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Multi-attribute sustainability assessment of wastewater treatment technologies using combined fuzzy multi-criteria decision-making techniques

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ABSTRACT

Water, which is predicted to be one of the most critical resources for the near future, also plays a vital role in society's sustainable development. Wastewater treatment is a critical part of the circular water management system and offers various technological alternatives. Taking appropriate decision for the technology selection is, therefore, essential for a long-term perspective. A complex yet imperative process is the sustainable selection of the wastewater treatment process. This paper presents the use of multi-criteria decision-making (MCDM) in the sustainability assessment of wastewater treatment technologies that may be very relevant to the growing sector with many emerging options. A comparison of six wastewater treatment technologies based on four sustainability parameters using three MCDM techniques, namely FSWARA, FMOORA and FTOPSIS is presented in detail. FSWARA is used for weighting criteria and the other two for technology ranking. The detailed step-by-step comparison study is presented and the results were somewhat predictable for the study, and this confirms the reliability of the methodology. This paper's primary objective is to propose a well-defined increscent practice for making sustainable wastewater treatment decisions among state-of-the-art technologies.

1. Introduction

Globally, water demand is projected to increase significantly over the coming decades. In addition to the agricultural sector, which accounts for 70% of water abstractions worldwide, large increases in water demand for industry and energy production are predicted (Connor et al., 2017). The availability of water is inherently linked to quantity as well as quality, and accelerated demand is the result of ever-increasing urbanization and expansion of municipal water supply. This leads to an increasing demand and supply gap, which can certainly be filled with circular water management (CWM) (Fig. 1), part of which is the recycling or treatment of wastewater. Besides, excluding emissions from untreated wastewater discharges, wastewater utilities are responsible for 3%–7% of GHG emissions, which can be reduced by 74% with appropriate treatment technologies. (United et al., 2020). According to the United Nations World Water Development Report 2017, where high-income countries treat 70% of their wastewater generated, this figure is approximately 32% and 8% for middle-income and low-income countries (Connor et al., 2017). In India, as per CPCB BULLETIN VOL.-I, JULY 2016, updated on December 6, 2016 (CPCB, 2021), out of 61,754 MLD wastewater generation, only 22,963 MLD (37%) are treated. As such, sanitation and wastewater treatment (WWT) are essential for sustainable development and critical for maintaining healthy ecosystems and human health. For this reason, the United Nations also adopted "Access to clean water and sanitation for all" as a goal of sustainable development at the global level (SDG) ("GOAL 6, 2021).

Releasing untreated or insufficiently treated wastewater can have harmful effects on three main vertical sectors: human health, the environment and economic activities. Even if treatment technologies are technically superior, economically viable, and incorporated with appropriate safety measures, the possibility of failure remains due to poor accounting for social acceptance dynamics. Wastewater management is therefore of the utmost importance for sustainable development and the cycle can be broken down into four phases:

- Prevention or reduction of pollution at the source (Reduce)
- Wastewater collection and treatment (Recycle)
- Using wastewater as an alternative source of water (Reuse)
- The recovery of useful by-products (Recover).

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List of abbreviations

ASP	Activated Sludge Process
AT	Appropriate Technology
C&I	Criteria and Indicators
CCi	Closeness Coefficient of ith alternative
CPCB	Central Pollution Control Board
CWM	Circular Water Management
D_i^+	Euclidean distance of alternatives from FPIS
D_i^-	Euclidean distance of alternative from FNIS
DSS	Decision Support System
E	Economic Criteria
E1	Average Area
E2	Power Requirement
E3	O&M cost
E4	Capital Expenditure (CAPEX)
EN	Environmental Criteria
EN1	Biological oxygen demand (BOD)
EN2	Chemical oxygen demand (COD)
EN3	Suspended Solids (SS)
EN4	Dissolved Oxygen (DO)
EN5	Nitrate and Phosphate Removal
EN6	Faecal Coliform
F	Functional Criteria
F1	Operational Flexibility
F2	Process Reliability
F3	Ease of Operation
F4	Fat, Oil, and Grease Tolerance
F5	Waste Sludge Quantity
FAB	Fluidized Aerobic Bed Reactor
FMOORA	Fuzzy Multi-Objective Optimization by Ratio Analysis
FNIS (Z^-)	Fuzzy Negative Ideal Solution
FPIS (Z^{+})	Fuzzy Positive Ideal Solution
FSWARA	Fuzzy Stepwise Weighted Assessment Ratio Analysis
FTOPSIS	Fuzzy Technique for Order of Preference by Similarity to Ideal Solution
GHG	Greenhouse Gases
K_j	Coefficient value
kWh	Kilo-watt-hour
LCC	Life Cycle Costs
Lakh	1 lakh = 100,000
m	meter
MADM	Multi-attribute Decision Making
MBBR	Moving Bed Biofilm Reactor
MBR	Membrane Bio Reactor
MCDM	Multi-criteria decision making
MLD	Million Litres per Day
Q_j	Recalculated weight value
$\widetilde{R_{ij}}$	Fuzzy normalized value of the jth criteria
S_j	Fuzzy Relative Importance Scores
S	Social Criteria
S1	Odour Impact
S2	Noise Impact
S3	Visual Impact
SDG	Sustainable Development Goals
$\widetilde{V_{ij}}$	Weighted normalized fuzzy value of the jth criteria
w_j	Local Weights
W	Criteria Weights
WWTT	Wastewater Treatment Technology
$\widetilde{Yi}$	Fuzzy Performance Value

Wastewater Treatment (WWT) is the process of removing contaminants from sewage or used water to convert them into effluents that can be returned to the water cycle with an acceptable environmental impact. It generally consists of four levels of increasing complexity: (i) Preliminary treatment – consisting of grits, barracks or grinders for the treatment of coarse solids; (ii) primary treatment – used for the removal of sedimentary solids and organic matter by gravity: (iii) secondary treatment – facilitates the removal of remaining solids, particulate matter, coliforms, etc.; and (iv) tertiary treatment – where nutrients and other micropollutants are removed (Ullah et al., 2020). The secondary stage, consisting of biological and chemical methods, offers a wide range of decision-making options such as Activated Sludge process, Membrane Biological Reactors, Fluidized Bed Bioreactors, Facultative Ponds and many more. Traditionally, these settlements were made intuitively and were primarily based on economic and technical factors. However, social and environmental factors should also be included in the decision-making process on the long-term sustainability of treatment plants (Garrido-Baserba et al., 2014). For this reason, and the rapid advent of novel non-conventional technologies worldwide, the intuitive selection of technology can sometimes be unreliable and questionable. The concept of appropriate technology (AT) was introduced by the British economist E. F. Schumacher in his famous book Small Is Beautiful (Kalbar et al., 2012). Technology is considered thus "appropriate" to the extent that it is consistent with the cultural, social, economic, and political institutions of the society in which it is used. This approach is anthropogenic and this study only considered the social and economic pillars of it along with the functional and environmental impacts. Hence, the selection of appropriate WWTTs is a complex process, given the linked objectives and conflicting criteria (Arroyo and Molinos-senante, 2018). To overcome such situations, various decision support systems (DSS) have been developed over time, which adopted mainly different approaches (Ullah et al., 2020), (Mannina et al., 2019), including Multi-Criteria Decision Making (MCDM) is one of the prominent approaches to choose the best alternative amongst available options.

MCDM refers to multi-criteria decision-making, a set of methods that combine alternative decisions with quantitative and qualitative results in compact solutions (Bhole and Deshmukh, 2018). The discipline of Operations Research provides optimal solutions where decision-making involves multiple criteria (S et al., 2018).

