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Selecting the Appropriate Wastewater Treatment System Using Analytic Hierarchy Process (AHP)

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Abstract: Water shortage is the biggest problem facing the world currently. Therefore, there is a strong focus on reusing treated wastewater and preserving available water sources from pollution. In order for it to be used well, the appropriate type of wastewater treatment method must first be chosen. The choice of the type of treatment method done by decision makers. Therefore, a selection wastewater treatment method was developed by using Analytical hierarchy process (AHP) to help decision makers take the optimal choice. The regions were divided into urban areas and rural areas, where the choice was from 10 different treatment systems of previously used. Four major with 10 sub-main selection criteria were established. We concluded that the best treatment system in the case of rural areas is Bio-block system, as it obtained a percentage of 11.54% where the most governing criteria of selection were complexity of the operation (T1) and energy consumption (T3). However Moving Bed Biofilm Reactor (MBBR) was the optimal choice in the case of urban areas and its percentage was 11.98% while the treatment system selection criteria were effluent quality (V2) and Amount of sludge (T2) because of the high standard of living and properly reuse of treated wastewater.

Keywords: Wastewater treatment, Analytical hierarchy process (AHP), Decision maker support.

1. Introduction

The primary objective of wastewater treatment is generally to facilitate the safe disposal of industrial and human wastewater, while ensuring that public health is not compromised and the environment is not subjected to intolerable damage. With growing interest in global environmental and healthcare issues, steps were taken to reduce environmental pollution, wastewater treatment becomes more and more important. Furthermore, wastewater treatment is increasingly important to recover water for use in other applications, such as agriculture. The World Health Organization's (WHO) research indicates that 85 to 90% of diarrheal illnesses in developing countries are caused by unsanitary conditions and practices, highlighting the ongoing need for improved access to sanitation and its advantages [1]. Despite tremendous efforts over the past few decades to establish wastewater water treatment (WWT) systems globally, 32% of the world's population lacked wastewater water treatment (WWT) facilities in 2015 [2] Most of those people lived in developing countries. More than 90% of untreated wastewater in developing countries discharged directly into rivers, lakes, or seas [3]. Before wastewater is released into the environment, the treatment system must cleanse it to meet the permissible limits set forth in a legislation intended to avoid water contamination [4]. Wastewater treatment is the significant activity as safeguards of human beings and the ecosystem from dangerous and poisonous substances. Where (Law No. 48 of 1982) specifies the disposal and reuse of treated wastewater in Egypt.

One of the most important steps in streamlining the wastewater treatment process is selecting the best option. Because of the consumption continues at its current rate, some research indicates that the world's population may eventually experience a water scarcity [5].

Wastewater treatment process consist of three phases, the first stage preliminary and treatment it is a physical treatment which its objectives is remove of coarse solids and other large materials often found in raw wastewater water such as debris and rags by screening, and also grit with diameter > 0.2 mm using grit removal chamber where one of its propose removing of oil and grease. While primary sedimentation tanks removes approximately 25 to 50% of the incoming biochemical oxygen demand (BOD_5), 50 to 70% of the total suspended solids (SS) [6]. Removal of these materials is necessary to enhance the operation of subsequent units.

The second stage of wastewater treatment include two contrasting methods: biological and physicochemical processes. Chemical-based methods, such as advanced oxidation processes (AOPs), have shown more effectiveness than biological procedures in eliminating organic complexes and stubborn chemicals found in industrial waste streams [7, 8, and 9]. Nevertheless, their use in wastewater treatment is restricted owing to the concomitant high energy consumption and chemical demands. When compared, biological processes are strong, effective, and economical. By using appropriate bacterial culture and process conditions, they have shown efficiency in breaking down persistent organic contaminants [10, 11, and 12].

The biological treatment which its main objective is removing biodegradable dissolved and colloidal organic matter using aerobic biological treatment processes. The aerobic microorganisms (mostly bacteria) carry out aerobic biological treatment in the presence of oxygen, breaking down the organic materials in the wastewater to produce additional microorganisms and inorganic end products (mainly CO2, NH_3, and H2O).The third stage of wastewater treatment is tertiary treatment, it was considered an optional stage according to the areas of reuse of produced water but nowadays the use of tertiary treatment systems was expanded to maximize the use of treated wastewater.

