Sustainability of textile waste-water management by using an integrated fuzzy AHP-TOPSIS method: a case study

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Abstract: The textile industry is quickly growing worldwide and has a universally beneficial effect on the economy. The waste-water generated with the growth of the textile industry can cause considerable health and environmental issues if it is not treated properly. Generally, physical, biological, and chemical processes are used independently or in combination to treat textile waste-water. The efficiency of any treatment process depends on the working criteria. In this paper, we implemented a new hybrid methodology based on the fuzzy analytic hierarchy process (FAHP) and fuzzy technique for order preference by similarity to ideal solution (FTOPSIS) to help workers in textile industries select the optimal waste-water treatment process. To illustrate how this hybrid methodology can be used to address the waste-water treatment problem, we conducted a case study involving 11 assessment criteria and four treatment processes used in the textile industry in India. Comparative analysis indicated that the survey overall mean was slightly lower than the overall mean for selected companies in the treatment process.

Keywords: textile industry; waste-water treatment; fuzzy analytic hierarchy process; FAHP; FTOPSIS; case study.

Reference to this paper should be made as follows: Pattnaik, P. and Dangayach, G.S. (2021) 'Sustainability of textile waste-water management by using an integrated fuzzy AHP-TOPSIS method: a case study', *Int. J. Environment and Sustainable Development*, Vol. 20, No. 2, pp.105–128.

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This paper is a revised and expanded version of a paper entitled 'Sustainability of textile wastewater management by using fuzzy AHP method' presented at SUSCOM-2019, Amity University Jaipur Rajasthan, India, 26–28 February 2019.

1 Introduction

Waste-water treatment is one of the most critical and mandatory technologies in global policy to ensure a clean environment and human safety (Pala and Tokat, 2002). Most of the manufacturing and mining industries produce vast quantities of waste-water, such as during the cleaning of semi-finished products or fabric treatment in the textile sector. In the textile industry, different dye solutions are used to treat the fabric, and dye containing effluent is often discharged into open water without proper treatment (Ghoreishi and Haghighi, 2003). The textile dyes are usually synthetic and have highly complex structures thus making textile waste-water treatment an expensive and challenging task. Conventional techniques such as physical, chemical, and biological methods have been used to treat textile waste-water (Sirianuntapiboon and Sansak, 2008; Sirianuntapiboon et al., 2006). Apart from their various advantages, such as effectiveness and less operational time, these conventional treatment processes have specific weaknesses, such as high chemical cost, complex sludge production, a requirement for regular maintenance, and high energy demand (Pala and Tokat, 2002; Ghoreishi and Haghighi, 2003; Sirianuntapiboon and Sansak, 2008; Sirianuntapiboon et al., 2006; Liehr et al., 2004). After studying six different techniques of textile waste-water treatment, Nawaz and Ahsan (2014) found that no single conventional technique can yield treatment efficiency as high as 80%. However, in combination, these techniques show a tremendous increase in treatment efficiency (94.5%) while decreasing both cost and operational difficulty. Garcia-Montano et al. (2006) have reported that the treatment efficiency of a biological process for dye removal from textile effluent improves drastically if it is coupled to another process. Moreover, combinations of two or more processes for increasing waste-water treatment efficiency have been reported (Álvarez et al., 2013; Hayat et al., 2015; Turan-Ertas, 2001).

Physical, biological, and chemical techniques have been implemented in different combinations for the efficient treatment of industrial waste-water. Because each combination has certain advantages and disadvantages, selecting the most effective treatment technique among the available options remains challenging (Minière et al., 2018; Kam et al., 2016; Bapat et al., 2016). This problem has been solved through decision-making techniques. Multi-criterion decision-making (MCDM) techniques involve the selection of the most appropriate alternative from a pool of options and have been widely applied in solving various decision-making problems (Singh et al., 2018; Van et al., 2006; Chauhan et al., 2016; Kumar et al., 2019).

Mahjouri et al. (2017b) have used MCDM and fuzzy logic for selecting the optimum waste-water treatment methodology. They have reported that most experts in the field have primarily examined environmental aspects, economic aspects, and technical issues through a multidimensional approach. These techniques have successfully demonstrated an optimal framework through which plant planners, as well as policymakers, can efficiently manage the generation of waste-water by implementing alternative treatment technologies.

Akhoundi and Nazif (2018) have reported a different MCDM method, the evidential reasoning approach, which broadly includes both quantitative and qualitative criteria. These techniques have been used to examine not only waste-water reusability but also the treatment technologies for sustainability assessment of plants in south Tehran and Iran. Similarly, Gardas and co-workers (2018) have discussed three dimensions of sustainability, i.e., social, economic, and environmental impact, to achieve balanced growth among the textile and other apparel sectors. Santos et al. (2019) have reported that the fuzzy analytic hierarchy process (FAHP) remains the most preferred tool to support sustainable development in various fields. Mahjouri et al. (2017a) have used hybrid fuzzy Delphi and FAHP to identify critical evaluation criteria as well as indicators that can be used to achieve sustainability in industrial waste-water treatment. Through this decision-making approach, the authors concluded that out of six selected criteria, reliability and system efficiency supports are efficient criteria for the development of technological aspects. Al Sawaf and Karaca (2018) have reported the use of textile mill waste-water treatment technologies in Turkey with respect to the sustainability of performance in terms of economic, environmental, and social impacts. The authors determined the performance scores and their necessary weights from different stakeholders and then applied MCDM methods and concluded that out of four different treatment technologies, chemical treatment technology was the least sustainable alternative in the textile industry.

In the present research, we examined the available literature on the sustainability of textile waste-water management and the use of the MCDM technique. To make the textile sector more sustainable, we used both the FAHP and FTOPSIS methods. First, we ranked the proposed criteria on the basis of their importance by FAHP. In a subsequent step, we used the FTOPSIS technique to prioritise the selected alternatives used in the textile manufacturing sectors to optimise the process parameters.

