 d^{-1}), and intermediate cycle extended aeration system (10000 m^3 d^{-1}).

The treatment process starts by passing the water through bar screens and then through the grit removal chamber, then the water goes to the main treatment step which is one of the mentioned technologies. In the microfiltration system the water flows through filters with pore size of about 6 micron where the BOD is removed with the aid of a very high MLVSS of about 11000 mg L^{-1}. In the case of sequencial batch reactor, the tank is filled with wastewater, and then aeration takes place in the same tank which helps accelerating the sedimentation of the organic matter then the treated water is taken from the top of the tank through a moving outflow weir to allow adequate discharge of significant amount of settled water, then the tank will be filled again with water to repeat the process for another batch. The intermediate cycle extended aeration system is the same as the previous one but the flow is continuous

The treated wastewater is discharged to Amria drain which ends up with the Mediterranean Sea, while the sludge is stored in storage tanks for about three months to be stabilized and then it is dried by the aid of polymers before it is transported to the disposal site.

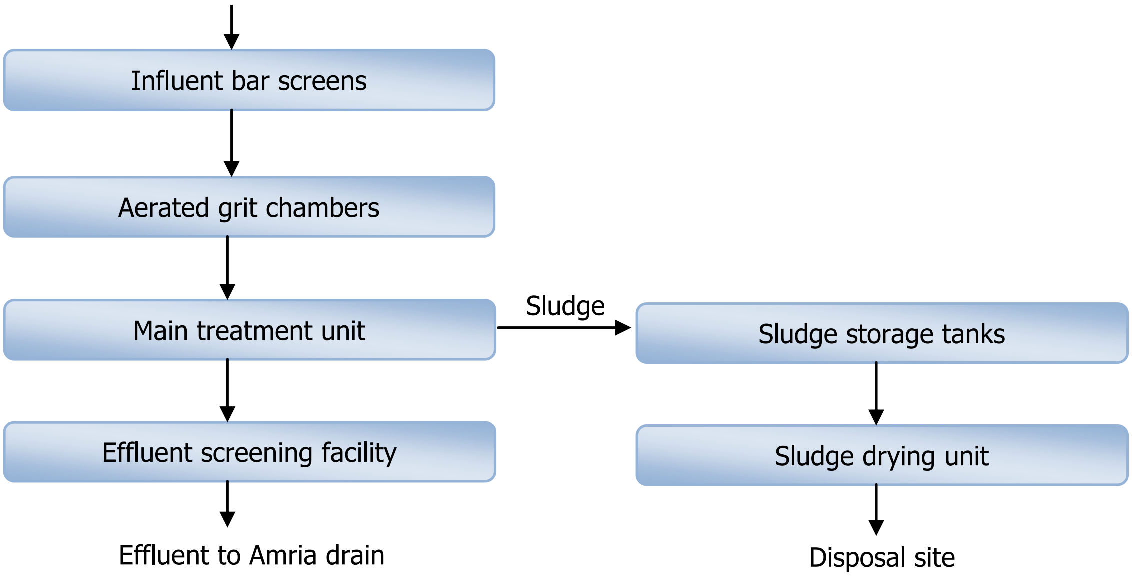

Figure 2. Schematic of Hanoville WWTP

Lake Manzala Engineered Wetland

Lake Manzala Engineered Wetland (LMEW) was established as a low cost biological treatment plant at the outlet of Bahr El-Baqar drain in the north eastern fringes of Nile Delta, Egypt. The project aimed to investigate the suitability of using engineered wetlands as a low-cost alternative for treating sanitary sewage from cities, towns and villages, wherever ample land area is available. It is a diversity of treatment options to allow primary, secondary, and tertiary treatments. The main objective is treating 25,000 m^3 per day of the polluted drainage water as a demonstration for low cost technique for wastewater treatment to protect the ecology of Lake Manzala and Mediterranean Sea.

The first step in the wastewater treatment is to hold the wastewater in the sedimentation ponds. LMEW uses two sedimentation ponds, into which screw pumps lift water from Bahr El-Baqar drain. The average water depth in the ponds is 1.5m. The retention time for water is two days in the sedimentation ponds. The water flows by gravity from the sedimentation ponds, through a distribution channel, to the surface treatment cells.

