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# Sustainability Assessment of Municipal Wastewater Treatment

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***Abstract*—**In this paper, our methodology to assess sustainability of wastewater treatment technologies in Egypt is presented. The preliminary list of factors to be considered, as well as their ranking listed. The factors include, but are not limited to pollutants removal efficiency and energy consumption under the environmental dimension, construction cost, operation and maintenance costs and required land area cost under the economic dimension and public acceptance, noise and generating job opportunities for local residents. This methodology is intended to be a user-friendly screening tool to support the decision making process when investigating different wastewater treatment technologies in Egypt. Based on the research work results presented in this paper, it can be generally concluded that the categorization of some of the social and environmental aspects of sustainability is subjective and highly dependent on the local conditions and researchers' background.

***Keywords*—**Sustainability, wastewater treatment, sustainability assessment, Egypt.

## I. Introduction

ASSESSING sustainability has gained increased attention in recent years. However, limited research is conducted to assess the sustainability of municipal wastewater treatment technologies taking into consideration its three core dimensions, namely environmental, social and economic.

Wastewater can be defined as water that is adversely affected by anthropogenic sources in terms of quality. There are different types of wastewater depending on the source, namely domestic, industrial and agricultural [1]. The main concerns arising from the inadequate management and disposal of wastewater is the unavoidable contamination of the environment. Unsafe disposal of wastewater contaminates water resources as well as soil, depending on the disposal method and/or affected area [2].

Consequently, there is an urgent need to appropriately treat the different types of wastewater. In general, the main objectives of wastewater treatment are to reduce the contaminants level in the discharged/treated water [3], [1]. Wastewater Treatment entails different steps, namely primary and secondary and in some cases tertiary [4].

### *A. Sustainability and Sustainable Development*

Sustainability is principally defined as the appropriate integration of environmental fineness, economic affluence and social even-handedness. Indeed, the notion of sustainability emphasizes the inseparable incorporation of economy, environment and social [2].

The term 'sustainability' refers to a broad concept, encompassing various interrelated parameters regarding the environment, people and energy resources. The significance of sustainability for built environments is well-known as a multidisciplinary approach to the deliberation of environmental, economic and socio-cultural concerns. It is to mitigate the negative environmental impacts and to harmonize the living environments with socio-economic patterns.

The concept of sustainable development (SD) was first introduced by the IUCN 1980 World Conservation Strategy which stated that "for development to be sustainable it must take account of social and ecological factors, as well as economic ones" [2]. It is worth mentioning that the term SD and sustainability are used commonly as synonyms [4].

The objectives of this paper are to present and analyze the available information on the different attempts made to assess the sustainability of wastewater treatment systems and to present an outline for a proposed assessment methodology by the authors.

## II. Sustainability Assessment of Wastewater Treatment

### *A. Factors Studied*

Historically, technical and financial aspects of wastewater treatment facilities have been considered the top priority of the decision making process when comparing between different alternatives or assessing the feasibility of applying certain treatment technology [5]. Nonetheless, in recent years the assessment of wastewater treatment sustainability has been subject to various researches. Some researches focused on the three aspects (dimensions) of sustainability; while other focused on two (*e.g.* economic and environmental) aspects or one (*e.g.* social). The general approach to assess sustainability investigated in this paper is to examine a number of factors under each sustainability aspect to eventually assess the overall sustainability of the wastewater treatment technology. In general and according to [6], sustainability assessment can guide the decision-making process and support the selection of the most appropriate alternative. These factors are varied. Various factors were categorized by some researchers under the environmental aspect; whereas, other researchers classified the same factors under the social aspect. However, less vagueness is documented for the economic aspect.

In general, the environmental aspect was typically

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represented by a number of directly related environmental factors such as energy use/efficiency/carbon footprint and process removal efficiency in several research works, such as [7]-[9].