Secondary treatment or biological treatment is the main function of the treatment plant. Therefore, consideration is always given to choosing the appropriate alternative for each treatment plant separately. selecting the suitable and sustainable wastewater treatment system requires analyses that permit the process of deciding which options are best to execute which depends on several factors such as economic, environmental, and social criteria such as, for example, the area, construction cost, operating cost, and the area to be served…etc. and also give decision makers have the ability to quickly assess and scale the issue in line with their needs [13].

The most common biological systems used are in Egypt showed in table 1, varying between suspended growth systems and attached growth systems while there are some systems that combine the two as hybrid systems. Where table 2 show the matrix of secondary treatment processes with different parameters

In suspended growth systems, such as activated sludge, aerated lagoons, and aerobic digestion, waste and microbes are mixed together as oxygen diffuses and enters the cell. The microorganisms, which are not attached to any surface, aggregate together to form biological flocs, and then they separate and settle down in the clarifier. The settling aggregates remain in a clarifier while a portion of the sludge is returned to the aeration tank. An appropriate proportion of recycled sludge may significantly impact the efficiency of biological treatment [14].

In contrast to suspended solid systems, attached growth processes use support medium on which they are either fixed or movable. Microorganisms form a biofilm, which is a community of microorganisms that adhere to a surface. The biofilm grows and is sustained on the medium, and the microorganisms come into touch with new Sewage water. Trickling filters and rotating biological contactors (RBCs) are widely used as attached growth [15, 16].

Table 1. WWT biological systems

Secondary treatment System	Type of Treatment	advantages	disadvantages
Conventional activated sludge	Suspended growth	-High Treatment Efficiency -Low Capital Costs -Flexible Design	-High Operating Costs -Nutrient Removal Limitations -Sensitive to Shock Loads -High Maintenance Requirements -Nutrient Removal Limitations
Trickling filter	Attached growth	-Low Energy Requirements -Waste Sludge Easy to Dewater -Low Maintenance Requirements -Consistent Effluent Quality -Resistant to Toxins and Shock Loads -Ease of Operation	-Odors and Nuisance Organisms -Potential for Clogged Media -Cold Weather Can Cause Freezing -Lack of Adjustment -Pumping Costs
Oxidation ditch	Suspended growth	- Can handle shock loads -Produces less sludge -Low Energy Requirements -Easy operation	-Requires a larger land area -High suspended solids effluent
Aerated lagoons	Suspended Growth	-Low Energy Requirements -Low Capital Costs -Flexible Design	-Large foot print required -Effected by weather conditions -Oder and insect vectors
Moving Bed Biofilm Reactor **(MBBR)**	Hybrid	-Less area required - Reduced sludge production -Responds to load fluctuations without operator intervention	-high energy consumption -Nitrification requires high oxygen inputs -High maintenance requirements -Required skilled labor
Sequencing Batch Reactor **(SBR)**	Suspended growth	-High Treatment Efficiency -Minimal footprint -Low Capital Costs -Can handle shock loads	-Higher level of maintenance -Complex operation -More mechanical equipment -High disinfection required

Rotating biological contactor **(RBC)**	Attached growth	-No need for aeration -Low operation cost -Low quantity of sludge	-Large area required -Effected by weather conditions. -High maintenance cost
Membrane Bioreactors **(MBR)**	Suspended growth	-smaller space requirements -High Treatment Efficiency - Operates with high volumetric loading - low concentrations of bacteria	-higher capital and operating costs -high cost of maintenance -high energy required -low rate settling sludge
BIO-BLOCK	Suspended growth	-low foot print required -low energy consumption -low capital cost -low sludge production	-Complex operation -More mechanical equipment
Integrated fixed film activated sludge **(IFAS)**	Hybrid	-low sludge production -Improved process stability -Nitrification restored faster	-Large energy requirements -Mechanical spare parts are not locally available -High construction and operation costs -Requires expert knowledge