Effluent from the sedimentation basins flows to ten surface flow cells each with approximate dimensions of 250x50 m and 55 cm average water depth. Cells are planted with reed (Phragmites communis) which is common to Lake Manzala Area.

Based on the system monitoring results, the technology is considered highly feasible in the context of Egypt. The country has very high quantities of similar types of secondary quality water resources, feasible to polish with this technology to allow further water demanding industrial and primary production applications (NIRAS, 2007).

Lake Manzala Engineered Wetland achieves high removal efficiencies in term of Fecal and Total Coliform. In addition it achieves satisfactory removal efficiencies for chemical parameters (Figure 4).

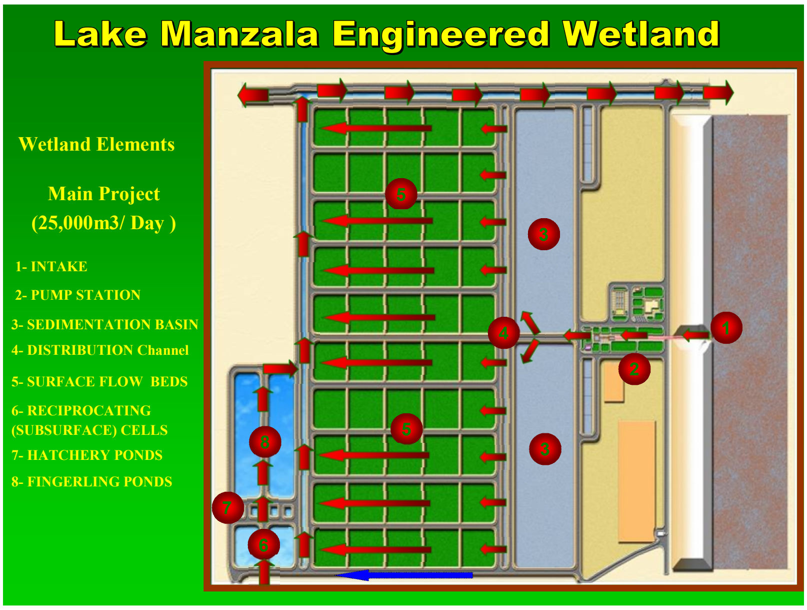

Figure 3. Components of the treatment system in LMEW

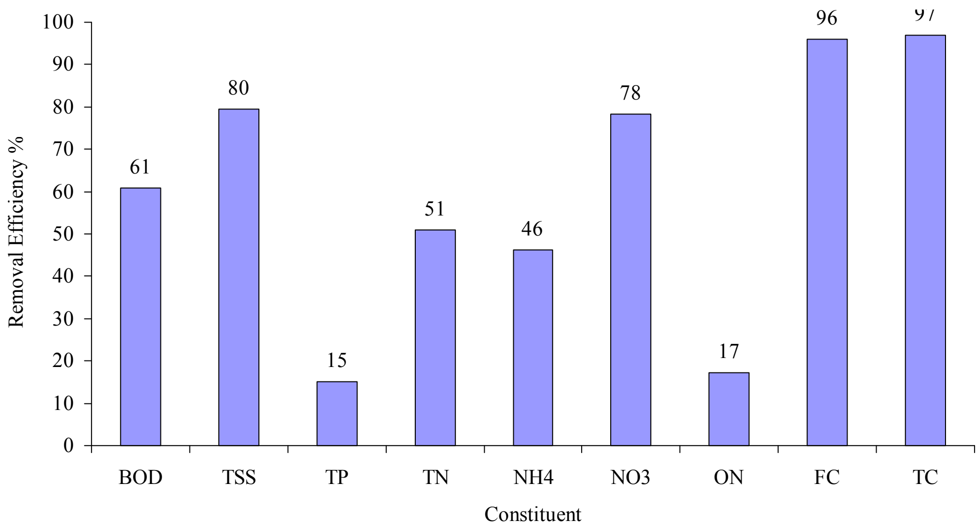

Figure 4. The treatment Efficiency of Lake Manzala Engineered Wetland

METHODOLOGY

Life Cycle Assessment (LCA) was carried out using SimaPro software using Eco-Indicator99, according to ISO-14040-1997, to assess the environmental burdens resulting in the current situation and for the improvement scenarios proposed by the research.