The literature review discussed further illustrates MCDM and other decision-making tools and techniques incorporated in the WWT field, primarily technology-based selections and optimisations. In real-life decision-making scenarios, such as those involving WWT technologies, a high degree of vagueness and ambiguity is involved, depending on the decision maker's experience and expertise (Zhang and Ju, 2021). Several factors, such as unquantifiable and incomplete information, unobtainable information and partial ignorance, have caused imprecision in decision-making. Since conventional MADM methods cannot effectively address such imprecise information effectively, fuzzy multiple attribute decision-making methods have been developed (Kahraman et al., 2015), (Mavi et al., 2017). Fuzzification helps to achieve concrete results when accurate data accumulation is not possible due to lack of information or data uncertainties. Also, fuzzy logic can detect the tendency weight of the Standard Operating Procedure (SOP) deviation. Process Based Fraud (PBF) detection has better accuracy in fuzzy sets than in non-fuzzy. Out of all MCDM techniques, the survey shows that the Analytical Hierarchy Process (AHP) (Aziz et al., 2016) and TOPSIS are the most commonly used ones for the selection process involved in wastewater treatment for their simplicity, straightforwardness, and unbiased decision making. Additionally, these methods are well established and implemented to solve various energy-related technology evaluation problems.

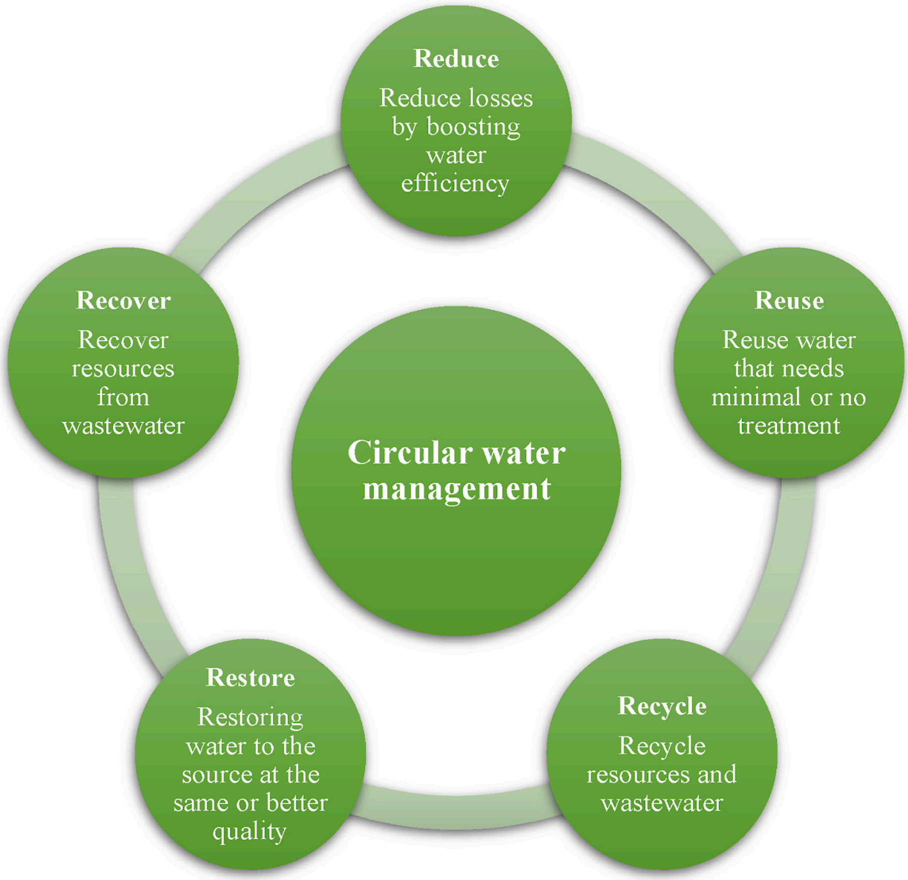

Fig. 1. Circular water management (United et al., 2020).

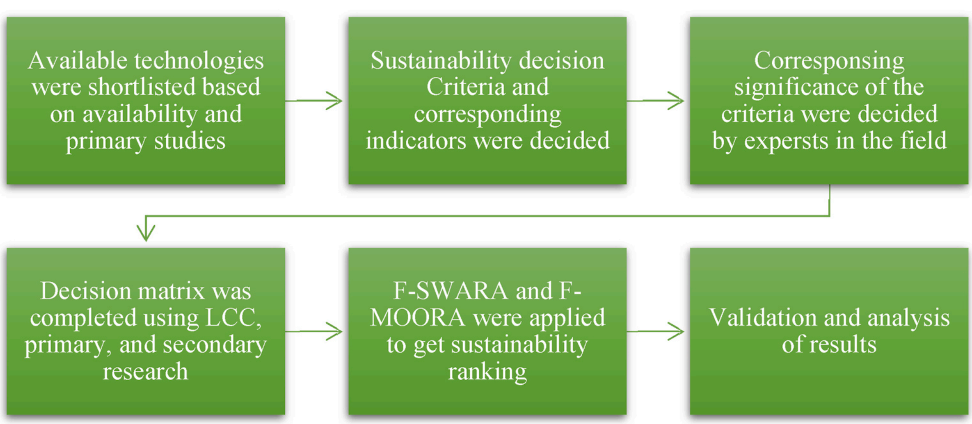

Fig. 2. Proposed stepwise methodology.

As discussed earlier, different decision support systems (DSS) have been used for WWTT selection. For instance, Ullah et al. (2020) developed a DSS to select WWTT depending on all levels of treatment. Turon et al. (2008) and Massoud et al. (2009) proposed an environmental decision support system (EDSS) for the purpose. Among the research on appropriate WWTT selection found in the literature, the most prominent tool is MCDM. MCDM is a cluster of techniques that explicitly evaluates multiple conflicting criteria while deciding to find the most optimal solution. These techniques, are however being used from the 1980s and many methods have been utilized since then to this multiobjective problem (Abu-Taleb, 1999; Tecle, 1986; Tecle et al., 1988). Many researchers utilized AHP/FAHP for weight calculations of criteria and sub-criteria (Zhang and Ju, 2021; Kamble et al., 2017; Karimi et al., 2011; Liu et al., 2020; Ouyang et al., 2015), whereas some (Arroyo and Molinos-senante, 2018), (Srdjevic et al., 2017) used the technique for selecting or comparing the results of the WWTT optimizations. Mooselu et al. proposed a leader-follower game theory to optimize allocation of treated wastewater (Ghorbani Mooselu et al., 2020). Other methods like decision-making trial and evaluation laboratory (DEMATEL) (Dursun, 2016) and SWARA (Khodadadi et al., 2017) are also used for weight calculations which are then coupled with other techniques for comparisons. Yahyaa et al. recently compared six WWTTs using fuzzy PROMETHEE incorporating triangular fuzzy scale and found out that Nano-filtration (NF) method is best suited for developed countries while

Table 1
Criteria and indicators.

