Full Paper of the WasteSafe 2023 –8th International Conference on
Integrated Solid Waste & Faecal Sludge Management
25-26 February 2023, Khulna, Bangladesh

APPLICATION OF ANALYTIC HIERARCHY PROCESS FOR THE SELECTION OF WASTEWATER TREATMENT METHOD FOR TEXTILE INDUSTRY

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ABSTRACT

Due to rapid industrialization, textile effluents have been causing severe contamination and require proper treatment before disposal. But the choice of the best wastewater treatment is a multi-criteria decision making problem. The Analytic Hierarchy Process (AHP) is a mathematical tool for dealing with complex decision-making. The paper demonstrates the application of Analytic Hierarchy Process for selecting the most sustainable wastewater treatment for textile industry. The model enables the factors of the decision making process to be considered, in particular, treatment plant flexibility, operation and maintenance, cost, and capacity. After assessing the criteria, priorities of alternatives have been done by comparing them. From weight estimation, cost minimization is the most significant indicator among the four criteria for selecting the best alternative. Finally, after evaluation, treatment with reverse osmosis along with sedimentation, chemical treatment, and aeration has the highest grand weight of 0.449 and has been selected as the preferred treatment technology of textile wastewater.

INTRODUCTION

Our Environment is being affected seriously due to rapid industrialization by discharging a large amount of effluents as wastewater in surrounding water bodies. The third world countries, including Bangladesh, are facing tremendous pressure for the disposal of huge industrial waste without proper treatment or no treatment at all (Malczewski, 2006). Only 10% of the effluent generated across the country is being processed; the rest is discharged as it is into surrounding streams (Roy et al., 2013). Textile plays an important role to run the economy of Bangladesh efficiently. But in terms of pollution, the dyeing and spinning sections of textile and garment industries have been regarded as one of the most vulnerable contributors (Islam et al., 2011). In Bangladesh, about 1700 washing, dyeing, and finishing factories manufacture fabric for export around Dhaka, Chittagong, and Mymensingh. The manufacturing processes in these industries are mainly water-intensive consuming 200-250 liters of water per kilogram of fabric produced (Hossain et al., 2013). Among them, 80-85% are ultimately discharged to the environment without proper treatment due to deficiency of adequately equipped plants and hygienic dumping sites.

Bhaluka is developing as an industrial zone with the rise of various categories of industries like textile, spinning, garments, pharmaceutical, and food manufacturing industry. However, textile manufacturers, along with dyeing and printing components dominate in this zone although only a few of them have established effluent treatment plants (ETP) (Zabir et al., 2016). Thus, a large quantity of industrial chemicals and waste products generated every day are being disposed of into the adjacent river Sutia. The impact is significant where several producers like Hwa Textiles Ltd., Orion Knit Textiles Ltd., and Noman Composite Textile Ltd. are situated at one-place discharging effluents into the same water body. Moreover, the dumping sites around Bhaluka industrial area are connected with the river, which not only deteriorates the water quality but also has a great impact on soil properties.

Several studies have been conducted to ascertain physicochemical parameters and metals concentration in industrial effluents of several textile and garments industries situated in Bhaluka industrial area, Mymensingh. Studies show that the water is slightly alkaline, gray to black in colour, containing dyes with both organic and inorganic chemical substances (B. Sarker et al., 2016). This implies that the effluents have substantial negative effects on the receiving streams after disposal resulting in unsuitable river water for land irrigation and fish yield. Nevertheless, three farmlands are using industrial wastewater discharged from dyeing and spinning industries in Bhaluka. Therefore, it is necessary to design appropriate preventive measures to ensure that the effluent quality in the stream is improved.

There are several technologies for wastewater treatment at disposal. In choosing the right technology overall impacts of wastewater discharges have to be considered. AHP is such an effective multi criteria decision making tool that can be utilized in almost all the applications related to decision making. The requirements of environmental legislation lead to consider all relevant factors. The main objective of a decision making problem is placed at the top level in an AHP hierarchy, and the decision factors are arranged at subsequent lower levels (Malczewski, 2006). The use of AHP allows for the consideration of socio-cultural and environmental factors as well as economic factors. AHP has been chosen due to its wide application in several problems regarding sustainability and environmental resources.