Table 2. Matrix for Secondary Treatment Processes

	Construction cost	Operation and maintenance	Foot print	Effluent quality	Oder and insects	Complexity of the operation	Amount of sludge	Energy consumption
Conventional activated sludge	+	+	+	++	+	++	--	+
Trickling filter	++	+	+	++	--	+++	++	+++
Oxidation ditch	+	++	+	++	+	+++	+	++
Aerated lagoons	++	++	--	+	--	++	+++	+++
Moving Bed Biofilm Reactor (MBBR)	++	+	++	+++	++	++	+++	+
Sequencing Batch Reactor (SBR)	+	--	+	++	+++	+	++	+
Rotating biological contactor RBC	+	--	++	++	++	++	+	+
Membrane Bioreactors **(**MBR)	--	--	++	+++	+++	+	+	--
BIO-BLOCK	++	+	+++	++	++	++	++	++
Integrated fixed film activated sludge **(**IFAS)	+	+	++	++	+++	+	++	+

Poor (--); Average (+); Good (++); Very Good (+++)

Using non-conventional waters as new sources, such as desalinated water, drainage water, and repurposed wastewater, is one of the several strategies to solve the problem of water shortage and stress [17, 18]. Selection of a suitable wastewater water treatment (WWT) technology is a pivotal and complicated process [19]. Selecting the incorrect technology will have an effect on water quality, cost, and efficiency [20].

Many environmental problems have been successfully solved with the application of multi-criteria decision making (MCDM), which includes choosing from different wastewater water treatment (WWT) options [21]. Analytical hierarchy process (AHP) and its offshoots have integrated physical and intangible components into the evaluation process, offering helpful strategies for handling the challenges of choosing wastewater water treatment (WWT) options.

Analytical hierarchy process (AHP) is a mathematical system which creates a hierarchical structure with the choice elements designed [22]. Both actual facts and the expert panel's subjective judgments have served as the foundation for the analytical hierarchy process (AHP) method. Analytical hierarchy process (AHP) enables users to incorporate a wide range of qualitative factors, such as those pertaining to social and environmental obligations, into evaluations [23].

Analytical hierarchy process (AHP) has several benefits over other multi-criteria approaches, including flexibility, an easy-to-use interface for decision makers, and the capacity to identify discrepancies. The pairwise comparison form of data entry is generally easy and comfortable for consumers to utilize. The analytical hierarchy process (AHP) approach computes the geometric mean of each pairwise comparison, facilitating group decision-making by agreement [24].

Enhance the Dojran, North Macedonia municipality's wastewater treatment system. An analysis was conducted on three potential approaches to enhance the municipality of Dojran's wastewater treatment capacity. The system's analysis during and after the tourist season, the efficiency of the new treatment plant in conjunction with the current wastewater treatment plant (WWTP), the treatment efficiency of wastewater treated using alternative technologies, the size of the site required to accommodate the capacity, and the proposed system's financial constraints were all taken into consideration when creating the shortlist of potential solutions. The analytical hierarchy process (AHP) was used to determine which enhancement option for the wastewater treatment system was the most advantageous [25].

An illustrative example under taken incorporate four wastewater treatment systems, these systems were sequencing batch reactor activated sludge process, Oxidation Ditch, , Anaerobic single-ditch oxidation and Anaerobic-Anoxic-Oxic process to help the decision-makers where Ten standards from the domains of the environment, economics, society-politics, and technology were used to measure sustainability [26]. The analytical hierarchy process (AHP) model was establish to evaluate system with 4 layers, 8 indexes and 5 schemes to analyze technical effectiveness, financial gain, and environmental effects of five municipal wastewater treatment systems. The multi-mode Anaerobic-Anoxic-Oxic (AAO) process is the most appropriate process when taking into account technical performance, economic gain, and environmental effect; the oxidation ditch method is the least advised technique [27]. The analytical hierarchy process (AHP) model evaluate 7 alternatives which Leeds to the using of Up Flow Anaerobic Sludge Blanket Reactor is the most suitable system in case of low and average income, where the optimum process in case of high income is compact unit Moving Bed Biofilm Reactor (MBBR) [28]. Certain academics have only employed traditional Analytic Hierarchy Process (AHP) techniques to assess and determine the optimal wastewater water treatment (WWT) technology for diverse urban and industrial wastewater situations. Where the others have added gray-relational analysis to the traditional analytical hierarchy process (AHP) technique, expanding it [29].