Criteria	Indicators	Units/Scale	References	Type
Environmental Sustainability **(EN)**	EN1: BOD	% removal	(S et al., 2018), (Liu et al., 2020), (Nuhu et al., 2020), (Nuhu et al., 2019)	Benefit
	EN2: COD	% removal	(S et al., 2018), (Liu et al., 2020), (Ouyang et al., 2015)	Benefit
	EN3: SS	% removal	(S et al., 2018), (Liu et al., 2020), (V Sasirekha et al., 2013)	Benefit
	EN4: DO	mg/l in effluent	V Sasirekha et al. (2013)	Benefit
	EN5: Nitrate and phosphate removal	Yes/No	(S et al., 2018), (V Sasirekha et al., 2013)	Benefit
	EN6: Faecal coliform	log unit in effluent	Ouyang et al. (2015)	Cost
Economic Affordability **(E)**	E1: Average Area	m^2/MLD	(V Sasirekha et al., 2013), (Kamble et al., 2017), (Nuhu et al., 2019), (An et al., 2018)	Cost
	E2: Power Requirement	kWh/day	(V Sasirekha et al., 2013), (Nuhu et al., 2020), (Nuhu et al., 2019)	Cost
	E3: O&M costs	Lakh/year	(Zhang and Ju, 2021), (Liu et al., 2020), (V Sasirekha et al., 2013)	Cost
	E4: CAPEX	Lakh	(Zhang and Ju, 2021), (Liu et al., 2020), (V Sasirekha et al., 2013), (An et al., 2018)	Cost
Social Acceptability **(S)**	S1: Odour	Scored out of 10	(Zhang and Ju, 2021), (V Sasirekha et al., 2013)	Cost
	S2: Noise	Scored out of 10	Zhang and Ju (2021)	Cost
	S3: Visual	Scored out of 10	(Zhang and Ju, 2021), (V Sasirekha et al., 2013), (Nuhu et al., 2020)	Benefit
Functional Aspects **(F)**	F1: Operational Flexibility	Scale of 5 (Low-High)	(Kamble et al., 2017)	Benefit
	F2: Process reliability	Scale of 5 (Low-High)	(Zhang and Ju, 2021)' (Kamble et al., 2017)	Benefit
	F3: Ease of operation	Scale of 5 (Low-High)		Benefit
	F4: Fat, oil and grease tolerance	Scale of 5 (Low-High)		Benefit
	F5: Waste sludge Quantity	Scale of 5 (Low-High)	(Zhang and Ju, 2021), (Nuhu et al., 2020)	Cost

the Activated sludge (AS) process is recommended for developing countries (Nuhu et al., 2020). Picture fuzzy numbers (PFN) were utilized for fuzzification for AHP and the responses from experts were aggregated using evidence theory to select rural WWTT (Zhang and Ju, 2021). The study was based on economic, environmental, technical, and social criteria and Sequencing Batch Reactor (SBR) was determined as the optimal technology. Kalbar et al. compared four most commonly used WWTTs based on six distinct scenarios using seven criteria with twelve indicators, including sustainability and TOPSIS method was used for the comparison (Kalbar et al., 2012). It is evident from this study that scenarios, and thus the criteria weights play a vital role in the selection process. Kamble et al. used life cycle analysis (LCA) and fuzzy Delphi technique combined with fuzzy AHP-TOPSIS methodology for the selection of an appropriate municipal wastewater treatment technology (Kamble et al., 2017). Membrane bio-reactor (MBR) was ranked first followed by SBR and moving bed biofilm reactor (MBBR) based on twelve criteria. Further, TOPSIS/F-TOPSIS is utilized by other researchers as well for the technology selection (S et al., 2018), (Liu et al., 2020), (Karimi et al., 2011), (Srdjevic et al., 2017), (Dursun, 2016), (Nuhu et al., 2019). In a recent study, Ali et al. (2020) concluded the activated sludge (AS) process to be most suitable for WWT based on ten pre-defined criteria using the fuzzy VIKOR method. VIKOR technique was also used to rank WWT plants in Tehran, Iran. The results indicated that integrating an up-flow anaerobic fixed bed with an intergraded fixed-film activated sludge process could be used as the most appropriate treatment technology (Saghafi et al., 2019). Choosing by advantages (CBA) was used by Arroyo et al. to compare seven WWTT alternatives for their sustainability and the results were compared with those from AHP approach (Arroyo and Molinos-senante, 2018). The paper also showed the benefits of using the CBA approach to support the decision-making process when experts must reach a consensus on selecting the most appropriate WWT technology available; however, financial aspects have not been considered. For optimizing WWTT selection, three models were used by Ilangkumaran et al., i.e. FAHP-PROMETHEE, AHP-PROMETHEE, and FAHP-GRA; and SBR was ranked first by all the three (V Sasirekha et al., 2013). Among all the literature studied by far, MOORA method was not used by anyone for the specific purpose of WWTT selection. Nevertheless, it is apparent from the recent reviews (Akkaya et al., 2015; Mardani et al., 2015; Siksnelyte et al., 2018; Stojčić et al., 2019) and research papers (Arabsheybani et al., 2018; Keshavarz and Amiri, 2017; Mishra et al., 2020; Streimikiene et al., 2012; Zolfani and Saparauskas, 2020), that SWARA and MOORA/MULTIMOORA give promising results in the field of energy and sustainability decisions.

Here, a comparatively novel combined Fuzzy-SWARA, Fuzzy-MOORA and Fuzzy-TOPSIS methods are used to rank the alternatives for the advantages of these methods over others. The prominent characteristic of the SWARA methodology is its ability to evaluate decision maker's preferences regarding the significance of the attributes for weight determination. So, it helps gather and coordinate data from experts and considers problem priorities based on companies' policies (Hashemkhani Zolfani et al., 2018). MOORA method exhibits the following advantages (Aruldoss, 2013; Attri and Grover, 2014; Hafezalkotob et al., 2019; Siksnelyte et al., 2018): i) Consistency and reliability, ii) More tolerance to deviations iii) Easy adaptability to solve energy sustainability issues, and iv) Less complexity and more stability. Similarly, TOPSIS is a conventional, stable, and reliable ranking technique associated with minimum calculation time and sophistication. This method is also used broadly in problems related to energy sustainability. The combined fuzzy approach will allow decision-makers to make wiser and more reliable decisions wherever sustainable selection of technology is the matter of concern. The ranking results are compared with the F-TOPSIS method for validity and reliability of F-MOORA.

The scope of MCDM and sustainability is expanding at an incredible rate right now, prompting researchers to investigate and expand its application in new fields. This research is inspired by this, and novel hybrid methods are applied on both conventional and non-conventional technologies, something that has never been done before. Furthermore, even in the economic criteria, the environmental impacts of technologies are given prominent consideration. Aside from that, social criteria are regarded as an important component of sustainability, which many previous studies lacked. The paper is divided into three main sections (Sections 2–4). Section 2 defines the problem statement, which includes all the criteria, alternatives and techniques used thoroughly and

Table 2
Initial data collected for assessment.

Alternatives	Environmental Sustainability						Economic Affordability				Social Acceptability			Functional Aspects				
	EN1	EN2	EN3	EN4	EN5	EN6	E1	E2	E3	E4	S1	S2	S3	F1	F2	F3	F4	F5
	BOD %	COD %	SS %	DO, mg/l (Final Effluent)	Nitrate and phosphate removal	Fecal Coliform, Log unit	Average area (Sq. Mt/MLD)	Total Power Requirement (kWh)	Annual O&M Costs	Capex per MLD (in lakhs)	Odour Impact	Noise Impact	Visual Impact	Operational Flexibility	Process Reliability	Ease of operation	Fat, oil and grease tolerance	Waste sludge Quantity
ASP (A1) (Dai et al., 2016)	91.5	85	87.5	2	NO	3.5	1000	232.5	57.5	230	6.857	6.285	6.428	Moderate	High	High	Low	High
MBBR (A2) (di Biase et al., 2019)	90	85	90	2	NO	3	500	287.0	70	200	5.142	5	5.857	High	Moderate	Low	High	Moderate
SBR (A3) (Wilderer, 1998)	92.5	92	93	1.5	YES	3	300	254.5	122.5	350	6.285	6	5.142	High	Moderate	Moderate	High	Moderate
MBR (A4) (Melin et al., 2006)	96.5	97.5	99	2	YES	6.5	800	304.5	282	600	5.142	4.714	6.142	Low	Moderate	Low	Low	High
FAB (A5) (di Biase et al., 2019)	87.5	82.5	85	2	NO	3	600	133.0	58.3	220	5.428	5.571	5.714	High	Moderate	Moderate	Moderate	Moderate
BIOPIPE (A6) (Group et al., 2021)	96.5	94	96.5	3	YES	4	186	250.0	14.07	400	2.714	2.428	7.428	High	High	High	High	Low

Table 3
Weight calculation for main criteria by F-SWARA method.