1) Assessment of East WWTP (current situation)

A. Inventory analysis

The data used for conducting LCA of East WWTP based on the data published by Mahgoub (2007). In addition, as in the current situation the sludge resulted from the east WWTP is being treated out the plant in a sludge treatment unit in the West WWTP, this unit has been also considered as part of the system to include the environmental impact of the sludge. Literature data from Almudena *et al.* (2005) was used to model the sludge composting (Table 2).

Table 2. Normalized data for sludge composting (Almudena *et al.,* 2005)

Item	Value	Item	Value
Energy consumption (kWh t^{-1})		**Emissions to soil (kg t^{-1}):**	
Electricity	58.5	Cr	0.08
Diesel	0.73	Cu	0.19
Air borne Emissions (kg t^{-1}):		Pb	0.33
CH_4	3.18	Zn	1.51
Avoided Products (kg t^{-1})		**Avoided Products (kg t^{-1})**	
N-Fertilizer	17.87	P-Fertilizer	14.32

B. Impact assessment
Eco-Indicator 99 is a damage oriented method (the damage that is caused by a product or a system on the environment). Unfortunately, the method gives no damage factors for disposal of nutrients (eutrophication) and COD. Therefore, the characterisation factor from Eco-invent report No.3 (2004) for total nitrogen was used and the characterisation factors for phosphorous and COD were based on Eco-indicator 95 (Table 3).

Table 3. Characterisation factors of N, P, and COD

Substance	Eco-indicator 95 characterisation	Calculated Characterisation factor
COD	0.022 kg PO_4	0.98
N	0.42 kg PO_4	18.8
P	3.06 kg PO_4	136.97

C. Interpretation of the results
The results of the system assessment were analyzed and interpreted to enable the identification of the most critical processes of the plant.

2) Assessment of the improvement scenarios
The same LCA methodology was used to assess the proposed improvement scenarios which are:

1. **Scenario (1) Natural System**: Using engineered wetland instead of the existing system.
2. **Scenario (2) Combined System**: The use of the engineered wetland as a secondary treatment system after the existing system, in a way that the effluent of the East WWTP will be considered as the influent of the wetland.
3. **Scenario (3) Traditional (Mechanical) System**: Replacing the existing system with a secondary WWTP using the same treatment approach used in Hanoville WWTP.

The data for Hanoville WWTP taken from Mahgoub (2007) and the data for the wetland were attained from the Drainage Research Institute (DRI) in Egypt. To compare the three scenarios, it was important to have the similar conditions in terms of the characteristics of the wastewater treated by each, so the characteristics of the wastewater was unified to be the same as the ones at the inlet of the East WWTP, and the output characteristics was calculated according to the real performance of each system according to the collected data from the previous mentioned sources (effluent characteristic = influent characteristic of East WWTP * removal efficiency for each plant).

RESULTS AND DISCUSSION
To assess the impact of the system, the LCA includes all the inputs and the outputs related to each process where the inputs or the outputs can have direct environmental impact (such as resources depletion) or indirect environmental impact (such as the impacts during the manufacturing of a certain type of chemical). The inputs of each process are volume of water or wastewater, energy consumption of each process, chemicals use in each process, and transportation distances for each type of chemical. The outputs are water-borne emissions, air-borne emissions, and solid waste

(Table 4). Most of the data was collected from the available sources; however some of the data was calculated based on formulas from literature. The air emissions from the WWTPs were calculated according to the formula: $C_6H_{12}O_6 + 6\ O_2 \longrightarrow 6CO_2 + 6H_2O$, where it has been assumed that all the COD is in the form of Glucose.