Using Analytical hierarchy process (AHP) and VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) proposed model obtain better results compared with other MCDM solutions. When it used to evaluate wastewater treatment technologies (WWTTs) for selecting the best WWTT among four alternatives and seven criteria [30]. Membrane bioreactor (MBR) is the optimal solution for Poong in Vina factory while The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Analytical hierarchy process (AHP) methods are used to support decision-making in choosing a wastewater treatment alternative [31].

Membrane bioreactor (MBR) was the most suitable wastewater treatment technology in India by applying Analytical hierarchy process (AHP) Taking into consideration thirteen sustainable basis related to social acceptability, suitability horticulture and economic aspects were identified and analyzed to evaluate the performance of sewage treatment technology[32]. An integrated fuzzy analytical hieracry process (F-AHP) and grey relational analysis (GRA) used to make the selection of wastewater treatment technology easier for small communities in Canada from seven commonly used wastewater treatment technologies, The assessment was conducted by considering a comprehensive review of technical, economic, social, and environmental factors. Each factor was further divided into multiple sub-indices [33]. the analytic hierarchy process (AHP) fuzzy method Confirm that membrane bioreactor (MBR) is the most appropriate alternative for treating the wastewater compared with up flow anaerobic sludge blanket (UASB) + membrane bioreactor (MBR), up flow anaerobic sludge blanket (UASB) + extended aeration (EA), anaerobic baffled reactor (ABR), anaerobic lagoon (ANL) + aerated lagoon (AL), and sequencing batch reactor (SBR) + (anaerobic baffled reactor (ABR), where this comparison is conducted using five specific criteria: energy consumption, effluent total suspended solids (TSS), effluent chemical oxygen demand (COD), cost, and level of technology [34].

The aim of this study is creating a system of hierarchical evaluation criteria with multiple aspects for measuring the sustainability of wastewater treatment processes. This system is inclusive, allowing decision-makers to add more criteria in each dimension or select only some of the criteria in each aspect based on their preferences.

2. Methodology

The three criteria domains of sustainability are the economy, environment, and society often employed for sustainability assessment [35, 36]. But decision makers need to increase these criteria to ensure sound selection. So that four aspect taken into consideration for sustainability evaluation, these four aspect showed in table 3.

The analytical hierarchy process (AHP) model applied to two cases of study, the first case was the optimum selection of wastewater water treatment (WWT) for rural areas (C1) when the second case is the selection for urban areas (C2). Where the four aspect have a different weights according to the social, intellectual, educational and financial levels.

The analytical hierarchy process (AHP) steps can summarized in that the problem is clearly defined and then the model is built in a hierarchical manner. The top starting with the goal, followed by selection criteria or comparisons, then finally is the available alternatives from which a choice is made.

Questionnaire was created for experts and responsible authorities to determine Selection criteria relative weights for each case then the nine scale technique was built for the available alternatives. Where the effect of each selection criteria on the available alternatives measured by a number from 1 to 9 to determine the extent of its influence on the selection process.

Table 3. Criteria of Wastewater Water Treatment (WWT) Selection

Aspect	Criteria	Symbol	Reference
Economic	Construction cost	E1	[37]
	Operation and maintenance	E2	[37]
Environmental	Foot print	V1	[38]
	Effluent quality	V2	[38]
	Oder and insects	V3	[38]
Technological	Complexity of the operation	T1	[39]
	Amount of sludge	T2	
	Energy consumption	T3	
Social-political	Governmental support	S1	[40]
	Public acceptability	S2	[40]

As we mentioned previously, the choice between these Alternatives depends on several factors. We will discuss the choice between ten types of the most common treatment systems as shown in table 4.

Table 4. Wastewater Water Treatment (WWT) Alternatives processes Symbols

Symbol	Alternative
A1	Conventional activated sludge
A2	Trickling filter
A3	Oxidation ditch
A4	Aerated lagoons
A5	MBBR
A6	SBR
A7	RBC
A8	MBR
A9	BIO-BLOCK
A10	IFAS

3. Results and discussion

According to the results of questionnaire and the information obtained from experts in the field of wastewater treatment and the authorities responsible for construction, operating, and maintenance of wastewater treatment plants, It has been observed that the selection criteria relative weights is close for all alternatives. However, there are factors that have a slight influence on the selection process, it varies according to terms of rural area (C1) or cities (C2) as shown in table 5.