Main Criteria	Comparative importance of average value sj			Kj = 1 + Sj			Qj = (Qj-1)/Kj			Wj = Qj/Σ(Qj)		
EN: Environmental				1.000	1.000	1.000	1.000	1.000	1.000	0.423	0.480	0.552
E: Economic	0.667	1.000	1.500	1.667	2.000	2.500	0.400	0.500	0.600	0.169	0.240	0.331
S: Social	0.400	0.500	0.667	1.400	1.500	1.667	0.240	0.333	0.429	0.102	0.160	0.237
F: Functional	0.286	0.333	0.400	1.286	1.333	1.400	0.171	0.250	0.333	0.073	0.120	0.184
							1.811	**2.083**	**2.362**			

Table 4
Weight calculation for Environmental factors (sub-criteria) by F-SWARA method.

Sub-criteria	Comparative importance of average value sj			Kj = 1 + Sj			Qj = (Qj-1)/Kj			Wj = Qj/Σ(Qj)			Final Weights		
EN1				1.000	1.000	1.000	1.000	1.000	1.000	0.487	0.505	0.522	0.206	0.243	0.288
EN2	1.000	1.000	1.000	2.000	2.000	2.000	0.500	0.500	0.500	0.243	0.253	0.261	0.103	0.121	0.144
EN3	1.000	1.000	1.000	2.000	2.000	2.000	0.250	0.250	0.250	0.122	0.126	0.131	0.052	0.061	0.072
EN4	0.667	1.000	1.500	1.667	2.000	2.500	0.100	0.125	0.150	0.049	0.063	0.078	0.021	0.030	0.043
EN5	0.667	1.000	1.500	1.667	2.000	2.500	0.040	0.063	0.090	0.019	0.032	0.047	0.008	0.015	0.026
EN6	0.400	0.500	0.667	1.400	1.500	1.667	0.024	0.042	0.064	0.012	0.021	0.034	0.005	0.010	0.019

Table 5
Weight calculation for Economic factors (sub-criteria) by F-SWARA method.

Sub-criteria	Comparative importance of average value sj			Kj = 1 + Sj			Qj = (Qj-1)/Kj			Wj = Qj/Σ(Qj)			Final Weights		
E1				1.000	1.000	1.000	1.000	1.000	1.000	0.428	0.486	0.561	0.073	0.117	0.186
E2	0.667	1.000	1.500	1.667	2.000	2.500	0.400	0.500	0.600	0.171	0.243	0.336	0.029	0.058	0.111
E3	0.400	0.500	0.667	1.400	1.500	1.667	0.240	0.333	0.429	0.103	0.162	0.240	0.017	0.039	0.080
E4				1.400	1.500	1.667	0.144	0.222	0.306	0.062	0.108	0.172	0.010	0.026	0.057

Table 6
Weight calculation for Social factors (sub-criteria) by F-SWARA method.

Sub-criteria	Comparative importance of average value sj			Kj = 1 + Sj			Qj = (Qj-1)/Kj			Wj = Qj/Σ (Qj)			Final Weights		
S1				1.000	1.000	1.000	1.000	1.000	1.000	0.484	0.533	0.593	0.049	0.085	0.140
S2	0.667	1.000	1.500	1.667	2.000	2.500	0.400	0.500	0.600	0.194	0.267	0.356	0.020	0.043	0.084
S3	0.286	0.333	0.400	1.286	1.333	1.400	0.286	0.375	0.467	0.138	0.200	0.277	0.014	0.032	0.065

Table 7
Weight calculation for Functional aspects (sub-criteria) by F-SWARA method.

Sub-criteria	Comparative importance of average value sj			Kj = 1 + Sj			Qj = (Qj-1)/Kj			Wj = Qj/Σ(Qj)			Final Weights		
F1				1.000	1.000	1.000	1.000	1.000	1.000	0.474	0.511	0.547	0.034	0.061	0.101
F2	1.000	1.000	1.000	2.000	2.000	2.000	0.500	0.500	0.500	0.237	0.255	0.274	0.017	0.031	0.050
F3	0.667	1.000	1.500	1.667	2.000	2.500	0.200	0.250	0.300	0.095	0.128	0.164	0.007	0.015	0.030
F4	0.667	1.000	1.500	1.667	2.000	2.500	0.080	0.125	0.180	0.038	0.064	0.098	0.003	0.008	0.018
F5	0.400	0.500	0.667	1.400	1.500	1.667	0.048	0.083	0.129	0.023	0.043	0.070	0.002	0.005	0.013

Table 8
Fuzzy scale for SWARA (Kayapinar Kaya and Erginel, 2020).

Linguistic Variables	Fuzzy Scale
Important	(1,1,1)
Moderately less Important	(2/3,1,3/2)
Less Important	(2/5,1/2,2/3)
Very less Important	(2/7,1/3,2/5)
Extremely less Important	(2/9,1/4,2/7)

presents the methodology used for the study in detail. Section 3 represents the results and discusses the sustainability ranks for the alternatives. Section 4 summarizes the key elements, gaps, findings, and main conclusions drawn from this work. At last, due acknowledgement to the experts is given for their valuable inputs and the references are listed.

2. Methodology

The methodology proposed was a 5-step process. Starting from the selection of technologies to be compared to the validation of both the process and the results, Fig. 2 describes the step-by-step procedure applied for this purpose. Details of the criteria and indicators (C&I) are discussed in more detail in the following sections.

This paper uses a combined MCDM approach to the sustainability assessment of various wastewater treatment technologies, namely A1-Activated Sludge Process (ASP), A2-Moving Bed Biofilm Reactor (MBBR), A3-Sequential Batch Reactor (SBR), A4-Membrane Bioreactor (MBR), A5-Fluidized Aerobic Bed Reactor (FAB) and A6-Biopipe. The selected main criteria and sub-criteria are given in Table 1, based on which the final assessment has been carried out. The proposed framework in this study could also be used for the comparison of various available industrial technologies on the market for helping the decision-maker. The data collected for the assessment is shown in Table 2.

Table 9
Fuzzy Initial decision matrix.

Sub-criteria	EN1			EN2			EN3			EN4			EN5			EN6			E1			E2			E3			E4		
Weights	0.206	0.243	0.288	0.103	0.121	0.144	0.052	0.061	0.072	0.021	0.030	0.043	0.008	0.015	0.026	0.005	0.010	0.019	0.073	0.117	0.186	0.029	0.058	0.111	0.017	0.039	0.080	0.010	0.026	0.057
A1	1.500	2.000	2.500	1.000	1.000	1.000	1.000	1.000	1.000	0.667	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	3.500	4.000	4.500	1.500	2.000	2.500	1.000	1.000	1.000	1.000	1.000	1.000
A2	0.667	1.000	1.500	1.000	1.000	1.000	0.667	1.000	1.500	0.667	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.667	1.000	1.500	3.500	4.000	4.500	0.667	1.000	1.500	1.000	1.000	1.000
A3	1.500	2.000	2.500	2.500	3.000	3.500	1.500	2.000	2.500	1.000	1.000	1.500	3.500	4.000	4.500	1.000	1.000	1.000	1.000	1.000	1.000	2.500	3.000	3.500	1.500	2.000	2.500	0.667	1.000	1.500
A4	3.500	4.000	4.500	3.500	4.000	4.500	3.500	4.000	4.500	0.667	1.000	4.500	3.500	4.000	4.500	3.500	4.000	4.500	2.500	3.000	3.500	3.500	4.000	4.500	3.500	4.000	4.500	3.500	4.000	4.500
A5	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.667	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.500	2.000	2.500	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
A6	3.500	4.000	4.500	2.500	3.000	3.500	3.500	4.000	4.500	3.500	4.000	2.500	3.500	4.000	4.500	0.667	1.000	1.500	1.000	1.000	1.000	2.500	3.000	3.500	1.000	1.000	1.000	1.500	2.000	2.500