Moreover, the AHP method fits the inspected issue with the help of informed knowledge. As this method does not rely on accurate measurements and indicators, it does not need any kind of specific data and physical scale (Mahmoud & Garcia, 2000). Absolute and relative are two sorts of comparisons that people make recognized by intellectual psychologists for quite a while. In absolute comparisons, a standard or baseline is used to compare the alternatives. On the other hand, alternatives are compared in pairs in relative comparisons according to a common attribute. The AHP has been utilized with the two sorts of correlations to describe ratio scales of estimation. According to Saaty & Vargas (2012), the scale of importance is represented as Table 1. The rating can also be reciprocals of the numbers mentioned in Table 1, indicating a reasonable assumption of the relative importance of the activities (Saaty & Vargas, 2012).

Table 1 Scale for pairwise comparison

Intensity of Importance	Explanation
1	Equally important
2	Weak or slight
3	Moderately important
4	Moderate plus
5	Strongly important
6	Strong plus
7	Very strongly important
8	Very, very strong
9	Extremely important

AHP has been widely used in solving several types of multi criteria decision making problems (Lu et al., 2017). Both Effat (2014) and Haque et al. (2021) used a multi criteria assessment method with GIS for choosing suitable and low-cost land for industry. Tsagarakis et al. (2003) included land requirement, construction, and operational and maintenance cost of treatment plant. AHP combines the criteria weights and the scores as well (Jajac et al., 2019). A simple and easily comprehensive AHP method is also used for the selection of renewable energy sources (Ahmad & Tahar, 2014). Therefore, this study exhibits the application of AHP for the selection of different treatment methods for the textile industry, the most growing industrial sector in Bangladesh.

However, from the environmental viewpoint, there is an alarming situation in waste water handling in Bangladesh (Karn & Harada, 2001). Proper steps should be taken by the industry to meet the standard environmental permissible limit of discharging waste water into the water body. An environmentally sustainable and economically viable treatment process for the industry is essential (Trubetskaya et al., 2021). Notwithstanding the declared national environmental policy, there is no significant progress in the effluent treatment field in Bangladesh due to technical factors as well as financial factors (Shams et al., 2017). The properties of wastewater in Bhaluka industrial area demand proper treatment before discharging the effluent to the surrounding surface or ground waters. Conventional treatments are inadequate for managing the imprecise or indistinct nature of semantic assessment.

The textile wastewater contains a huge amount of complex elements with high concentrations of organic matter, high-color and hard in nature. Conventional technologies for textile wastewater treatment mainly include activated sludge process, sedimentation, coagulation and flocculation, oxidation and finally adsorption. However, multiple investigations show that biologically, color removal is low during normal retention durations (Sarayu & Sandhya, 2012). Adsorption and ion exchange are usually low in capacity, requiring large amounts of materials. Ion-exchange instead of reverse osmosis is ineffective against wastewater having dye content and its effectiveness decelerates when wastewater contains other additives along with non-sulfur dyes (Adane et al., 2021). The effluent stream of textile waste having high salt concentration is low in volume and its treatment can be done following a sequential process of chemical treatment, followed by evaporation and crystallization.