Table 4. Normalized data for East WWTP under current situation

Item	**Value**	**Item**	**Value**
Influent Water borne pollutants	(kg m^{-3})	**Effluent Water borne pollutants**	(kg m^{-3})
T.S.S	0.228042	T.S.S	0.111816
BOD	0.175798	BOD	0.129069
COD	0.482934	COD	0.328281
N, total	0.038400	N, total	0.035300
P, total	0.026200	P, total	0.023000
Energy consumption (kWh m^{-3}):		**Air borne Emissions (kg m^{-3}):**	
Process energy	0.010899	Carbon dioxide(CO_2)	0.149688
Pumping energy	0	**Solid Emissions (kg m^{-3})**	
Total energy	0.010899	Screenings	0.000123
Transportation (t km m^{-3})		Grits	0.000809
Transportation of sludge	0.003487	Sludge	0.116226
		Total (Screenings+Grits+Sludge)	0.117157

1. Environmental impact of the East WWTP

The total environmental impact of the East WWTP was 0.329 eco-points (Pt). Most of the impact (98%) was in the category of eutrophication and acidification (Figure 5) due to the fact that the effluent is very rich of nutrients which discharged on open water (Mariout Lake). Very small impact was shown in the categories of fossil fuels, climate change and respiratory inorganics as a result of the use of fossil fuel-dependent-energy source. Obviously, any further improvement of such system has to be based on increasing the removal efficiency of nutrients.

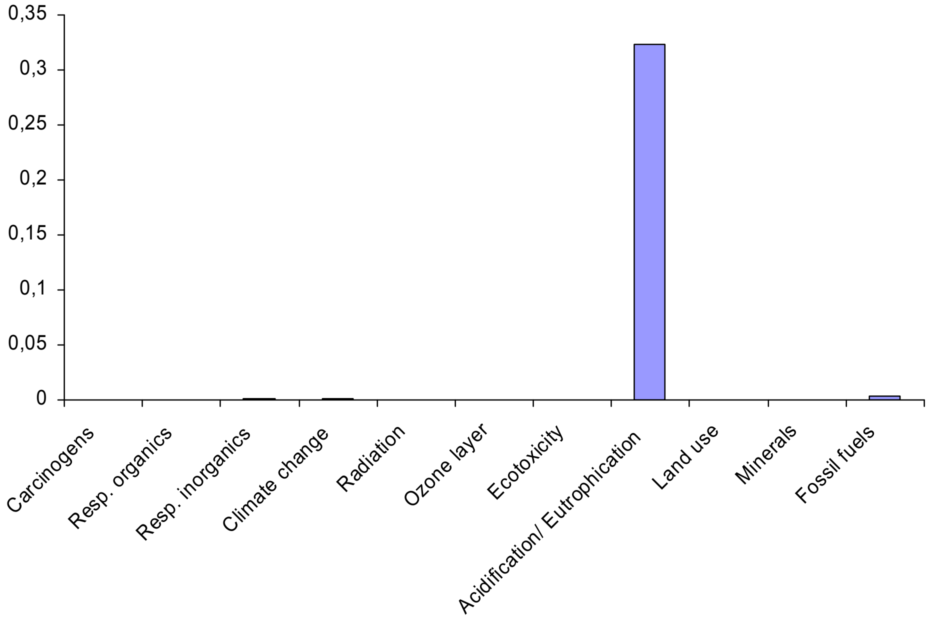

Figure 5. Environmental impacts of the East WWTP

2. Environmental impact of the improvement scenarios

The total environmental impact of the improvement scenarios was 0.287, 0.251, and 0.259 Eco-points for Scenario 1, Scenario 2 and Scenario 3 respectively (Figure 6). The highest contribution to the total impact in the three scenarios was the impact resulting from eutrophication and acidification, with a share of about 97.6%, 97.2% and 93.1% in Scenario 1, Scenario 2, and Scenario 3 respectively. This result emphasises the important role of nutrients removal in wastewater treatment plant, where the same result were shown also along the current situation.

Although Scenario 3 had lower impact with respect to eutrophication and acidification when compared with the other scenarios, but it showed higher impact in categories of fossil fuels and ecotoxicity, the reason is the higher use of energy in this scenario, where the current source of energy is fossil fuel-dependent, that cause very harmful emissions during the production of this type of energy (this considered as indirect impact for the WWTP which calculated by LCA).