As for the social aspect, clear social factors including generating job opportunities were studied in the research of [7] in 2008. On the other hand, a number of "grey" factors that were classified under the environmental aspect by some researchers can be also considered as factors affecting the social dimension of sustainability and vice versa. A clear example on a grey factor is the odor. Odor was classified by [9] under the social sustainability aspect; whereas, the same factor can be under the environmental dimension of sustainability. Similarly, public acceptance was classified under the social aspect in the research of [3]. Another example on a grey factor would be the factor suggested by [7], which is "enhancing the surrounding environmental conditions" that would be initially interpreted as an environmental factor; nonetheless, it is classified under the social aspects of sustainability. Similar remarks are made by [10], where in this research the social sustainability of wastewater treatment facilities was assessed and one of the factors studied was the percentage of reused water. This factor can be classified as an environmental factor; nonetheless, it was classified under the social aspect of sustainability.

As stated earlier, much less ambiguousness was observed for the economic aspect. Almost all the reviewed researches including [7], [9], [8], [11], identified capital and running costs as economic factors to assess the economic sustainability of the different technologies. This can be attributed to the fact that economic aspects are generally less subjective and arguable unlike the social aspects.

### *B. Case Studies*

In the research of [7], the three basic classic dimensions of sustainability, namely environmental, economic and social were considered to develop sustainability indicators to assess the sustainability of different alternative wastewater treatment technologies. The assessed technologies were conventional activated sludge treatment, lagoons and land treatment. No solid conclusion was made by this research. According to [7], the goal of the research was "to initiate a discussion on how to address a more integrated evaluation of the overall sustainability of wastewater treatment technologies".

Reference [9] utilized Multi-criteria analyses (MCAs) to identify the most sustainable wastewater secondary treatment technology for small communities. Constructed wetland, extended aeration, membrane bioreactor, pond system, rotating biological contactor, sequencing batch reactor and trickling filter technologies were assessed. The traditional sustainability dimensions were considered, namely economic, environmental and social. The results of the research showed that constructed wetlands and pond systems were the most sustainable wastewater secondary treatment technology for small communities.

The sustainability of different domestic wastewater treatment technologies for high rise buildings in urban communities in India was studied by [12]. Three commonly used treatment technologies were assessed in this research, namely activated sludge process, sequencing batch reactors and membrane bio-reactor. The traditional dimensions of sustainability (*i.e.* environmental, economic and social) were not clearly defined in this research; instead, the research referred to seven dimensions/criteria that mixed between the different traditional dimensions. The seven dimensions were global warming, eutrophication, life cycle costs, land requirements, operational manpower requirements, robustness of the system and sustainability. Each of these criteria had a set of indicators. The results of this research showed that membrane bio-reactor is the preferred technology.

Reference [13] presented a comprehensive sustainability composite indicator that incorporates the three dimensions of sustainability (*i.e.* economic, environmental and social) to assess the sustainability of different wastewater treatment techniques for small communities in Spain. The technologies assessed were constructed wetlands, pond systems, extended aeration, membrane bioreactor, rotating biological contactor, trickling filter and sequencing batch reactor. The results showed that among the different technologies, extended aeration was the most sustainable technology. It should be noted that some other research work considered one or two dimensions only of sustainability. For example, [10] accounted for social dimension only when assessing the sustainability of wastewater treatment technologies.

The literature review that was conducted as part of this paper revealed that limited research is documented on assessing the sustainability of wastewater treatment technologies in Egypt despite the importance of this issue.

## III. Problem Statement and Objective

In Egypt, approximately 50% of the urban population and 6% of rural population are connected to a sewerage system according to a Ministry of Irrigation report released in 2014 [14]. Consequently, the need to assess the sustainability of wastewater treatment alternatives to support the decision-making process is of vital importance.

Work done by other researchers in other countries revealed that a major challenge to develop a robust sustainability assessment approach would be the categorization of some of the social and environmental aspects, as they are subjective and highly dependent on the researchers' background/opinion.

The proposed approach will examine the three main dimensions of sustainability, namely social, environmental and economic for wastewater treatment technologies in Egypt. The main objective of the methodology is to provide decision makers with a screening tool to assess the sustainability of different alternatives of wastewater treatment in Egypt and consequently enhance the selection criteria and process.