Most of the synthetic dyes have dense and complex chemical structures which resist them to degrade easily. When they are exposed to light and aerobic condition, they become extremely stable (Dwivedi & Tomar, 2018). Aerobic and anaerobic method with MBR is very effective and produce less sludge but it requires large area along with special type of micro-organism (Bhatia et al., 2017). Advanced oxidation with NaOCl requires high capital as well as operating costs and may generate complex pollution-based products.The selection of the most suitable treatment process with optimum operating conditions is established with the help of AHP. The application of reverse osmosis or membrane filter in combination with sedimentation, chemical treatment, and aeration can prove to be a superior alternative for reducing pollutants from high concentrated spent dyeing and spinning effluents (Amar et al., 2009). Reverse osmosis has been a promising treatment method of a broad range of complex industrial wastes from textile, chemical, pulp, paper and food industries. Membranes can be used not only to remove pollutants but also to isolate organisms from water. The effluent after treatment can be discharged into natural waters, or can be reused for irrigation purposes (Galambos et al., 2004). The selection of alternative methods to design the actual treatment system is based on the capability of particular treatment processes to eliminate certain waste elements (Englande et al., 2015). The evaluation of alternatives regarding wastewater treatment plants is difficult due to multiple quantitative as well as qualitative objectives. AHP has been used for prioritizing various technologies with help of its recent implementation. The model considers all the factors and attributes related to the decision-making process, in particular ecological perspectives, technological aspects, and economic factors, and to choose the best alternative by comparing them.

METHODOLOGY

Study area

The study area is situated in Habirbari union of Bhaluka Upazila under Mymensingh in Bangladesh (latitude 24.3750ºN and longitude 90.3778°E) (Figure 1). B. C. Sarker et al. (2015) reported that concentration of heavy metal in wastewater collected from the textile and apparel industries was very low and within permissible limits.

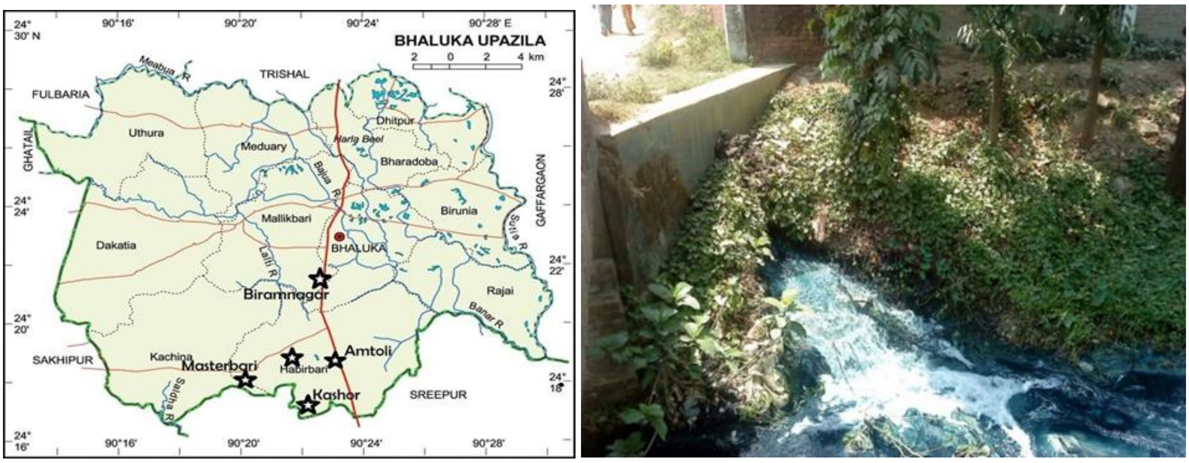

Figure 1 (a) Map of Bhaluka Upazila, (b) Effluent discharged from Hwa Textiles Ltd. Jamirdia, Dobaliapara, Bhaluka

Characteristics of wastewater

The main physicochemical parameters to characterize the quality of textile effluents are dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), color, odor, total dissolved solids (TDS), temperature, electrical conductance (EC), and pH (Dey & Islam, 2015). To analyze the quality of wastewater, samples were collected from various sources such as open areas, drain and discharge points as shown in Figure 1. Dense colour, and pungent and foul odor were found in almost all wastewater samples. Table 2 summarizes the values of different parameters of collected wastewater.