Sub-criteria	S1			S2			S3			F1			F2			F3			F4			F5		
Weights	0.049	0.085	0.140	0.020	0.043	0.084	0.014	0.032	0.065	0.034	0.061	0.101	0.017	0.031	0.050	0.007	0.015	0.030	0.003	0.008	0.018	0.002	0.005	0.013
A1	2.500	3.000	3.500	2.500	3.000	3.500	2.500	3.000	3.500	1.500	2.000	2.500	2.500	3.000	3.500	2.500	3.000	3.500	0.667	1.000	1.500	2.500	3.000	3.500
A2	1.500	2.000	2.500	1.500	2.000	2.500	2.500	3.000	3.500	2.500	3.000	3.500	1.500	2.000	2.500	0.667	1.000	1.500	2.500	3.000	3.500	1.500	2.000	2.500
A3	2.500	3.000	3.500	2.500	3.000	3.500	1.500	2.000	2.500	2.500	3.000	3.500	1.500	2.000	2.500	1.500	2.000	2.500	2.500	3.000	3.500	1.500	2.000	2.500
A4	1.500	2.000	2.500	1.500	2.000	2.500	2.500	3.000	3.500	0.667	1.000	1.500	1.500	2.000	2.500	0.667	1.000	1.500	0.667	1.000	1.500	2.500	3.000	3.500
A5	1.500	2.000	2.500	1.500	2.000	2.500	1.500	2.000	2.500	2.500	3.000	3.500	1.500	2.000	2.500	1.500	2.000	2.500	1.500	2.000	2.500	1.500	2.000	2.500
A6	0.667	1.000	1.500	1.000	1.000	1.000	3.500	4.000	4.500	2.500	3.000	3.500	2.500	3.000	3.500	2.500	3.000	3.500	2.500	3.000	3.500	3.500	4.000	4.500

Table 10
Fuzzy scale of CHANG (Hashemkhani Zolfani et al., 2018).

Linguistic evaluation scale	Score	Fuzzy Scale
Very high	$\tilde{1}$	(1,1,1)
High	$\tilde{2}$	(2/3,1,3/2)
Medium	$\tilde{3}$	(3/2,2,5/2)
Low	$\tilde{4}$	(5/2,3,7/2)
Very Low	$\tilde{5}$	(7/2,4,9/2)

A comparative study involving these steps elaboratively has been discussed in the further sections. The goal is to aid the decision makers to seek and select the most reliable, sustainable and easy to maintain wastewater treatment technology among the available alternatives. An important point to note is that the study is based on pre-collected data from literature and results can significantly change based on the preferences of decision takers and decision environment involving the moment of decision, place or region, stakeholders and decision agents.

2.1. *Selection of C&I and alternatives*

It is critical to select the most relevant criteria and indicators for technology evaluation. Indicators should be equalized according to the decision maker's expectations. The indicators are cost and benefits indicators (Liu et al., 2020). Cost indicators, such as energy consumption, associated costs, etc., are those to be minimized and the benefit indicators, such as reliability, life span, etc., are those whose higher values are beneficial.

Sub-criteria or indicators are chosen for their availability and their impact on decision-making. Some indicators are significant and cannot, therefore, be excluded in any case. In this study, four pillars, namely environmental (EN), social (S), functional (F) and economic (E) criteria, were considered as the main criteria. The environmental pillar refers to the environmental impacts of any technology. In this study, for example, wastewater treatment had a positive impact on the environment by removing BOD, COD, and SS. As a result, indicators are chosen based on the parameters that have a direct impact on the environment. Similarly, the social and economic pillars refer to the criteria associated with the project's social impacts, acceptance, and finances. A sustainable technology must be financially viable and socially acceptable to users and all stakeholders, including the affected community. Profits can be used as benefit criteria (to be maximized) or costs can be used as cost criteria (to be minimized). This study employs the latter, as indicators such as area utilized, power requirements, operating and fixed costs are taken into account. Finally, functional criteria are technology-related performance functions that help make the decision more sustainable, such as flexibility, reliability, and ease of operation. These criteria include not only technical parameters, but also user experience and technology expectations. The details are further discussed and shown in Table 1, including the nature of the indicators.

2.1.1. *The alternatives*

The alternatives are shortlisted by the researchers based on the availability of the data and such that both conventional and unconventional technologies are included. This aided the authors to validate the results and verify the method in a more concrete way. In practice, however, the alternatives are chosen based on factors like financial limitations, availability, personal orientations of major stakeholders and many other local factors. Activated sludge process or ASP is the process of treating wastewater or sludge using aeration and a biological floc composed of bacteria and protozoa. The formation of flocculent sludge is dependent on the aerobic microbial growth under continuous aeration in wastewater, and the flocculent sludge can adsorb and oxidize organic compounds due to the zooglea(Dai et al., 2016). Membrane bioreactor (MBR) is ASP combined with a low pressure membrane separation process(Melin et al., 2006). The membrane configuration can be

Table 11
Weighted normalized decision matrix by F-MOORA method.

	EN1			EN2			EN3			EN4			EN5	
A1	0.0273	0.0428	0.0636	0.0097	0.0114	0.0136	0.0047	0.0056	0.0066	0.0017	0.0037	0.0053	0.0007	0.0012
A2	0.0121	0.0214	0.0381	0.0097	0.0114	0.0136	0.0031	0.0056	0.0099	0.0017	0.0037	0.0053	0.0007	0.0012
A3	0.0273	0.0428	0.0636	0.0243	0.0343	0.0476	0.0071	0.0111	0.0165	0.0025	0.0037	0.0079	0.0023	0.0049
A4	0.0636	0.0855	0.1144	0.0340	0.0457	0.0612	0.0165	0.0222	0.0297	0.0017	0.0037	0.0236	0.0023	0.0049
A5	0.0182	0.0214	0.0254	0.0097	0.0114	0.0136	0.0047	0.0056	0.0066	0.0017	0.0037	0.0053	0.0007	0.0012
A6	0.0636	0.0855	0.1144	0.0243	0.0343	0.0476	0.0165	0.0222	0.0297	0.0088	0.0147	0.0131	0.0023	0.0049

external circulation or submerged membranes. On the other hand, the moving bed biofilm reactors (MBBR) and the fluidized aerobic bed reactors (FAB) are mostly used for better removal of organic matter and nutrients(di Biase et al., 2019). MBBR utilizes floating plastic carriers in the aeration tank which increases the microorganisms to treat the wastewater. In FAB, the principle of bacteria growth is supported by air and specially designed eco-friendly media. The sequential batch reactors or SBR is a multi-level fill-and-draw activated sludge system and have similar unit processes to the ASP. Biopipe also uses bacteria to remove pollutants by engaging with them. Air is automatically vacuumed to allow aerobic bacteria to treat wastewater which then passes through a cartridge filter or equivalent and a UV filter to complete the treatment (Group et al., 2021). As Biopipe is still protected by a patent, its performance characteristics were judged by its users using ordinal scales, primarily and other parameters were taken from performance or specification sheets("Secretary Complex Water Test Report). The data was considered reliable to depict the application of the proposed methodology for the purpose and fuzzification further improved the dependability.