## IV. Proposed Methodology

In the proposed sustainability assessment, the following aspects are to be studied:

- Environmental

- Economic
- Social

The proposed weights for each of the above aspects are as follows:

- Environmental: 30%
- Economic: 40%
- Social: 30%

The above mentioned weights are only tentative and based on the authors opinion and knowledge. Furthermore, the methodology is based on the assumption that the different factors under a certain aspect have equal weight. These weights shall be revised at a later stage of the research. The revision will be made based on a survey among environmental specialists with background in wastewater treatment technologies utilized in developing countries and preferably Egypt.

Factors to be studied are grouped under the main sustainability aspects, namely environmental, social and economic. Semi-quantitative approach shall be followed. In this approach a scale of 1 to 3 will be used, where 2 stands for the neutrally sustainable (NS) case, 1 stands for unsustainable (U) and 3 stands for sustainable (S) as shown in Fig. 1 below:

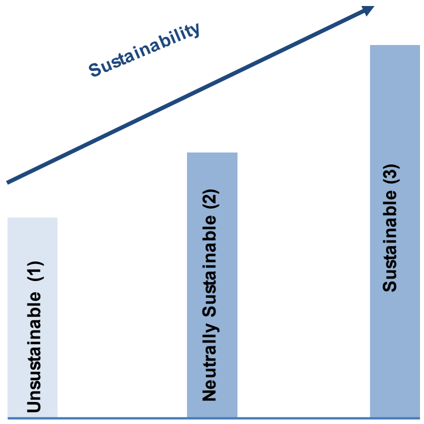


Fig. 1 Proposed sustainability ranking

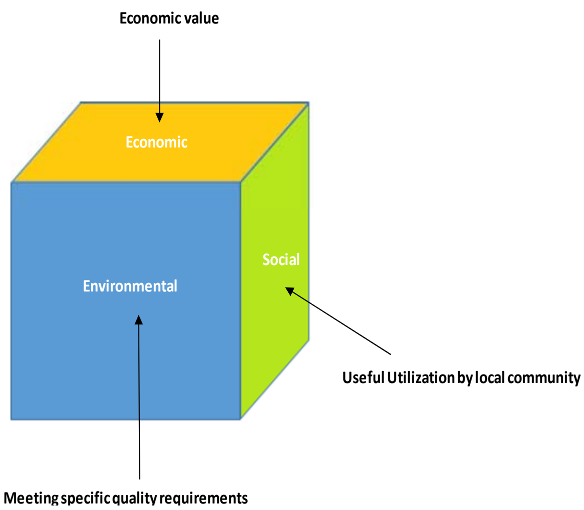


Fig. 2 Sludge assessment under different sustainability aspects

In the methodology, an attempt is made to overcome the grey-factors problem that was highlighted earlier. Thus, some of the factors are categorized under more than one dimension (*e.g.* noise and sludge). However, the factors are not regarded as repeated or double-counted, as they are assessed from different perspectives under each category.

A clear example is sludge (Fig. 2). When assessed under economic aspect, the possible economic value of it is investigated. When assessed under the environmental aspect, it is investigated in terms of its quality; whereas, the social aspect assessment is done by evaluating whether it has a useful utilization by the local community or not.

### A. Environmental

The following factors are suggested to be investigated as part of the environmental aspect. Semi-Qualitative approach will be followed.

1. Pollutants removal efficiency (this factor includes: organic matter, suspended solids, nitrogen, phosphorus and pathogens)
2. Energy consumption
3. Energy production
4. Sludge quality
5. Odor
6. Wastes quantities (estimated on annual basis)

Tables I-VI show the proposed ranking for each of the above mentioned factors.

It should be noted that in case of one or more pollutant is not meeting the legal limit, the overall ranking of the alternative shall be classified under "Unsustainable" as the treated effluent quality is generally regulated by the local law.

In case of all the pollutants are meeting the applicable limit with some are below the limit, an average weight of their corresponding value shall be calculated to represent the overall ranking of the pollutant removal efficiency factor.