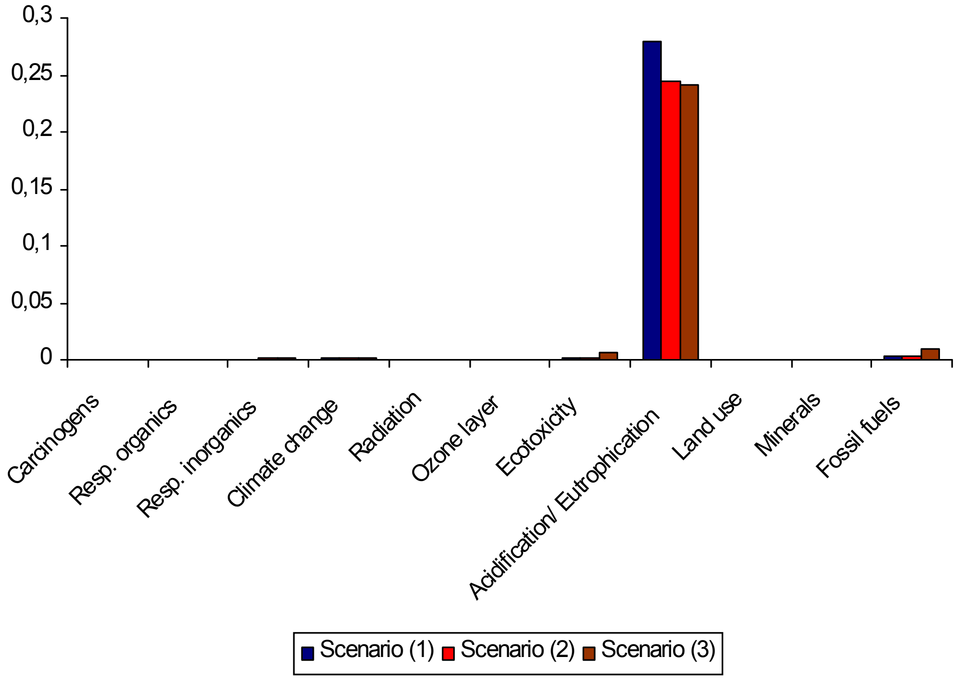

Figure 6. Environmental impacts of the improvement scenarios

3. Influence of the improvement scenarios on the environmental impact of the system

The analysis of the three improvement scenarios revealed that the use of combined system from natural and traditional systems (scenario 2) is the best scenario, where it achieved a reduction in the total environmental impact by about 23.71% (Table 5). However, scenario 3 achieved a very close result with a reduction of about 21.28%. The lowest improvement was from scenario 1 (12.77%).

Table 5. Reduction in environmental impact achieved by the various scenarios (a negative percentage is a reduction)

Impact category	Unit	Scenario (1)	Scenario (2)	Scenario (3)
Carcinogens	Pt	-17.04	0.49	183.95
Resp. organics	Pt	-17.30	1.47	130.21
Resp. inorganics	Pt	-18.17	0.91	138.86
Climate change	Pt	30.36	54.46	1.79
Radiation	Pt	0.00	0.00	0.00
Ozone layer	Pt	-17.36	0.81	130.07
Ecotoxicity	Pt	645.00	325.50	2720.00
Acidification/ Eutrophication	Pt	-13.31	-24.46	-25.39
Land use	Pt	0.00	0.00	3434.48
Minerals	Pt	0.00	0.00	3432.41
Fossil fuels	Pt	-18.04	0.26	152.06
Total	Pt	-12.77	-23.71	-21.28

The total reduction showed in Table 5 is not the direct summation of the change in each category, but it can be mathematically expressed as: Total = Σ (±change in impact category * contribution of impact category to the total impact as percentage).

The main improvement achieved in all the scenarios is in the category of eutrophication and acidification (Figure 7), as the three scenarios have higher removal efficiency for the nutrients than the current system. Unlike the total reduction in the environmental impact, scenario 3 gave the highest reduction in the category of eutrophication and acidification (25.39%) followed by scenario 2 (24.46%) and the lowest reduction achieved by scenario 1 (13.31%).

Unexpectedly scenario 3 showed higher impact regarding land use while it is known that natural systems use more land than traditional system. This is due to that the LCA accounts not only for the direct impacts but also the indirect ones during the life cycle under focus, therefore the land use here doesn't mean only the lands for the plant construction but also lands used indirectly by the plant (e.g. during the energy production).