Table 5. Selection criteria relative weights

Aspect	Criteria	C1 (%)	C2 (%)
Economic	E1	12.75	11.60
	E2	15.50	12.20
Environmental	V1	10.20	9.57
	V2	6.20	12.80
	V3	5.10	8.13
Technological	T1	18.23	8.50
	T2	6.33	12.02
	T3	15.20	9.67
Social-political	S1	5.69	7.90
	S2	4.80	7.61

Rural areas case (C1)

Table 6. Shows the relation between the alternatives and the selection criteria, where the impact factor of each alternative is the sum of selection criteria relative weights. Due to the impact factor alternative A9 (Bio-Block) is the most suitable treatment system in the rural areas as shown in figure 1.

This choice was based on a number of factors that have the highest percentages in The analytical hierarchy process (AHP) model, which are the ease of operating this system due to the lack of experienced manpower in rural areas, in addition to the low energy consumption required to operate this system, as well as the small size of the unit used and the presence of more than one module that varies depending on the quantities of water required to be treated where there are module 1000, 1500, 2500 up to 10,000 m^3/day while all of this is reflected in the operation and maintenance process to be effective in the system selection. this is without compromising the efficiency of wastewater treatment, which reaches 85 – 95 % Noting that wastewater has somewhat different characteristics in rural areas due to the increase in organic loads because of Use relatively smaller amounts of water than the urban areas, where the biochemical oxygen demand (BOD) range of 80-550 mg/L, chemical oxygen demand (COD) in the range of 250-1000 mg/L and total suspended solids 200-1300 mg/L [41, 42].

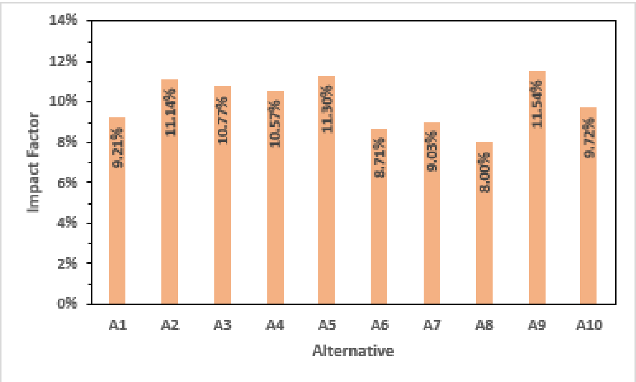

Figure 1. Rural areas case (C1) alternative impact factors

The other factors had varying proportions, but had less influence on the choice, as they were close in most alternatives, such as construction cost, amount of sludge and Social-political selection criteria.

Urban areas case (C2)

In case of urban areas the treatment system selection criteria was different where the quality effluent was the main driver in the selection process because of the ruse of treated water for green area irrigation according to (Law No. 48 of 1982), which it is reflect on public health. The process of choice includes the societal aspect and the high standard of living, which rejects the presence of odors and the difficulty of disposing of the sludge produced as shown in table 7.

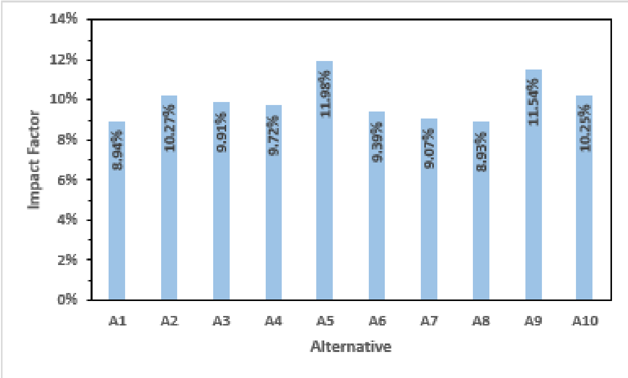

Figure 2. Urban areas case (C2) alternative impact factors

Table 6. Rural areas case (C1) relative weights of alternative and selection criteria