TABLE I
ASSESSMENT RANKING FOR POLLUTANTS REMOVAL EFFICIENCY

| Achieved removal % above the applicable limit | Ranking | Corresponding value |
|---|---|---|
| Not meeting applicable local limits | U | 1 |
| Meeting the applicable local limits | NS | 2 |
| Below the applicable local limits | S | 3 |

TABLE II
ASSESSMENT RANKING FOR ENERGY CONSUMPTION

| Energy Consumption Status | Ranking | Corresponding value |
|---|---|---|
| Extensive energy consumption | U | 1 |
| Moderate energy consumption | N | 2 |
| No energy consumption or energy production | S | 3 |

TABLE III
ASSESSMENT RANKING FOR ENERGY PRODUCTION

| Energy Production Status | Ranking | Corresponding value |
|---|---|---|
| Energy production/consumption < 1 | U | 1 |
| Energy production/consumption = 1 | NS | 2 |
| Energy production/consumption > 1 | S | 3 |

TABLE IV
ASSESSMENT RANKING FOR SLUDGE QUALITY

| Sludge Quality Status | Ranking | Corresponding value |
|---|---|---|
| Low quality sludge containing pollutants (heavy metals, parasites) | U | 1 |
| Sludge suitable for composting and/or landscape | S | 3 |

TABLE V
ASSESSMENT RANKING FOR ODOR

| Status | Ranking | Corresponding value |
|---|---|---|
| No odor outside the facility boundaries | S | 3 |
| Odor outside the facility boundaries | U | 1 |

TABLE VI
ASSESSMENT RANKING FOR WASTE QUANTITY

| Waste Quantity Status | Ranking | Corresponding value |
|---|---|---|
| Large amounts of liquid and/or solid wastes are generated from the process | U | 1 |
| Moderate amounts of liquid and/or solid wastes are generated from the process | NS | 2 |
| Small amounts or no liquid and/or solid wastes are generated from the process | S | 3 |

### *B. Economic*

The following factors are suggested to be investigated as part of the economic aspect:

1. Construction cost
2. Operation and maintenance costs
3. Required land area cost
4. Possibility of producing valuable products (*e.g.* sludge suitable for composting and reuse in irrigation *etc.*).

Tables VII-X show the proposed ranking for each of the previously mentioned factors.

TABLE VII
ASSESSMENT RANKING FOR CONSTRUCTION COST

| Construction Cost Status | Ranking | Corresponding value |
|---|---|---|
| High construction cost | U | 1 |
| Moderate construction cost | NS | 2 |
| Low construction cost | S | 3 |

TABLE VIII
ASSESSMENT RANKING FOR OPERATION AND MAINTENANCE COST

| Operation and Maintenance Cost Status | Ranking | Corresponding value |
|---|---|---|
| High cost | U | 1 |
| Moderate cost | NS | 2 |
| Low cost | S | 3 |

TABLE IX
ASSESSMENT RANKING FOR REQUIRED LAND COST

| Required Land Cost Status | Ranking | Corresponding value |
|---|---|---|
| High cost | U | 1 |
| Moderate cost | NS | 2 |
| Low cost | S | 3 |

TABLE X
ASSESSMENT RANKING FOR POSSIBILITY OF PRODUCING VALUABLE PRODUCTS

| Possibility of Producing Valuable Products Status | Ranking | Corresponding value |
|---|---|---|
| No | U | 1 |
| Yes | S | 3 |

### *C. Social*

The following factors are suggested to be investigated as part of the social aspect. The qualitative approach will be followed.

1. Visual impact (*e.g.* landscape of the treatment plant)
2. Public acceptance
3. Complexity
4. Noise
5. Job opportunities for local residents
6. Need for international/non-local experts
7. Land value decrease
8. Valuable products that can be inputs to other activities/industries (*e.g.* sludge for composting purposes and energy)
9. Safety

Tables XI-XIX show the proposed ranking for each of the above mentioned factors.