2 Evaluation methodology

2.1 Selection of performance attributes

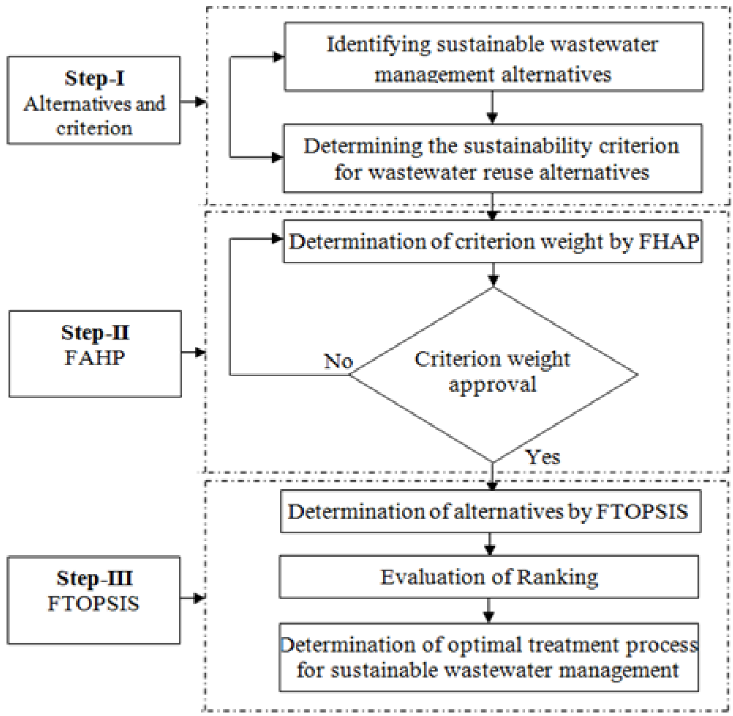
The MCDM techniques are potential tools for evaluating complex problems, because of their various dependent and independent variables for solving problems in textile sector manufacturing. In this manuscript, 11 criteria were proposed to improve processes from labour input to operational performance through the implementation of various policies (Table 1).

Cases mentioned in Table 1 rely solely on the collected survey reports, which are not sufficient to provide sustainability in the textile sector and address related problems; therefore, for further improvement, implementation of an MCDM such as FAHP is necessary for in depth analysis. FAHP is mainly used to predict the weights of different criteria to improve performance in the textile sector as well as to rank the criteria in decreasing order. The methodology consists of the following three main steps, as shown in Figure 1. In the first step, the alternatives are identified, then subsequently used to evaluate optimal sustainability in the textile waste-water management approach. In the second step, a weight is assigned to each criterion by using the FAHP technique, according to the literature, survey reports, and experts' opinions. In the last step, through the FTOPSIS method, the best alternative is determined. First, we briefly review the basis of fuzzy set theory before defining the fuzzy AHP and fuzzy TOPSIS approaches.

Table 1 Description of the different performance defining attributes

Performance defining attributes	*Description*	*Performance implications*
Labour input in the textile industry	It is a measure of the effectiveness and efficiency of an organisation in generating output with the resources available.	C-1 lower-the-better
Policy implications	Policy implementation in developing countries called carbon tariffs policy for better performance in the international market and subsequently examined the policy from time to time.	C-2 lower-the-better
Dyes and additives	Dye and additives are the major ingredients to improve the performance of the textile fibres, and because of these dyes, the final cloth image changes drastically as per present customer desire.	C-3 lower-the-better
Wastewater treatment and disposal	Effective utilisation of water and reuse of wastewater for different applications again and again to control the environment.	C-4 lower-the-better
Energy consumption and carbon dioxide emissions	Energy conservation with emission reduction in textile industries because most of the textile industries generate much heat during treatment as well as other sources of heat generated through air conditioner and compressors.	C-5 lower-the-better
Textile industry productivity	Improvement of production rate in textile sectors.	C-6 higher-the-better
Textile reuse and recycling	Effective utilisation of textile fibre wastes and or other solid wastes for further use in the same textile industry application or some other applications like agriculture or construction applications.	C-7 higher-the-better
Improvement of sustainability-related performance	The sustainable textile sector needs to be developed environment-friendly by installing pollution-control technology.	C-8 higher-the-better
Economic performance	Economic performance mainly defined the growth of textile products export and its contribution to total exports.	C-9 lower-the-better
Environmental impact	The textile industry is considered as one of the most polluting industries in the world, and hence the reduction of pollution in the environment is highly needed.	C-10 higher-the-better
Operational performance	Operational performance overall depends on the utilisation of advanced technology and economic performance also.	C-11 higher-the-better

Figure 1 Proposed methodology



2.2 *Hybrid fuzzy AHP and TOPSIS analysis*

2.2.1 *Fuzzy set theory*

Fuzzy set theory, developed by Zadeh (1965), is a valuable mathematical tool used to strengthen the effectiveness of decision-making techniques. This theory was developed to incorporate the ambiguities, vagueness, and uncertainties associated with the decision-maker's subjective judgments. A fuzzy set is defined as:

$$X = \{(\chi, \xi(\chi)), \chi \in \mu\} \tag{1}$$

where χ is defined on the real line for the universe of discourse, and μ and $\xi(\chi)$ represent a membership function having a defined value in between 0 to 1. In the present research, fuzzy triangular numbers were utilised, and the membership function for a triangular fuzzy number $(\hbar = h_1, k_1, l_1)$ was defined as:

$$\xi(\chi) = \begin{Bmatrix} 0, & \chi < h \\ \dfrac{\chi - h}{k - h} & h \le \chi \le k \\ \dfrac{\chi - l}{k - l} & k \le \chi \le l \\ 0 & \chi > l \end{Bmatrix} \tag{2}$$

The various operation laws of two triangular fuzzy numbers such as $\hbar = h_1, k_1, l_1$ and $\lambda = h_2, k_2, l_2$ are presented in Table 2 (Saaty, 1980). Moreover, to determine the distance between these triangular fuzzy numbers, a vertex method was used as follows:

$$D(\hbar, \lambda) = \sqrt{\frac{1}{3}\left[(h_1 - h_2) + (k_1 - k_2) + (l_1 - l_2)\right]} \tag{3}$$

Table 2 Operational laws of triangular fuzzy numbers

Operational laws	*Description*
Addition	$\hbar + \lambda = (h_1, k_1, l_1) + (h_2, k_2, l_2) = (h_1 + h_2, k_1 + k_2, l_1 + l_2)$
Subtraction	$\hbar - \lambda = (h_1, k_1, l_1) - (h_2, k_2, l_2) = (h_1 - h_2, k_1 - k_2, l_1 - l_2)$
Multiplication	$\hbar \times \lambda = (h_1, k_1, l_1) \times (h_2, k_2, l_2) = (h_1 \times h_2, k_1 \times k_2, l_1 \times l_2)$
Division	$\hbar / \lambda = (h_1, k_1, l_1) / (h_2, k_2, l_2) = (h_1/h_2, k_1/k_2, l_1/l_2)$
Inverse	$(\hbar)^{-1} = (h_1, k_1, l_1)^{-1} = \left(\frac{1}{h_1}, \frac{1}{k_1}, \frac{1}{l_1}\right)$

The uncertainties in a textile waste-water management system complicate the task of a designer to assign the correct score to the selected alternative. Hence, the concept of a linguistic variable was introduced. Linguistic values such as low, very low, medium, very high, and high have been reported to be useful in solving many complex decision-making problems. These linguistic values can be converted to triangular fuzzy numbers, as presented in Table 3.