	E1	E2	V1	V2	V3	T1	T2	T3	S1	S2	Impact Factor
A1	1.14%	1.62%	0.85%	0.60%	0.39%	1.87%	0.30%	1.27%	0.68%	0.49%	**9.21%**
A2	1.59%	1.62%	0.85%	0.60%	0.23%	2.43%	0.69%	2.28%	0.49%	0.35%	**11.14%**
A3	1.14%	2.26%	0.85%	0.60%	0.39%	2.43%	0.50%	1.77%	0.49%	0.35%	**10.77%**
A4	1.59%	2.26%	0.51%	0.43%	0.23%	1.87%	0.89%	2.28%	0.29%	0.21%	**10.57%**
A5	1.59%	1.62%	1.19%	0.78%	0.70%	1.87%	0.89%	1.27%	0.74%	0.64%	**11.30%**
A6	1.14%	0.96%	0.85%	0.60%	0.70%	1.34%	0.69%	1.27%	0.67%	0.49%	**8.71%**
A7	1.14%	0.96%	1.19%	0.60%	0.54%	1.87%	0.50%	1.27%	0.48%	0.49%	**9.03%**
A8	0.68%	0.96%	1.19%	0.78%	0.70%	1.34%	0.50%	0.75%	0.48%	0.64%	**8.00%**
A9	1.59%	1.62%	1.54%	0.60%	0.54%	1.87%	0.69%	1.77%	0.68%	0.64%	**11.54%**
A10	1.14%	1.62%	1.19%	0.60%	0.70%	1.34%	0.69%	1.27%	0.68%	0.49%	**9.72%**
Sum											**100 %**

Table 7. Urban areas case (C2) relative weights of alternative and selection criteria

	E1	E2	V1	V2	V3	T1	T2	T3	S1	S2	Impact Factor
A1	1.04%	1.28%	0.80%	1.24%	0.62%	0.87%	0.56%	0.81%	0.95%	0.78%	8.94%
A2	1.45%	1.28%	0.80%	1.24%	0.37%	1.13%	1.31%	1.45%	0.68%	0.56%	10.27%
A3	1.04%	1.78%	0.80%	1.24%	0.62%	1.13%	0.94%	1.12%	0.68%	0.56%	9.91%
A4	1.45%	1.78%	0.47%	0.89%	0.37%	0.87%	1.70%	1.45%	0.40%	0.33%	9.72%
A5	1.45%	1.28%	1.11%	1.61%	1.11%	0.87%	1.70%	0.81%	1.03%	1.01%	11.98%
A6	1.04%	0.75%	0.80%	1.24%	1.11%	0.62%	1.31%	0.81%	0.93%	0.78%	9.39%
A7	1.04%	0.75%	1.11%	1.24%	0.86%	0.87%	0.94%	0.81%	0.66%	0.78%	9.07%
A8	0.62%	0.75%	1.11%	1.61%	1.11%	0.62%	0.94%	0.48%	0.66%	1.01%	8.93%
A9	1.45%	1.28%	1.44%	1.24%	0.86%	0.87%	1.31%	1.12%	0.95%	1.01%	11.54%
A10	1.04%	1.28%	1.11%	1.24%	1.11%	0.62%	1.31%	0.81%	0.95%	0.78%	10.25%
Sum											**100 %**

So that alternative (A5) Moving Bed Biofilm Reactor (MBBR) is the appropriate for the urban areas as shown in figure 2. Although it requires trained and skilled workers in operation and maintenance, the construction cost is somewhat high due to the presence of many mechanical parts and the carrier media.

4. Conclusion

The process of choosing the appropriate treatment system is considered a complex process due to the presence of a large number of influences that make decision makers confused, therefore, it was important to have tools to assist in the selection process

- Analytical hierarchy process (AHP) is considered one of the important tools that assist in decision-making processes.
- The selection process depends on several factors, including social and educational level.
- Bio-block treatment system is most suitable for rural area.

- Moving Bed Biofilm Reactor (MBBR) treatment system is the appropriate for the urban areas.

Conflicts of interest

“There are no conflicts to declare”.

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