Table 2 Characteristics of Wastewater

Parameters	Values
Temperature	25 to 49.6℃
pH	3.9 to 12.6
TDS	90.7 to 2980 mg/L
DO	0 to 6.3 mg/L
COD	41 to 1430 mg/L
BOD	10 to 420 mg/L
TSS	24.9 to 1950 mg/L
EC	250 to 23750 µS/cm

The process is performed beginning from objective at the top and continuing to the bottom for criteria afterward, sub-criteria, and finally to alternatives. The process is based on splitting the problem, comparing different alternatives in pair, and then finding the most suitable preferences. Numerous criteria, both quantitative and qualitative, affect the selection of treatment process. In this research, four criteria and their associated sub-criteria have been taken into consideration as performance parameters for the wastewater treatment plant as shown in Table 3. The objectives of the design are defined from experts' opinions from industrial management and supervisors of the line.

Table 3 Attributes of wastewater treatment

Target layer	**Criteria layer**	**Indicator layer**
Industrial wastewater treatment (A)	Maximize treatment plant flexibility (B1)	Flexibility of changing treatment option by future expansions (C1) Treatment process flexibility for changing chemicals (C2) Flexibility for using locally available chemicals (C3) Flexibility in process conversion (C4)
	Maximize operation and maintenance (B2)	Facility of easy operation of the treatment plant (C5) Ease of supervision (C6) Ease of maintenance (C7)
	Minimize cost (B3)	Minimize the distance of disposal site (C8) Minimize waste-water/waste-load (C9) Maximize utilization of biodegradable materials (C10)
	Maximize capacity (B4)	Maximize the efficiency of the treatment plant (C11) Minimize space utilization for treatment plant/efficient space utilization (C12) Minimize maintenance/capacity ratio (C13)

However, there is no established specific treatment process that can be considered effective for all dyes irrespective of their constituents. It is clear from field survey that operation of activated sludge plant and plant with MBR are not satisfactory due to lack maintenance and proper operational steps. It is due to lack of skilled operator. But in Bangladesh, RO is used in different industries and skilled personnel for operation of RO and recovery technique is familiar to them (Siddique et al., 2017). Moreover, the waste of the industry surveyed is in small scale, so it is feasible to generate small scale anaerobic plant within the space available. Moreover, anaerobic digestion is not widely employed in Bangladesh at large scale because main challenge with regard to the production of electricity from biogas lies in the lack of skills personnel. On the other hand, membrane technology provides the scope to remove dissolved solids. Therefore, to choose the most sustainable wastewater treatment technology, the following alternatives have been considered.

Alternative 1: Conventional treatment

Alternative 2: Treatment with reverse osmosis along with sedimentation, chemical treatment with oxidation and aeration with anaerobic treatment (small scale)

Alternative 3: Treatment with membrane filter along with sedimentation, chemical treatment, and aeration with aerobic and anaerobic treatment (small scale)

The following steps represent the AHP evaluation process to select the best alternative.

1) At first, a comparative judgment matrix was established. The relative importance was defined through the comparative matrix from experts' opinions.

2) The AHP evaluation process begins with the calculation of the eigenvector. The entries in each row of the matrix were multiplied together and then the n^{th} root of that product was taken, where n is the number of levels. The n^{th} roots were summed and that sum was used to normalize each column element in the matrix.

3) Then the comparative matrix was multiplied by the normalized weight vector to obtain a new eigenvector. This vector is the product of Aw where w is the relative weight and A is the comparative square matrix.

4) Finally, the maximum eigenvalue λ_{max} of the matrix A was obtained by solving the following Eq. (1).

$$\lambda\max = \sum_{i=1}^{n} \frac{(Aw)_i}{nw_i} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

5) The judgment matrix must pass the consistency test to consider the eigenvectors as weights. Consistency index (CI) measures the uniformity of the matrix. and calculated by Eq. (2).

$$CI = \frac{\lambda\max - n}{n - 1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

To estimate the consistency of the comparative matrix, the consistency ratio (CR) was calculated by Eq. (3).

$$CR = \frac{CI}{RI} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

RI is the random index for the corresponding CI value as shown in Table 4 which has been derived from Saaty's book for purely random judgments with large samples (Saaty & Vargas, 2012, 2013). The order of the random matrix is in first row, and their corresponding index of consistency is in second row. If CR is < 0.1, the comparative matrix is acceptable otherwise; the matrix will need adjustment.