Table 3 Linguistic values and fuzzy numbers

Linguistic values	*Fuzzy numbers*
Very low (VL)	(0, 0.10, 0.25)
Low (L)	(0.15, 0.30, 0.45)
Medium (M)	(0.35, 0.50, 0.65)
High (H)	(0.55, 0.70, 0.85)
Very high (VH)	(0.75, 0.90, 1)

2.2.2 Step 1: identification of alternatives and criteria

In this step, the various alternatives and criteria used in assessing the sustainability of textile waste-water management were identified. Alternatives were selected from the literature, and criteria were determined by the expert team consisting of members from both industry and academia.

2.2.3 Step 2: FAHP for criterion weight determination

Saaty (1980) clearly defined the hierarchy process approach as a structured technique that utilises mathematical calculations for criterion priority or weight determination. FAHP was initiated by structuring a pair-wise comparison matrix based on a nine-point scale, as presented in Table 4. Generally, for n criteria, the pair-wise comparison matrix (ζ_{nn}) is given as:

$$\zeta_{nn} = \begin{bmatrix} \zeta_{11} & \zeta_{12} & \cdots & \zeta_{1n} \\ \zeta_{21} & \zeta_{22} & \cdots & \zeta_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \zeta_{n1} & \zeta_{n2} & \cdots & \zeta_{nn} \end{bmatrix} \zeta_{ii} = 1, \zeta_{ji} = \frac{1}{\zeta_{ij}}, \zeta_{ij} \neq 0 \tag{4}$$

where the importance of the i^{th} concerning j^{th} criterion is represented by ζ_{ij}.

Furthermore, each entity of this comparison matrix converted to a linguistic value is tabulated in Table 4. The linguistic comparison matrix is given as:

$$\bar{\zeta}_{nn} = \begin{bmatrix} \bar{\zeta}_{11} & \bar{\zeta}_{12} & \cdots & \bar{\zeta}_{1n} \\ \bar{\zeta}_{21} & \bar{\zeta}_{22} & \cdots & \bar{\zeta}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \bar{\zeta}_{n1} & \bar{\zeta}_{n2} & \cdots & \bar{\zeta}_{nn} \end{bmatrix} \bar{\zeta}_{ii} = 1, \bar{\zeta}_{ji} = \frac{1}{\bar{\zeta}_{ij}}, \bar{\zeta}_{ij} \neq 0 \tag{5}$$

Subsequently, the weight of each criterion is computed through a geometric mean method. For the i^{th} criterion, the weight is calculated as:

$$\bar{\sigma}_i = \left[\bar{\zeta}_{i1} \times \bar{\zeta}_{i2} \times \cdots \times \bar{\zeta}_{in}\right]^{1/n} \tag{6}$$

$$\bar{\varpi}_i = \bar{\sigma}_i \times \left[\bar{\sigma}_1 + \bar{\sigma}_2 + \cdots + \bar{\sigma}_n\right]^{-1} \tag{7}$$

This computed weight is then defined in terms of triangular fuzzy numbers. If $\bar{\varpi}_i = (p\bar{\varpi}_i, q\bar{\varpi}_i, r\bar{\varpi}_i)$ is the fuzzy weight triangular number, then non-fuzzy weight (NFW) is calculated by using the following equation:

$$NFW = \left(\frac{(r-p)+(q-p)}{3} + p\right) \tag{8}$$

Again, the average eigenvalue ($\lambda_{\max}$) is calculated by multiplying the NFW values by $\bar{\zeta}_{nn}$ column-wise.

The superiority of the FAHP is rigorously associated with the consistency of $\bar{\zeta}_{nn}$. The consistency is assessed according to the computed consistency ratio (C.R.) as:

$$C.R. = \frac{\lambda_{\max} - n}{n-1} \times \frac{1}{RI} \tag{9}$$

where RI is the random index of the matrix, and its value is decided according to the order of the constructed $\bar{\zeta}_{nn}$. For a perfectly consistent matrix, the C.R. should remain ≥ 0.1.

2.2.4 Step 3: FTOPSIS for ranking evaluation

In this step, a fuzzy decision matrix between alternatives and criteria is constructed in terms of linguistic values, as presented in Table 4.

Table 4 The fundamental relational scale for pair-wise comparisons

Absolute scale	*Definition*	*Explanation*	*Fuzzy numbers*
1	Equal importance	Both the activities equally contributed to the objective	(1, 1, 1)
2	Weak importance	Favour slightly one activity over another as per experts opinion and judgment	(1, 2, 3)
3	Moderate importance	Moderately favour one activity over another as per experts opinion and judgment	(2, 3, 4)
4	Preferable	Experience and judgment strongly support one activity over another	(3, 4, 5)
5	Strong importance	Experts opinion and judgment strongly favour one activity over another	(4, 5, 6)
6	Fairly importance	Experts opinion and judgment strongly favour one activity over another	(5, 6, 7)
7	Very importance	An activity is very strongly favoured	(6, 7, 8)
8	Absolute	An activity is absolutely favoured	(7, 8, 9)
9	Extreme importance	Highest possible order of affirmation one activity over another is of the	(8, 9, 10)

If there were *m* alternatives to be evaluated against n criteria, then a fuzzy decision matrix is constructed as:

$$D_{ij} = \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1n} \\ s_{21} & s_{22} & \cdots & s_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ s_{m1} & s_{m2} & \cdots & s_{mn} \end{bmatrix} i = 1, 2, \cdots, m; \; j = 1, 2, \cdots, n \tag{10}$$