The first criteria, in terms of the environment, were measured using a set of six indicators (sub criteria), consisting of the removal of pollutants that are biological oxygen demand (BOD %), chemical oxygen dissolved (COD %) and suspended solids (SS %), nitrate and phosphate, and the amount of fecal coliform (log scale) and dissolved oxygen (DO) (mg/l) in the effluent. The appearance, noisiness, and visual impact of WWT plants were the three leading indicators for social criteria. These indicators were based on primary user experiences and industry input. Economic criteria included area required, operational and maintenance costs, and capital expenditures. The functional aspects finally emerged using operational flexibility, process reliability, simplicity, flexibility of operation, fat, oil and grease tolerance and waste sludge amount.

BOD- Biological oxygen demand; COD- Chemical oxygen demand; SS- Suspended solids; DO- Dissolved oxygen; MLD- Megaliters per day; kWh-kilowatt hour.

2.2. Weighing MCDM method: Fuzzy SWARA

Step-Wise Weight Assessment Ratio Analysis (SWARA) was introduced and applied by Keršulienė et al. (Ker š ulien ė et al., 2010) in 2010 to calculate the weights of the criteria. In this method, determining the relative weights of criteria occurs as follows (Authors, 2019), (Kayapinar Kaya and Erginel, 2020):

Step 1. Evaluation criteria are ranked according to their expected significance in descending order of their importance, i.e., the least significant criterion is assigned the last rank as shown in Table 3 for main criteria and Tables 4–7 for sub-criteria.

Step 2. Aggregated values of judgements are averaged: relative importance scores of the criteria and indicators are determined and the arithmetic mean of all the responses are taken. The fuzzy comparison scale shown in Table 8 (Zarbakhshnia et al., 2018) is used to convert the average scores to fuzzy numbers. These fuzzy number scores are represented by S_j.

Step 3. Coefficient K_j is then calculated as:

$$K_j = \begin{cases} \tilde{1} & j = 1 \\ S_j + \tilde{1} & j > 1 \end{cases} \tag{1}$$

Step 4. Next, we calculate recalculated weight values Q_j as:

$$Q_j = \begin{cases} \tilde{1} & j = 1 \\ \dfrac{Q_{j-1}}{k_j} & j > 1 \end{cases} \tag{2}$$

Step 5. Respective weights of criteria (W_j) and local weights of indicators (w_j) are calculated whose sum is always equal to 1 as:

$$W_j = \frac{Q_j}{\sum_{k=1}^{n} Q_k} \tag{3}$$

For indicators/sub-criteria, final weights (W_j) are calculated by multiplying local weights with the weights of corresponding criteria calculated in step 5. The final weights would be $\boldsymbol{W_j}$. Where, $\boldsymbol{W_j} = (\boldsymbol{l_j}, \boldsymbol{m_j}, \boldsymbol{u_j})$ is the fuzzy weight of jth indicator and 'n' is the total number of indicators. The coefficient K_j, recalculated weights, and final weights for the main criteria are given in Table 3 and for sub-criteria, it is given in Tables 4–7

2.3. Ranking MCDM method: Fuzzy MOORA

MULTI-OBJECTIVE OPTIMIZATION BY RATIO ANALYSIS (MOORA) was introduced and implemented by Brauers and Zavadskas (2006) in "Control and Cybernetics" in 2006. According to them, MOORA refers to a ratio system in which each response of an alternative on an objective is compared to a denominator, representing all alternatives concerning that objective. This denominator is the best when square root of sum of squares of each alternative per objective is chosen (Brauers et al., 2008). This is also called vector normalization.

The following steps describe the ranking methodology using F-MOORA method (Akkaya et al., 2015):

Step 6. Decision matrix is formed using fuzzy numbers (refer Table 10) shown in Table 9.

$$A = \begin{bmatrix} (L_{11}, M_{11}, U_{11}) & \cdots & (L_{1n}, M_{1n}, U_{1n}) \\ \vdots & \ddots & \vdots \\ (L_{m1}, M_{m1}, U_{m1}) & \cdots & (L_{mn}, M_{mn}, U_{mn}) \end{bmatrix}$$

where, 'm' is the number of alternatives and 'n' is the total number of indicators.

Step 7. Normalization is done to form all entries free of units. This is done to facilitate proper comparison among criteria. The normalized entities would be calculated as:

$$\widetilde{R_{ij}} = \left(r_{ij}^{l^*}, r_{ij}^{m^*}, r_{ij}^{u^*}\right) \forall \ \text{i}, \ \text{j};$$

EN5	EN6			E1			E2			E3			E4		
0.0021	0.0006	0.0013	0.0023	0.0256	0.0471	0.0843	0.0034	0.0090	0.0215	0.0020	0.0045	0.0093	0.0012	0.0030	0.0066
0.0021	0.0006	0.0013	0.0023	0.0049	0.0118	0.0281	0.0078	0.0180	0.0387	0.0014	0.0045	0.0139	0.0012	0.0030	0.0066
0.0094	0.0006	0.0013	0.0023	0.0073	0.0118	0.0187	0.0056	0.0135	0.0301	0.0030	0.0091	0.0232	0.0008	0.0030	0.0099
0.0094	0.0022	0.0050	0.0104	0.0183	0.0353	0.0656	0.0078	0.0180	0.0387	0.0071	0.0181	0.0417	0.0043	0.0121	0.0298
0.0021	0.0006	0.0013	0.0023	0.0110	0.0236	0.0468	0.0022	0.0045	0.0086	0.0020	0.0045	0.0093	0.0012	0.0030	0.0066
0.0094	0.0004	0.0013	0.0035	0.0073	0.0118	0.0187	0.0056	0.0135	0.0301	0.0020	0.0045	0.0093	0.0018	0.0060	0.0166

$$r_{ij}^{l^*} = \frac{x_{ij}^l}{\sqrt{\sum_{i=1}^m \left(r_{ij}^l\right)^2 + \left(r_{ij}^m\right)^2 + \left(r_{ij}^u\right)^2}} \quad (4)$$

$$r_{ij}^{m^*} = \frac{x_{ij}^m}{\sqrt{\sum_{i=1}^m \left(r_{ij}^l\right)^2 + \left(r_{ij}^m\right)^2 + \left(r_{ij}^u\right)^2}} \quad (5)$$

$$r_{ij}^{u^*} = \frac{x_{ij}^u}{\sqrt{\sum_{i=1}^m \left(r_{ij}^l\right)^2 + \left(r_{ij}^m\right)^2 + \left(r_{ij}^u\right)^2}} \quad (6)$$

Step 8. Subsequently, the weightages calculated by F-SWARA method need to be incorporated by multiplying them with the respective normalized indicator values like:

$$\widetilde{V_{ij}} = \left(v_{ij}^{l^*}, v_{ij}^{m^*}, v_{ij}^{u^*}\right) \forall \text{i}, \ \text{j};$$

$$v_{ij}^l = r_{ij}^{l} * l_j \quad (7)$$

$$v_{ij}^m = r_{ij}^{m} * m_j \quad (8)$$

$$v_{ij}^n = r_{ij}^{n} * u_j \quad (9)$$

where, (l_j, m_j, u_j) is the weight of jth indicator. The weighted normalized matrix is shown in Table 11.