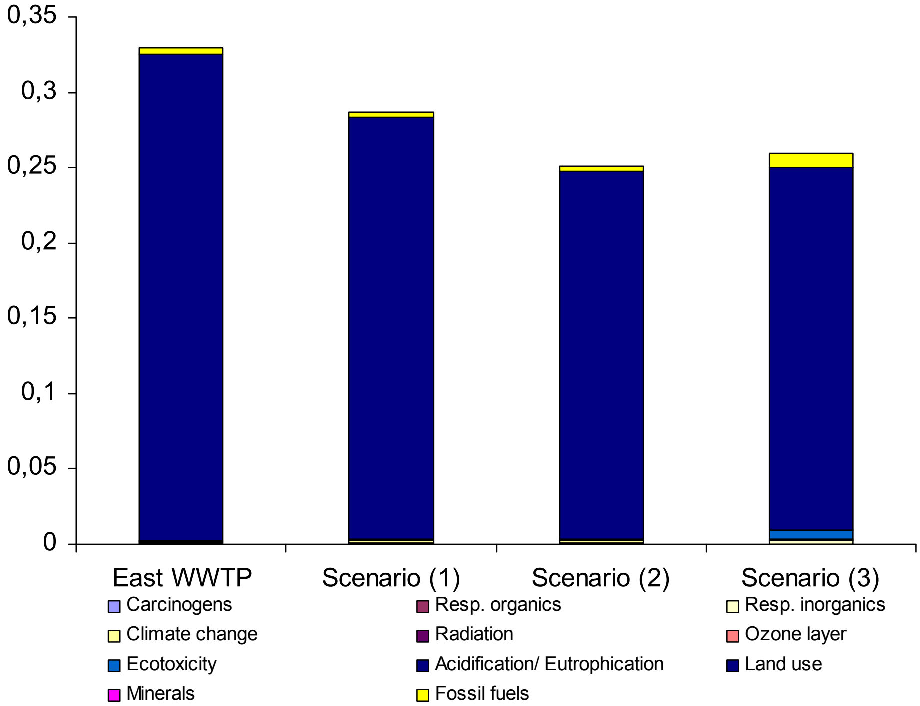

Figure 7. Total environmental impacts of the improvement scenarios and the current situation

4. Recommended improvement scenario

The improvement achieved, in all the scenarios, is not that much as expected (Figure 7), so replacing the current system with one of the improvement scenarios could be very controversial. However scenario 2 can be recommended as it is environmentally the best scenario and from the practicability point of view it is better than the other two scenarios where the other two scenarios depend on totally make new systems and get red of the current system.

Moreover, according to El-Quosy (2009), the estimated removal efficiency (original design) for total nitrogen and total phosphorus for the engineered wetland used in this research is 90% and 50% respectively, which is much higher than the removal efficiency measured in the field (51% and 15% for total nitrogen and total phosphorus respectively). Wetland is very sensitive eco-system also in case of El-Manzala engineered wetland the influent loads were very low and there is always a minimum expected outflow of contaminants which lead to such modest removal efficiency, should the loads go higher (as per original design) the system can achieve higher removal efficiency, which in turn will reduce the environmental impact. Therefore, the combined system (Scenario 2) is recommended to replace the current system.

CONCLUSIONS

This research used the LCA approach to assess the possibility of improving the current primary wastewater treatment plants in Alexandria city in Egypt. The results showed that the highest contribution to the total impact was the impact resulting from the low removal efficiency of the nutrients due to its negative impact on the open water bodies (causing eutrophication) where the treated wastewater is discharged to Lake Mariout. Therefore, the proposed improvement scenarios focused mainly on improving the removal efficiency of the nutrients.

The analysis of the three improvement scenarios revealed that the use of combined system from natural and traditional systems (scenario 2) is the best scenario, where it achieved a reduction in the total environmental impact by about 23.71%. However, scenario 3 achieved a very close result with a reduction of about 21.28%. The lowest improvement was from scenario 1 (12.77%). Moreover, better results in scenarios 2 and 3 could be achieved by better optimization of the wetland operation, as the studied engineered wetland didn't reach its maximum removal efficiency (El-Quosy, 2009).

The current research focused only on the environmental aspects, however it is recommended to study the economical aspects as well in terms of land, construction, running and maintenance costs to present a complete image about the system and the improvement scenarios to the decision makers.

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