The fuzzy decision matrix is constructed in terms of linguistic values representing triangular fuzzy numbers and generally has values 0–1; thus, there is no need to normalise this fuzzy decision matrix. Computed weights are next used to construct a weighted fuzzy decision matrix as:

$$\bar{D}_{ij} = D_{ij} \times \varpi_i \tag{11}$$

After a weighted fuzzy decision matrix is defined, a positive (φ^+) and negative (φ^-) fuzzy ideal solution is identified as:

$$\varphi^+ = \left(\overline{D_1}^+, \overline{D_2}^+, \cdots, \overline{D_n}^+\right) \quad \text{and} \quad \varphi^- = \left(\overline{D_1}^-, \overline{D_2}^-, \cdots, \overline{D_n}^-\right) \tag{12}$$

$$\overline{D_j}^{+} = \begin{cases} \underset{i}{\overset{m}{Max}}\, \overline{D}_{ij} \text{ if } j \text{ is a benefit criterion} \\ \underset{i}{\overset{m}{Min}}\, \overline{D}_{ij} \text{ if } j \text{ is a cost criterion} \end{cases}$$

and (13)

$$\overline{D_j}^{-} = \begin{cases} \underset{i}{\overset{m}{Min}}\, \overline{D}_{ij} \text{ if } j \text{ is a benefit criterion} \\ \underset{i}{\overset{m}{Max}}\, \overline{D}_{ij} \text{ if } j \text{ is a cost criterion} \end{cases} \qquad \text{for } j = 1, 2, ..., n$$

Consequently, every alternative distance from φ^+ and φ^- is determined as:

$$\Theta_i^+ = \sqrt{\sum_{j=1}^{n} \left(\overline{D}_j^+ - \overline{D}_{ij}\right)^2}$$

and (14)

$$\Theta_i^- = \sqrt{\sum_{j=1}^{n} \left(\overline{D}_{ij} - \overline{D}_j^-\right)^2} \qquad \text{for } i = 1, 2, ..., m$$

Next, the closeness coefficient values are computed, and for the i^{th} alternative, the closeness coefficient (Ω_i) is determined as:

$$\Omega_i = \frac{\Theta_i^+}{\Theta_i^+ + \Theta_i^-}, \qquad \text{for } i = 1, 2, ..., m \tag{15}$$

3 Case study

The main purpose of the case study was to identify the best treatment alternative for improving the overall performance of the textile manufacturing sector. In this study, five experts were selected to evaluate the proposed criteria for sustainable development of textile waste-water treatment in various textile sectors. Three of the experts were technical personnel (production managers) in the textile sector, and two of the experts were from academic groups studying various treatment technologies specifically in the environmental and management fields. The same group has already published literature on textile waste-water with and without treatment (Pattnaik et al., 2018). Finally, fuzzy linguistic terms were incorporated by the selected decision-makers from the eight different textile industries in India. A literature search indicated that a combination of traditional processes was the most preferred approach for waste-water treatment. Hence, the combinations P-1 (the combination of physical and chemical processes), P-2 (the combination of physical and biological processes), P-3 (the combination of biological and chemical processes), and P-4 (the combination of physical, chemical and biological processes) were selected as alternatives. The importance of key criteria and indicators associated with the sustainability of the textile waste-water management were mainly dependent on 11 primary criteria relating to the Indian textile sector. Labour input in the textile industry (Islam, 1990) directly or indirectly improves the textile industry's productivity (Sinha and Sawhney, 1968) in a manner entirely dependent on the policy implications (Shui et al., 1993), waste-water treatment and disposal (Boda et al., 2017), textile reuse and recycling (Baruque-Ramos et al., 2017), and dyes and additives (Olmez et al., 2007). Similarly, for improving sustainability-related performance (Shen et al., 2017), most textile sectors currently depend primarily on the following three-dimensional criteria: economic performance (Liu et al., 2014), environmental impact for environmentally friendly production (Toprak and Anis, 2017), and operational performance (Liu et al., 2014). Increases in energy consumption and carbon dioxide emissions (Sarkar et al., 2015) have been found to be proportional to the increase in the expansion of economic activities as well as the increased population size worldwide. Finally, we established 11 important criteria (Figure 2) for assessing the sustainability of textile waste-water management. In the present analysis, 264 industries were selected from all parts of the country: nearly 39 industries used physical and chemical treatment processes, 28 industries used physical and biological processes, 120 industries used biological and chemical processes, and 77 industries used physical, chemical and biological processes (Table 5). According to the treatment processes, the following data were collected through surveys, as reported in Table 5, and then the overall mean was calculated from the survey mean (Table 5). After survey analysis, we again reselected each treatment category; two companies were selected for further analysis, and the detailed analysis is shown in Table 5, with the company names designated A, B, C, D, E, F, G, and H. The survey overall mean was slightly lower than the overall company mean.

Figure 2 Various criteria for evaluation of the performance in terms of sustainability of the textile wastewater management system (see online version for colours)