Step 9. The fuzzy performance values of the alternatives are then calculated by adding the beneficial criteria and subtracting the non-beneficial (Cost) criteria as shown below.

$$\widetilde{Y}_i = \left(y_i^l, y_i^m, y_i^u\right) \text{ and } \widetilde{Y}_i = \sum_{j=1}^{g} \check{v}_{ij} - \sum_{j=g+1}^{n} \check{v}_{ij} \quad (10)$$

where $\sum_{j=1}^{g} \check{v}_{ij} = \textit{Sum of beneficial criteria}$ and. $\sum_{j=g+1}^{n} \check{v}_{ij} = \textit{Sum of non-beneficial criteria}$

Step 10. Final step is to convert the fuzzy performance values of the alternatives into non-fuzzy (Best non-fuzzy performance/BNP (Akkaya et al., 2015)) numbers as:

$$Y_i = \frac{y_i^l + y_i^m + y_i^u}{3} \quad (11)$$

The final BNP values are ranked in descending order and corresponding alternatives get the final ranks for their evaluation and shown in Table 12.

2.4. Fuzzy TOPSIS

Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) is a conventional method for ranking alternatives which is predominantly based on the principle of choosing the alternative which has the shortest distance from the positive ideal solution and the longest from the negative ideal (Cavallaro, 2010a). The best intended criteria, that is, maximization of benefit criteria and minimization of cost criteria, are referred to as positive ideals. Negative ideal, on the other hand, is the polar opposite of what is appropriate and includes the minimization of benefit criteria and vice versa. This means that the positive ideal will have the highest value of benefit criteria and the lowest value of cost criteria, while the negative ideal will have the opposite. This method was developed by Hwang and Yoon in 1981 (Hwang and Yoon, 1981). Fuzzy TOPSIS used here is used to improve the robustness of the decision-making process by fuzzification of data. Several fuzzy TOPSIS applications have been developed recently (Kamble et al., 2017; Karimi et al., 2011; Cavallaro, 2010b; Solangi et al., 2019; Sasikumar and Ayyappan, 2019. This section describes the step-by-step evaluation method for the same.

Step 11. Fuzzy decision matrix remains the same as used in the F-MOORA method that is shown in Table 9.

Step 12. To find the normalized matrix and weighted normalized matrix (as in the case of F-MOORA). Table 11 shows the weighted normalized decision matrix for F-TOPSIS as well.

Step 13. Determination of Fuzzy positive ideal solution (FPIS) (Z^+) and fuzzy negative ideal solution (FNIS) (Z^-).

$$Z^+ = \left(\widetilde{z}_1^+, \widetilde{z}_2^+, \widetilde{z}_3^+, \ldots, \widetilde{z}_n^+\right) \ ; \ Z^- = \left(\widetilde{z}_1^-, \widetilde{z}_2^+, \widetilde{z}_3^-, \ldots, \widetilde{z}_n^-\right) \quad (12)$$

$$\widetilde{Z}_{\widetilde{Z}}^{+} = \left(\widetilde{zz}_{aj}^{+}, \widetilde{zz}_{bj}^{+}, \widetilde{zz}_{cj}^{+}\right) \ ; \ \widetilde{ZZ}_1^{-} = \left(\widetilde{zz}_{aj}^{-}, \widetilde{zz}_{bj}^{+}, \widetilde{zz}_{cj}^{-}\right) \quad (13)$$

$$z_{aj}^+ = max_i\{z_{aij}\} \ , \ z_{bj}^+ = max_i\{z_{bij}\}, \ z_{cj}^+ \ max_i\{z_{cij}\} \quad (14)$$

$$z_{aj}^1 = min_i\{z_{aij}\} \ , \ z_{bj}^- = min_i\{z_{bij}\}, \ z_{cj}^- = min_i\{z_{cij}\} \quad (15)$$

where $(z_{aij}, z_{bij}, z_{cij})$ are the fuzzy numbers a, b, and c of the fuzzy element Z_{ij}.

Step 14. Calculation of distance of each alternative from FPIS and FNIS. For the ith alternative, positive distance and negative distance are

Table 12
Final assessment values and rank for alternatives given by F-MOORA method.

Alternatives	Performance Values Yi			Combined Yi	Ranks
A1	0.011921907	0.005523765	−0.014889947	0.000851908	6
A2	0.017827465	0.02030312	0.013917436	0.01734934	5
A3	0.046959334	0.06411259	0.078948039	0.063339988	3
A4	0.078613709	0.076186109	0.064149121	0.07298298	2
A5	0.023501914	0.020372418	0.010122886	0.017999073	4
A6	0.112775485	0.15682885	0.199458586	0.156354307	1

Table 13
Distances of alternative from FPIS.

Alternatives	EN1	EN2	EN3	EN4	EN5	EN6	E1	E2	E3	E4	S1	S2	S3	F1	F2	F3	F4	F5
A1	0.0437	0.0367	0.0178	0.0130	0.0048	0.0001	0.0446	0.0079	0.0004	0.0002	0.0201	0.0135	0.0034	0.0063	0.0000	0.0000	0.0023	0.0007
A2	0.0648	0.0367	0.0168	0.0130	0.0048	0.0001	0.0054	0.0193	0.0027	0.0002	0.0100	0.0079	0.0034	0.0000	0.0035	0.0043	0.0000	0.0000
A3	0.0437	0.0117	0.0114	0.0117	0.0000	0.0001	0.0014	0.0136	0.0085	0.0019	0.0201	0.0135	0.0069	0.0000	0.0035	0.0021	0.0000	0.0000
A4	0.0000	0.0000	0.0000	0.0076	0.0000	0.0053	0.0312	0.0193	0.0206	0.0145	0.0100	0.0079	0.0034	0.0125	0.0035	0.0043	0.0023	0.0007
A5	0.0685	0.0367	0.0178	0.0130	0.0048	0.0001	0.0179	0.0000	0.0004	0.0002	0.0100	0.0079	0.0069	0.0000	0.0035	0.0021	0.0011	0.0000
A6	0.0000	0.0117	0.0000	0.0061	0.0000	0.0007	0.0014	0.0136	0.0004	0.0060	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0014

Table 14
Distances of alternative from FNIS.

Alternatives	EN1	EN2	EN3	EN4	EN5	EN6	E1	E2	E3	E4	S1	S2	S3	F1	F2	F3	F4	F5
A1	0.0267	0.0000	0.0009	0.0000	0.0000	0.0052	0.0000	0.0115	0.0205	0.0145	0.0000	0.0000	0.0034	0.0062	0.0035	0.0043	0.0000	0.0007
A2	0.0073	0.0000	0.0019	0.0000	0.0000	0.0052	0.0402	0.0000	0.0182	0.0145	0.0101	0.0057	0.0034	0.0125	0.0000	0.0000	0.0023	0.0014
A3	0.0267	0.0251	0.0069	0.0016	0.0048	0.0052	0.0443	0.0058	0.0121	0.0128	0.0000	0.0000	0.0000	0.0125	0.0000	0.0021	0.0023	0.0014
A4	0.0700	0.0367	0.0182	0.0106	0.0048	0.0000	0.0135	0.0000	0.0000	0.0000	0.0101	0.0057	0.0034	0.0000	0.0000	0.0000	0.0000	0.0007
A5	0.0035	0.0000	0.0009	0.0000	0.0000	0.0052	0.0269	0.0193	0.0205	0.0145	0.0101	0.0057	0.0000	0.0125	0.0000	0.0021	0.0011	0.0014
A6	0.0700	0.0251	0.0182	0.0088	0.0048	0.0047	0.0443	0.0058	0.0205	0.0085	0.0201	0.0135	0.0069	0.0125	0.0035	0.0043	0.0023	0.0000

Table 15
Closeness coefficient value and ranks for alternative given by F-TOPSIS.