Table 4 Random index of the matrices of order 1-15

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.00	0.00	0.58	0.90	1.12	1.14	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Alternatives are compared in pair according to described criteria. After setting priorities, the grand weightage for each alternative is calculated based on their individual ratings under every criterion and summation of them for all criteria.

RESULTS AND DISCUSSIONS

The choice of the most suitable treatment process for any textile industry is influenced by the combination of different treatment methods depending on the nature of waste water. The factors and criteria for sustainability in case of treatment efficiency have been selected based on focus group discussion with experts and after reviewing relevant articles. In this study, for the textile industry, the factors related to different technical and operational parameters as well as financial aspects from the owner's (owner of industry) point of view. Sustainability of the location of industry, people's acceptability, and quality of life have been omitted.

For the determination of the weight for corresponding attributes under each of the criterion, AHP evaluation process has been repeated. The weight results for four criteria are shown in Table 5 and those for thirteen attributes relative to criteria and alternatives are also calculated in Table S1-S17 (Tables are added as supplementary materials). Finally, Table 6 represents the total evaluations of three alternatives over thirteen attributes under four criteria. From Table: λ_{max} = 4.049; CI = 0.016; RI = 0.9; CR = 0.018<0.1

From the comparative matrix for criteria in Table 5, 'minimize cost B3' and 'maximize treatment plant flexibility B1' play dominant roles in the evaluation of wastewater treatment weighting 0.515 and 0.321 respectively. Among four attributes of criterion B1, obtain flexibility for using locally available chemicals (C3) has the maximum relative importance indicating chemical has a great impact on the flexibility of treatment process. Among the attributes under 'maximize operation and maintenance B2' criterion, the facility of easy operation of the treatment plant (C5) has shown the highest weight being the most significant determinant. Because wastewater treatment must first consider the construction of the efficient treatment plant, and then discuss the supervision and maintenance issues. Minimize the distance of the disposal site (C8) has the highest influence among three attributes for the criterion of 'minimize cost (B3). Maximize the efficiency of the treatment plant (C11) is the most important attribute to maximize the capacity (B4) of the treatment plant.

Table 5 Comparative matrix for selection of wastewater treatment

A	B1	B2	B3	B4	n^{th} root value	Weights
B1	1	3	1/2	7	2.893	0.321
B2	1/3	1	1/5	2	0.604	0.108
B3	2	5	1	7	0.318	0.515
B4	1/7	1/2	1/7	1	1.800	0.057

The choice of the treatment process for an industry is a very complex and dynamic step. It requires a thorough critical analysis of all indicators as well as alternatives. From the overall priority vector after analysis, Table 6 indicates that Alt-2 earns the highest grand weight (0.449), followed by Alt-3 (0.394) and Alt-1 (0.236). The findings show that based on the technical aspects, treatment with reverse osmosis along with sedimentation, chemical treatment, and aeration is the most preferred option for the textile industry.

Table 6 Alternative evaluation by grand weight calculation

Objective	Weight	Attribute	Weight	Alt-1	Alt-2	Alt-3
B1	0.321	C1	0.076	0.655	0.055	0.290
		C2	0.305	0.890	0.352	0.559
		C3	0.575	0.187	0.687	0.127
B2	0.057	C4	0.043	0.091	0.691	0.218
		C5	0.216	0.152	0.630	0.218
		C6	0.103	0.328	0.260	0.413
		C7	0.682	0.163	0.504	0.267
B3	0.515	C8	0.760	0.072	0.279	0.649
		C9	0.144	0.320	0.558	0.122
		C10	0.096	0.243	0.669	0.088
B4	0.108	C11	0.2297	0.582	0.110	0.309
		C12	0.6483	0.104	0.770	0.127
		C13	0.1220	0.114	0.481	0.405
		Grand Weight		**0.236**	**0.449**	**0.394**

Among thirteen attributes, eight attributes (C3, C4, C5, C7, C9, C10, C12, and C13) have the highest weightage factor for Alt-2. This alternative not only provides ease in treatment operation using locally available material but also ensures ease of maintenance along with process conversion. Moreover, the requirement of less space for the treatment unit yields a minimum impact on the environment supporting environmental law. Being the most important criterion having the highest weight, cost minimization as an economic factor has influenced the reverse osmosis process significantly. The core elements of this factor are the minimum production of wastewater and the proper utilization of biodegradable materials for organic decomposition. All these factors have made this method to be the preferred alternative having fewer environmental hazards and optimum benefits.