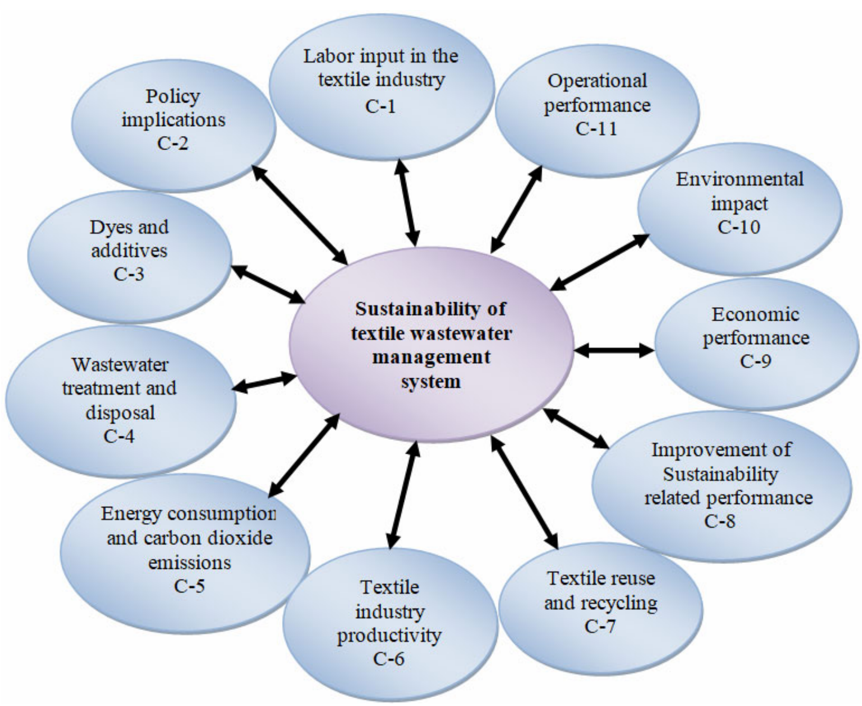


Table 5 Comparisons of survey overall mean and selected company overall mean

Types of treatment process	*Attributes*	*Survey mean value*	*Overall mean*	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*
P1: Physical and chemical processes (39 industries)	Labour input in textile industry	4.231	3.93	5	5	–	–	–	–	–	–
	Policy implication	4.244		5	5	–	–	–	–	–	–
	Textile reuse and recycle	3.865		4	5	–	–	–	–	–	–
	Dyes and additives	3.853		4	5	–	–	–	–	–	–
	Wastewater treatment and disposal	3.654		4	4	–	–	–	–	–	–
	Energy consumption and carbon dioxide emission	4.199		5	5	–	–	–	–	–	–
	Textile industry productivity	4.321		5	5	–	–	–	–	–	–
	Improvement of sustainable related performance	3.551		4	4	–	–	–	–	–	–
	Economic performance	3.788		4	4	–	–	–	–	–	–
	Environmental impact	3.571		4	4	–	–	–	–	–	–
	Operational performance	3.955		4	4	–	–	–	–	–	–
	Company A and B (overall mean)			4.364	4.545						
P2: Physical and biological processes (28 industries)	Labour input in textile industry	3.804	3.906	–	–	4	5	–	–	–	–
	Policy implication	3.911		–	–	4	5	–	–	–	–
	Textile reuse and recycle	3.750		–	–	4	5	–	–	–	–
	Dyes and additives	3.714		–	–	4	4	–	–	–	–
	Wastewater treatment and disposal	3.848		–	–	4	4	–	–	–	–
	Energy consumption and carbon dioxide emission	4.259		–	–	5	5	–	–	–	–
	Textile industry productivity	4.241		–	–	5	5	–	–	–	–
	Improvement of sustainable related performance	3.902		–	–	5	4	–	–	–	–
	Economic performance	3.875		–	–	5	4	–	–	–	–
	Environmental impact	3.661		–	–	4	4	–	–	–	–
	Operational performance	4.009		–	–	5	5	–	–	–	–
	Company C and D (overall mean)					4.455	4.545				

Notes: On five-point scale: 1 – strongly disagree and 5 – strongly agree.
A: company A (overall mean), B: company B (overall mean), C: company C (overall mean), D: company D (overall mean),
E: company E (overall mean), F: company F (overall mean), G: company G (overall mean) and H: company H (overall mean).

Table 5 Comparisons of survey overall mean and selected company overall mean (continued)

Types of treatment process	*Attributes*	*Survey mean value*	*Overall mean*	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*
P3: Biological and chemical processes (120 industries)	Labour input in textile industry	4.390	4.053	---	---	---	---	5	5	---	---
	Policy implication	4.060		---	---	---	---	4	4		
	Textile reuse and recycle	4.290		---	---		---	4	4	---	---
	Dyes and additives	3.860		---	---	---	---	4	4	---	---
	Wastewater treatment and disposal	3.840		---	---	---	---	4	5	---	---
	Energy consumption and carbon dioxide emission	4.490		---	---	---	---	5	5	---	---
	Textile industry productivity	4.560		---	---	---	---	4	5	---	---
	Improvement of sustainable related performance	3.650		---	---	---	---	4	4	---	---
	Economic performance	4.380		---	---	---	---	5	5	---	---
	Environmental impact	3.710		---	---	---	---	4	5	---	---
	Operational performance	3.360		---	---	---	---	4	4	---	---
	Company E and F (overall mean)							4.273	4.545		
P4: Physical, chemical and biological processes (77 industries)	Labour input in textile industry	4.013	3.871	---	---	---	---	---	---	5	5
	Policy implication	3.912		---	---	---	---	---	---	4	4
	Textile reuse and recycle	3.620		---	---	---	---	---	---	4	4
	Dyes and additives	3.744		---	---	---	---	---	---	4	5
	Wastewater treatment and disposal	3.831		---	---	---	---	---	---	4	5
	Energy consumption and carbon dioxide emission	4.127		---	---	---	---	---	---	5	5
	Textile industry productivity	4.221		---	---	---	---	---	---	5	5
	Improvement of sustainable related performance	3.438		---	---	---	---	---	---	5	5
	Economic performance	3.977		---	---	---	---	---	---	4	5
	Environmental impact	3.562		---	---	---	---	---	---	4	4
	Operational performance	4.133		---	---	---	---	---	---	5	5
	Company G and H (overall mean)									4.455	4.727

Notes: On five-point scale: 1 – strongly disagree and 5 – strongly agree.
A: company A (overall mean), B: company B (overall mean), C: company C (overall mean), D: company D (overall mean),
E: company E (overall mean), F: company F (overall mean), G: company G (overall mean) and H: company H (overall mean).

Table 6 Pair-wise comparison matrix

	C-1	*C-2*	*C-3*	*C-4*	*C-5*	*C-6*	*C-7*	*C-8*	*C-9*	*C-10*	*C-11*
C-1	1	1	1	1	2	3	4	7	8	9	9
C-2	1	1	1	1	2	3	5	5	8	9	9
C-3	1	1	1	1	2	3	3	5	7	7	9
C-4	1	1	1	1	1	2	3	4	6	7	8
C-5	1/2	1/2	1/2	1	1	1	3	3	4	5	6
C-6	1/3	1/3	1/3	1/2	1	1	1	3	3	3	4
C-7	1/4	1/5	1/3	1/3	1/3	1	1	1	2	3	3
C-8	1/7	1/5	1/5	1/4	1/3	1/3	1	1	1	2	3
C-9	1/8	1/8	1/7	1/6	1/4	1/3	1/2	1	1	1	1
C-10	1/9	1/9	1/7	1/7	1/5	1/3	1/3	1/2	1	1	1
C-11	1/9	1/9	1/9	1/8	1/6	1/4	1/3	1/3	1	1	1