TABLE XI
ASSESSMENT RANKING FOR VISUAL IMPACTS

| Visual Impact Status | Ranking | Corresponding value |
|---|---|---|
| No visual impact | S | 3 |
| Moderate visual impact | NS | 2 |
| High visual impact | U | 1 |

TABLE XII
ASSESSMENT RANKING FOR PUBLIC ACCEPTANCE

| Public Acceptance Status | Ranking | Corresponding value |
|---|---|---|
| Very strong public acceptance /support | S | 3 |
| Community is indifferent towards the technology | NS | 2 |
| Community is rejecting the technology | U | 1 |

TABLE XIII
ASSESSMENT RANKING FOR COMPLEXITY

| Complexity Status | Ranking | Corresponding value |
|---|---|---|
| Simple technology | S | 3 |
| Moderately complex technology and well established | NS | 2 |
| Not-well established technology (new/experimental) | U | 1 |

TABLE XIV
ASSESSMENT RANKING FOR NOISE

| Noise Status | Ranking | Corresponding value |
|---|---|---|
| No noise emissions | S | 3 |
| Noise is limited to treatment plant boundaries | NS | 2 |
| Noise levels are high and extend beyond the plant boundaries | U | 1 |

TABLE XV
ASSESSMENT RANKING FOR JOB OPPORTUNITIES FOR LOCAL RESIDENTS

| Job Opportunities for Local Residents Status | Ranking | Corresponding value |
|---|---|---|
| No | U | 1 |
| Yes | S | 3 |

TABLE XVI
ASSESSMENT RANKING FOR NEED FOR INTERNATIONAL/NON-LOCAL EXPERTS

| Need for International/non-local Experts Status | Ranking | Corresponding value |
|---|---|---|
| Yes | U | 1 |
| No | S | 3 |

TABLE XVII
ASSESSMENT RANKING FOR NEED FOR LAND VALUE DECREASE

| Land Value Decrease Status | Ranking | Corresponding value |
|---|---|---|
| No land value decrease | S | 3 |
| Minor decrease in land value | NS | 2 |
| Very high decrease in land value | U | 1 |

TABLE XVIII
ASSESSMENT RANKING FOR NEED FOR USEFUL PRODUCTS PRODUCTION POSSIBILITY

| Useful Products Production Possibility Status | Ranking | Corresponding value |
|---|---|---|
| No | U | 1 |
| Yes | S | 3 |

TABLE XIX
ASSESSMENT RANKING FOR SAFETY

| Safety Status | Ranking | Corresponding value |
|---|---|---|
| The technology is associated with major accidents that resulted into fatalities and/or sever injuries to on-site workers and/or local community members. | U | 1 |
| The technology is associated with minor accidents that resulted into mild injuries (*i.e.* that does not require affected person's absence from work) and limited to on-site workers. | NS | 2 |
| The technology is not associated with accidents. | S | 3 |

## V. CONCLUSION AND FUTURE WORK

Efforts have been exerted to measure sustainability of wastewater treatment technologies world-wide. Each of the developed sustainability measurement frameworks was clearly dependent on the local conditions, and the available information and perspective of each country/researcher. The sustainability includes three main aspects; namely, economic social and environmental. The assessment of sustainability of the wastewater treatment technology is to examine a number of factors under each sustainability aspect to eventually assess the overall sustainability. The factors investigated in literature include:

1. Economic factors: Capital costs; running costs.
2. Environmental factors: Removal efficiency; energy use.
3. Social factors: Job opportunities
4. Grey (overlapping) factors: Some of the social and environmental factors that are overlapping such as odor.

To date and based on the literature review that was made as part of this paper, limited attempts have been documented to assess the sustainability of wastewater treatment technologies in Egypt despite its importance in supporting the effective decision making process. It is highly recommended to purse research in this specific topic.

In our proposed methodology to assess wastewater treatment technologies in Egypt, we took into consideration the three aspects of sustainability, namely environmental, social and economic. We presented in this paper, the preliminary list of factors to be investigated and assessed, as well as their ranking.

A survey is planned to be conducted to revise the given weight of each sustainability aspect, as well as to enhance the preliminary list by addition and/or elimination. The final methodology shall promote the utilization of a user-friendly and simple screening tool to support the decision making process in Egypt.

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