Efficient space utilization is the most crucial attribute for Alt-2, having the highest weight of all attributes. On the other hand, the prerequisite for both membrane filter and conventional treatment method is huge free space in the industry, which eventually reduces treatment capacity. Being the second most crucial factor, support in process conversion makes reverse osmosis technology suitable for implementation in the textile industry. However, there is no scope for conversion in the conventional treatment process and a little scope for that in membrane filter containing low weightage factors in both cases. Along with this, the reverse osmosis process involves using biodegradable materials, and these facilitate the treatment operation not only from a financial perspective but also from an environmental aspect.

According to the priorities level, treatment with a membrane filter (Alt-3) is the second preferred treatment alternative having a grand weight of 0.394. With the facility of onsite recovery, this method minimizes the distance of the disposal site from the treatment plant, being the most prioritized attribute (Jeong et al., 2017). However, in maximizing the operation, maintenance, and capacity of a treatment plant, membrane filter technology shows the least flexibility that has reduced the overall weightage of Alt-3. Conventional technology (Alt-1) has been selected as the last prioritized method among the three alternatives. Alt-1 can maximize the efficiency of treatment plants by providing flexibility in changing chemical and treatment options. But it minimizes the capacity of the treatment process due to its less support to the environmental law of the country.

It is clear from the discussion that AHP provides flexibility in such critical decision-making situations for decision-makers for an industry. According to previous research, reverse osmosis is one of the most efficient decoloring and desalting method against various types of dye wastes. But Yu & Lee (2014) used the AHP method for choosing optical filter as a part of the treatment plant, in this study AHP method has been used for the whole treatment process for the textile industry as an exciting potential for the treatment of wastewater and it will provide eco-friendly and optimal sustainable process. However, Poonia & Punia (2018) used the AHP method with socio-economic factors, natural hazards indicators, and technological factors for drinking water in their study. So from the outcome of this research, it can be concluded that the effectiveness of the combination of a different treatment process for a textile industry will give sustainability for the industry for proper handling of waste water.

CONCLUSION

The textile and dyeing industries are considered as a threat to eco-system in Bangladesh and phase it out gradually to protect environment. Considering capability of owner of industry and size of industry, ETP is a unique solution against the threats. The advantages of the integrating approach are that it provides partial treatment at the factory producing waste water has to be cleaned at a threshold level in order to promoting industries. Combined treatment technology and reducing water consumption along with necessary options should be given priority as an integrated approach to handle the waste water. Every textile industry waste stream should be considered separately, then it is possible to develop a realistic option for effective ETP for the industry. AHP strategy for the selection of wastewater treatment in textile industries has been done in this study. The evaluation chooses design alternative treatment method-2 that has the highest grand weight of 0.449 as the most desirable and preferred design solution. In this work, the hierarchy structure of the maximization of treatment plant flexibility, capacity, operation and maintenance, and minimization of cost as the criteria layer was developed, with thirteen attributes as the sub-criteria layer. The established AHP model was incorporated for the evaluation of three wastewater treatment alternatives. According to the grand weight of alternatives, the ranking order of wastewater treatment has been obtained as treatment with reverse osmosis > treatment with membrane filter > conventional treatment. This method has the potential to evaluate not only the treatment method of effluent but also give references for the establishment of other industrial wastewater treatment assessments. However, some industrialists opine that alternatives related to membrane filter will get more acceptability for the mega textile industry although Alt-2 is the most preferred option for the particular industry. As time progress in Bangladesh, some experts will earn experience in handling and operating membrane filter technology.

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