Table 7 Pair-wise comparison matrix in terms of fuzzy numbers

	C-1	*C-2*	*C-3*	*C-4*	*C-5*	*C-6*	*C-7*	*C-8*	*C-9*	*C-10*	*C-11*
C-1	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1.2, 3)	(2, 3, 4)	(3, 4, 5)	(6, 7, 8)	(7, 8, 9)	(8, 9, 10)	(8, 9, 10)
C-2	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1.2, 3)	(2, 3, 4)	(4, 5, 6)	(4, 5, 6)	(7, 8, 9)	(8, 9, 10)	(8, 9, 10)
C-3	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1.2, 3)	(2, 3, 4)	(2, 3, 4)	(4, 5, 6)	(6, 7, 8)	(6, 7, 8)	(8, 9, 10)
C-4	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1.2, 3)	(2, 3, 4)	(3, 4, 5)	(5, 6, 7)	(6, 7, 8)	(7, 8, 9)
C-5	(0.333, 0.5, 1)	(0.333, 0.5, 1)	(0.333, 0.5, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(2, 3, 4)	(2, 3, 4)	(3, 4, 5)	(4, 5, 6)	(5, 6, 7)
C-6	(0.25, 0.333, 0.5)	(0.25, 0.333, 0.5)	(0.25, 0.333, 0.5)	(0.333, 0.5, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(2, 3, 4)	(2, 3, 4)	(2, 3, 4)	(2, 3, 4)
C-7	(0.2, 0.25, 0.333)	(0.167, 0.2, 0.25)	(0.25, 0.333, 0.5)	(0.25, 0.333, 0.5)	(0.25, 0.333, 0.5)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1.2, 3)	(2, 3, 4)	(2, 3, 4)
C-8	(0.125, 0.143, 0.167)	(0.167, 0.2, 0.25)	(0.167, 0.2, 0.25)	(0.2, 0.25, 0.333)	(0.25, 0.333, 0.5)	(0.25, 0.333, 0.5)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1.2, 3)	(2, 3, 4)
C-9	(0.111, 0.125, 0.143)	(0.111, 0.125, 0.143)	(0.125, 0.143, 0.167)	(0.14, 0.166, 0.2)	(0.2, 0.25, 0.333)	(0.25, 0.333, 0.5)	(0.333, 0.5, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)
C-10	(0.1, 0.111, 0.125)	(0.1, 0.111, 0.125)	(0.125, 0.149, 0.167)	(0.125, 0.143, 0.167)	(0.17, 0.2, 0.25)	(0.25, 0.333, 0.5)	(0.25, 0.333, 0.5)	(0.333, 0.5, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)
C-11	(0.1, 0.111, 0.125)	(0.1, 0.111, 0.125)	(0.1, 0.111, 0.125)	(0.11, 0.125, 0.14)	(0.14, 0.166, 0.2)	(0.2, 0.25, 0.333)	(0.25, 0.333, 0.5)	(0.25, 0.3, 0.5)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)

Table 8 Calculation of best non-fuzzy weight performance

Criterion	$\overline{\zeta}_{i1} \times \overline{\zeta}_{i2} \times \cdots \times \overline{\zeta}_{in}$	$\overline{\sigma}_i = \left[\overline{\zeta}_{i1} \times \overline{\zeta}_{i2} \times \cdots \times \overline{\zeta}_{in}\right]^{1/n}$ (fuzzy geom. mean)	$\varpi_i = \overline{\sigma}_i \times \left[\overline{\sigma}_1 + \overline{\sigma}_2 + \cdots + \overline{\sigma}_n\right]^{-1}$ *fuzzy weight*	*[(r – p) + (q – p)] / 3+ p NFW*	*Rank*
C-1	(16,128, 108,864, 432,000)	(2.415, 2.873, 3.257)	(0.132, 0.186, 0.255)	0.19117	1
C-2	(14,336, 97,200, 388,800)	(2.389, 2.844, 3.226)	(0.131, 0.184, 0.253)	0.189252	2
C-3	(4,608, 39,690, 184,320)	(2.155, 2.621, 3.014)	(0.118, 0.170, 0.236)	0.174638	3
C-4	(1,260, 8,064, 30,240)	(1.915, 2.267, 2.557)	(0.105, 0.147, 0.201)	0.150679	4
C-5	(8.888889, 135, 3,360)	(1.220, 1.563, 2.094)	(0.067, 0.101, 0.164)	0.110692	5
C-6	(0.125, 2, 40)	(0.828, 1.065, 1.399)	(0.045, 0.069, 0.110)	0.074642	6
C-7	(0.002083, 0.033333, 0.5)	(0.570, 0.734, 0.939)	(0.031, 0.048, 0.074)	0.050773	7
C-8	(8.68E-05, 0.00068, 0.010417)	(0.427, 0.515, 0.660)	(0.023, 0.033, 0.052)	0.036153	8
C-9	(3.67E-06, 1.55E-05, 0.000113)	(0.320, 0.365, 0.437)	(0.018, 0.024, 0.034)	0.025151	9
C-10	(5.43E-07, 2.8E-06, 2.71E-05)	(0.269, 0.312, 0.384)	(0.015, 0.020, 0.030)	0.021687	10
C-11	(1.98E-07, 7.94E-07, 4.65E-06)	(0.246, 0.279, 0.327)	(0.013, 0.018, 0.026)	0.019038	11
Sum			*(12.75294, 15.43757, 18.29449)*		

Table 9 Pair-wise comparison matrix after putting the BNP value

Criteria	*C-1*	*C-2*	*C-3*	*C-4*	*C-5*	*C-6*	*C-7*	*C-8*	*C-9*	*C-10*	*C-11*
C-1	0.191	0.189	0.175	0.151	0.221	0.224	0.203	0.253	0.201	0.195	0.171
C-2	0.191	0.189	0.175	0.151	0.221	0.224	0.254	0.181	0.201	0.195	0.171
C-3	0.191	0.189	0.175	0.151	0.221	0.224	0.152	0.181	0.176	0.152	0.171
C-4	0.191	0.189	0.175	0.151	0.111	0.149	0.152	0.145	0.151	0.152	0.152
C-5	0.096	0.095	0.087	0.151	0.111	0.075	0.152	0.108	0.101	0.108	0.114
C-6	0.064	0.063	0.058	0.075	0.111	0.075	0.051	0.108	0.075	0.065	0.076
C-7	0.048	0.038	0.058	0.050	0.037	0.075	0.051	0.036	0.050	0.065	0.057
C-8	0.027	0.038	0.035	0.038	0.037	0.025	0.051	0.036	0.025	0.043	0.057
C-9	0.024	0.024	0.025	0.025	0.028	0.025	0.025	0.036	0.025	0.022	0.019
C-10	0.021	0.021	0.025	0.022	0.022	0.025	0.017	0.018	0.025	0.022	0.019

4 Results and discussion

4.1 Calculation of criterion weight

The weights of the different criteria utilised in this ranking procedure were determined with the FAHP technique. Table 4 was used to construct the pair-wise comparison matrix according to the selected criteria to assess the sustainability of textile waste-water management. These 11 key criteria were arranged in a square matrix, as shown in Table 6, according to their relative importance values. These numbers were inserted in the matrix according to the experts' opinions and offline survey questionnaires. Then the prepared fuzzy numbers were incorporated in the pair-wise comparison matrix, as shown in Table 7.

According to equation (6), the fuzzy geometric means of all 11 key criteria were calculated, as shown in Table 8, and the respective fuzzy weights were calculated, as shown in Table 8, by using equation (7). The best NFW was calculated by using equation (8) to rank the key criteria in descending order. The criteria with larger NFW values were nominated as having significant impact, as compared with other criteria (Table 8). In the present study, labour input in the textile industry showed a maximum NFW value, thus clearly indicating that in any sector, including the textile sector, labour input significantly contributes to improving the quality of the product output and also aids in sustainability in textile manufacturing sectors.

After the NFW value was calculated with equation (8) row-wise, the NFW values were multiplied by the pair-wise comparison matrix (Table 4) column-wise, as shown in Table 9, to estimate the row sum and eigenvalue (row sum/NFW). Finally, the λ_{max} random index (R.I., Table 10) was used to calculate the C.R., as presented in Table 11. Saaty (1980) has suggested that a consistency index value less than 0.1 indicates data in line with the desired outcome and the consistency of the matrix. If the C.R. value was less than 0.1, the estimated value was accepted; otherwise, a new modified comparison matrix was used.

4.2 FTOPSIS for alternative ranking

Table 12 presents the linguistic fuzzy evaluation matrix filled with the help of the selected decision-maker during the survey. The defined fuzzy numbers were then incorporated in the fuzzy decision matrix for further analysis, as shown in Table 13. The fuzzy weighted evaluation matrix was calculated by multiplying the criterion weight with the fuzzy decision matrix by using equation (11) to determine the fuzzy positive ideal solution (φ^+) and fuzzy negative ideal solution (φ^-), as presented in Table 14. Finally, the closeness coefficient Ω_i and ranking of the alternative were calculated by using equation (15), and the alternatives were ranked by Ω_i value. The alternative having the highest Ω_i was denoted as rank one, and the rankings of the remaining alternatives were arranged accordingly, as shown in Table 15. In this study, biological and chemical treatment techniques were demonstrated to be effective in achieving sustainability in textile waste-water recycling.

Table 10 Values of the random index (R.I.) for problems ($m \leq 15$)

Matrix order	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
R.I.	0	0	0.52	0.90	1.12	1.25	1.35	1.42	1.46	1.49	1.52

Table 11 Results of the comparison matrix by using FAHP

Criterion	*Row sum*	*Calculation of eigenvalue*	*Fuzzy weight criteria*	*Best non-fuzzy weight (NFW)*	*λ_{max}, RI*	*Consistency ratio (CR)*
C-1	2.174942	11.37699025	(0.132, 0.186, 0.255)	0.19117	λ_{max} = 11.17943874	C.R. = 0.01180518
C-2	2.15341	11.37851351	(0.131, 0.184, 0.253)	0.189252	R.I. = 1.52 (Table 10)	
C-3	1.983339	11.35688039	(0.118, 0.170, 0.236)	0.174638		
C-4	1.717664	11.39950818	(0.105, 0.147, 0.201)	0.150679		
C-5	1.197588	10.81912228	(0.067, 0.101, 0.164)	0.110692		
C-6	0.82159	11.00714804	(0.045, 0.069, 0.110)	0.074642		
C-7	0.565024	11.12833325	(0.031, 0.048, 0.074)	0.050773		
C-8	0.412101	11.39891372	(0.023, 0.033, 0.052)	0.036153		
C-9	0.277583	11.03669386	(0.018, 0.024, 0.034)	0.025151		
C-10	0.236639	10.9117268	(0.015, 0.020, 0.030)	0.021687		
C-11	0.212469	11.15999586	(0.013, 0.018, 0.026)	0.019038		
Sum		122.9738262				
Avg. of eigenvalue = λ_{max}		*11.17943874*				

Table 12 Linguistic fuzzy evaluation matrix

Alternatives	*C-1*	*C-2*	*C-3*	*C-4*	*C-5*	*C-6*	*C-7*	*C-8*	*C-9*	*C-10*	*C-11*
P-1 (P + C)	M	H	H	H	L	H	L	M	VH	L	L
P-2 (P + B)	M	H	H	H	M	H	L	M	H	L	L
P-3 (B + C)	M	M	M	M	H	M	M	H	H	M	M
P-4 (P + C + B)	H	L	M	M	VH	L	H	VH	L	M	M

Table 13 Fuzzy decision matrix

Alternatives	*C-1*	*C-2*	*C-3*	*C-4*	*C-5*	*C-6*	*C-7*	*C-8*	*C-9*	*C-10*	*C-11*
P-1 (P + C)	(0.35, 0.5, 0.65)	(0.55, 0.7, 0.85)	(0.55, 0.7, 0.85)	(0.55, 0.7, 0.85)	(0.15, 0.3, 0.45)	(0.55, 0.7, 0.85)	(0.15, 0.3, 0.45)	(0.35, 0.5, 0.65)	(0.75, 0.9, 1)	(0.15, 0.3, 0.45)	(0.15, 0.3, 0.45)
P-2 (P + B)	(0.35, 0.5, 0.65)	(0.55, 0.7, 0.85)	(0.55, 0.7, 0.85)	(0.55, 0.7, 0.85)	(0.35, 0.5, 0.65)	(0.55, 0.7, 0.85)	(0.15, 0.3, 0.45)	(0.35, 0.5, 0.65)	(0.55, 0.7, 0.85)	(0.15, 0.3, 0.45)	(0.15, 0.3, 0.45)
P-3 (B + C)	(0.35, 0.5, 0.65)	(0.35, 0.5, 0.65)	(0.35, 0.5, 0.65)	(0.35, 0.5, 0.65)	(0.55, 0.7, 0.85)	(0.35, 0.5, 0.65)	(0.35, 0.5, 0.65)	(0.55, 0.7, 0.85)	(0.55, 0.7, 0.85)	(0.35, 0.5, 0.65)	(0.35, 0.5, 0.65)
P-4 (P + C + B)	(0.55, 0.7, 0.85)	(0.15, 0.3, 0.45)	(0.35, 0.5, 0.65)	(0.35, 0.5, 0.65)	(0.75, 0.9, 1)	(0.15, 0.3, 0.45)	(0.55, 0.7, 0.85)	(0.75, 0.9, 1)	(0.15, 0.3, 0.45)	(0.35, 0.5, 0.65)	(0.35, 0.5, 0.65)
Weight criteria	(0.132, 0.186, 0.255)	(0.131, 0.184, 0.253)	(0.118, 0.170, 0.236)	(0.105, 0.147, 0.201)	(0.067, 0.101, 0.164)	(0.045, 0.069, 0.110)	(0.031, 0.048, 0.074)	(0.023, 0.033, 0.052)	(0.018, 0.024, 0.034)	(0.015, 0.020, 0.030)	(0.013, 0.018, 0.026)

Table 14 Fuzzy weighted evaluation matrix

Alternatives	*C-1*	*C-2*	*C-3*	*C-4*	*C-5*	*C-6*	*C-7*	*C-8*	*C-9*	*C-10*	*C-11*
P-1 (P + C)	(0.046, 0.093, 0.166)	(0.072, 0.129, 0.215)	(0.065, 0.119, 0.201)	(0.058, 0.103, 0.170)	(0.010, 0.030, 0.074)	(0.025, 0.048, 0.093)	(0.005, 0.014, 0.033)	(0.008, 0.017, 0.034)	(0.013, 0.021, 0.034)	(0.002, 0.006, 0.014)	(0.002, 0.005, 0.012)
P-2 (P + B)	(0.046, 0.093, 0.166)	(0.072, 0.129, 0.215)	(0.065, 0.119, 0.201)	(0.058, 0.103, 0.170)	(0.023, 0.051, 0.107)	(0.025, 0.048, 0.093)	(0.005, 0.014, 0.033)	(0.008, 0.017, 0.034)	(0.010, 0.017, 0.029)	(0.002, 0.006, 0.014)]	(0.002, 0.005, 0.012)
P-3 (B + C)	(0.046, 0.093, 0.166)	(0.046, 0.092, 0.164)	(0.041, 0.085, 0.154)	(0.037, 0.073, 0.130)	(0.037, 0.071, 0.140)	(0.016, 0.034, 0.071)	(0.011, 0.024, 0.048)	(0.013, 0.023, 0.044)	(0.010, 0.017, 0.029)	(0.005, 0.010, 0.020)	(0.005, 0.009, 0.017)
P-4 (P + C + B)	(0.073, 0.130, 0.217)	(0.020, 0.055, 0.114)	(0.041, 0.085, 0.154)	(0.037, 0.073, 0.130)	(0.050, 0.091, 0.164)	(0.007, 0.021, 0.049)	(0.017, 0.033, 0.063)	(0.018, 0.030, 0.052)	(0.003, 0.007, 0.015)	(0.005, 0.010, 0.020)	(0.005, 0.009, 0.017)
φ^+	$\overline{D_1}^+ = (0, 0, 0)$	$\overline{D_2}^+ = (0, 0, 0)$	$\overline{D_3}^+ = (0, 0, 0)$	$\overline{D_4}^+ = (0, 0, 0)$	$\overline{D_5}^+ = (0, 0, 0)$	$\overline{D_6}^+ = (1, 1, 1)$	$\overline{D_7}^+ = (1, 1, 1)$	$\overline{D_8}^+ = (1, 1, 1)$	$\overline{D_9}^+ = (0, 0, 0)$	$\overline{D_{10}}^+ = (1, 1, 1)$	$\overline{D_{11}}^+ = (1, 1, 1)$
φ^-	$\overline{D_1}^- = (1, 1, 1)$	$\overline{D_2}^- = (1, 1, 1)$	$\overline{D_3}^- = (1, 1, 1)$	$\overline{D_4}^- = (1, 1, 1)$	$\overline{D_5}^- = (1, 1, 1)$	$\overline{D_6}^- = (0, 0, 0)$	$\overline{D_7}^- = (0, 0, 0)$	$\overline{D_8}^- = (0, 0, 0)$	$\overline{D_9}^- = (1, 1, 1)$	$\overline{D_{10}}^- = (0, 0, 0)$	$\overline{D_{11}}^- = (0, 0, 0)$

Table 15 Fuzzy closeness index and ranking of alternatives

Alternatives	Θ_i^+	Θ_i^-	Ω_i	*Ranking*
P-1 (P + C)	4.865185722	4.997476916	0.506707	3
P-2 (P + B)	4.86766177	4.964593144	0.504929	4
P-3 (B + C)	4.824375494	5.104061492	*0.514085*	*1*
P-4 (P + C + B)	4.828110105	5.091533658	0.513278	2

5 Conclusions

This study mainly focused on determining the significant crucial criteria for improving the sustainability of textile waste-water management and using simultaneous implementation of FAHP to identify the best suitable criteria. FAHP is an MCDM approach that can potentially benefit the textile manufacturing sectors by minimising waste utilisation. In the present study, labour input in the textile industry showed the maximum BNP value, thus indicating that in any sector, including the textile sector, labour input significantly contributes to improving the quality of the product output and simultaneously helps to achieve sustainability in the textile manufacturing sector. Similarly, implementation of FTOPSIS specifically for different treatment methodologies used in the textile processing industry indicated that biological and chemical treatment is the most suitable approach for better, more efficient methodology in textile manufacturing. According to the analysis, a combination of the above three treatments is recommended to be implemented in the textile sector for waste reduction. In the future, this study may be extended by using other decision-making models, such as VIKOR, PSI, COPRAS, and MOORA, to optimise the textile treatment process.

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