Alternatives	Di+	Di-	Cci	Ranks
A1	0.21562876	0.097428032	0.3112152	**6**
A2	0.192885051	0.122685714	0.388774017	**5**
A3	0.150045007	0.163641097	0.521671489	**3**
A4	0.143005119	0.173581968	0.54829137	**2**
A5	0.191008279	0.123839139	0.393330648	**4**
A6	0.04122048	0.273620247	0.869075133	**1**

Table 16
Comparison between assessment values and rank by F-MOORA and F-TOPSIS.

Alternatives	F-MOORA		F-TOPSIS	
	Performance value (Yi)	Rank	Closeness coefficient (Cci)	Ranks
ASP (A1)	0.0008519	6	0.3112152	6
MBBR (A2)	0.0173493	5	0.38877401	5
SBR (A3)	0.0633399	3	0.52167148	3
MBR (A4)	0.0729829	2	0.54829137	2
FAB (A5)	0.0179990	4	0.39333064	4
BIOPIPE (A6)	0.1563543	1	0.86907513	1

calculated as:

$$d_i^+ = \sum_{j=1}^{n} d\left(\tilde{z}_{ij}, \tilde{z}_j^+\right), \; d_i^- = \sum_{j=1}^{n} d\left(\tilde{z}_{ij}, \tilde{z}_j^-\right) \tag{16}$$

$$d\left(\tilde{z}_{ij}, \tilde{z}_j^+\right) = \sqrt{\frac{1}{3}\left[\left(z_{aij} - z_{aj}^+\right)^2 + \left(z_{bij} - z_{bj}^+\right)^2 + \left(z_{cij} - z_{cj}^+\right)^2\right]} \tag{17}$$

$$d\left(\tilde{z}_{ij}, \tilde{z}_j^-\right) = \sqrt{\frac{1}{3}\left[\left(z_{aij} - z_{aj}^-\right)^2 + \left(z_{bij} - z_{bj}^-\right)^2 + \left(z_{cij} - z_{cj}^-\right)^2\right]} \tag{18}$$

Table 13 and Table 14 show the distances of alternative from FPIS and FNIS, respectively.

Step 15. Relative closeness coefficient (Table 15).

The most appropriate alternative must be closest to the FPIS and farthest from FNIS. So, the closeness coefficient (CC) for the same purpose is calculated as-

$$CC_i = \frac{d_i^-}{d_i^- + d_i^+} \tag{19}$$

where, CC_i is the relative CC of the i^{th} technology and higher value of CC corresponds to more conformation to the expectation.

3. Results and discussions

3.1. Sustainability of WWT technologies

As explained in Section 3, a panel of 6 experts were consulted for the significance of the decision-making criteria. Data were collected utilizing a literature survey and LCC analysis for some indicators from well-established databases, and the values were validated and verified by various field experts such as consultants. For other social and functional criteria and sub-criteria, questionnaires and interviews, which were majorly based on ordinal ranking scales with field professionals from academics and industry were used. The criteria weightage were determined by F-SWARA and followed by the ranking implementing F-MOORA and F-TOPSIS for the validation of the results.

As the study was carried out to evaluate the sustainability of technologies, environmental sustainability was given the utmost importance, followed by economic affordability. For the same reason, the "area used" was ranked first among the cost criteria, as it also significantly affected other criteria such as social and environmental criteria. After that, electricity consumption was given importance for its indirect relation to carbon emissions, resource utilization, and environmental impact. In the same way, odour impact and operational flexibility have been given the highest rankings in social and functional criteria.

According to the ranking results (see Table 16), the only non-conventional alternative chosen for the study, Biopipe (A6) proved to be the most sustainable wastewater treatment technology. This is consistent because Biopipe is associated with high levels of contaminant removal, low footprint, no odour and sludge production, and adequate functional performance. These highly weighted sustainability indicators overpower others to make them the most sustainable technology of all. Talking about conventional technologies, MBR and SBR ranked with little difference between their BNP numbers and this result matched a lot of research that had already been done and verified. MBR's sustainability has been supported by its best waste disposal capabilities and decent social and functional aspects. However, SBR had much better economic parameters than MBR. Finally, ASP, being one of the most

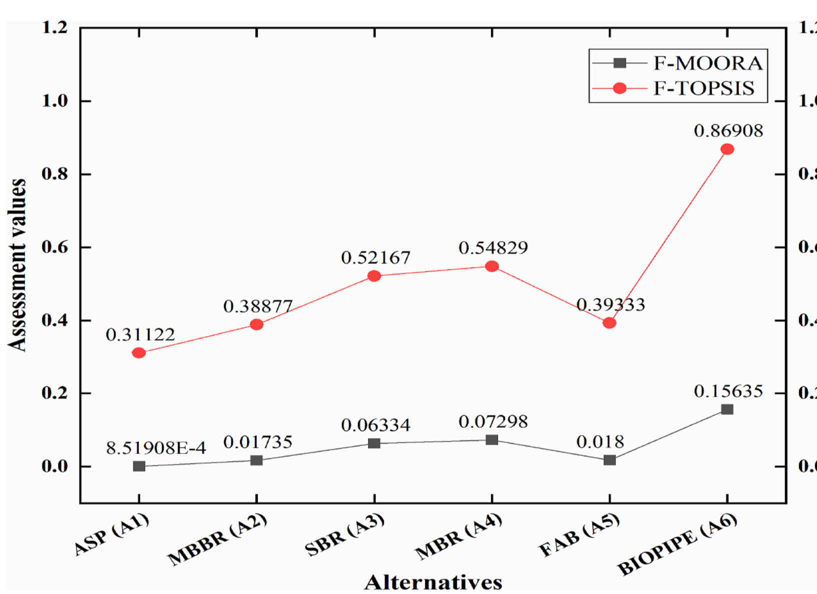

Fig. 3. Assessment values by F-MOORA and F-WASPAS.

traditional methods, was ranked last in terms of sustainability due to its higher costs, in particular, the highest footprint and relatively mediocre reduction rates for environmental criteria. The same results were also obtained by using the F-TOPSIS method, which, as discussed above, is a widely used methodology for technology comparison. The result, including the performance value, the proximity indices and the alternative rankings, are also shown in Table 16, which is a comparison between F-MOORA and F-TOPSIS (shown in Fig. 3).

4. Conclusions

This paper focuses on decision-making for sustainable WWTT concerning suit criteria (environmental, social, economic, and functional). More specifically, this paper demonstrated a methodology for multi-criteria decision-making tools for selecting appropriate WWT technology. The fuzzy SWARA-MOORA method is used for water management and the paper provides a detailed description of the procedure for its application. This approach offers a number of advantages to the decision-makers, such as fairness, transparency, reliability and simplicity. These are linked to the inclusion of cardinal and ordinal data collection and the reliable methodological mathematical procedure. Our study assessed six alternatives to WWT, primarily for secondary treatment, using four criteria and eighteen indicators. Data collection was supported by both primary and secondary research and analysis, including a life-cycle cost analysis of technologies. The inclusion of experts in the procedural manoeuvres has added to the reliability of the results. Biopipe was ranked as the most sustainable alternative by both MOORA and TOPSIS, followed by the membrane bioreactor (MBR) and the sequential batch reactor (SBR), respectively. These findings are based on data gathered through both primary and secondary research, as previously discussed, and are only indicative of how the methodology can be effectively used as a decision support system in such scenarios. However, these rakings can vary significantly depending on changes in performance parameters, the decision environment, or the preferences of the decision makers.

From a policy point of view, three significant inferences can be drawn from the analysis. First of all, it is necessary to choose the appropriate MCDM technique and to select indicators according to the preferences of the organisations. Secondly, expert team members have a vital role in the process, making them quite sensitive to their individual opinions. The involvement of the right personnel and an adequate number of experts from a variety of backgrounds is imperative. Thirdly, the SWARA-MOORA methodology is reliable and straightforward, and fuzzification further improves the stability of the results.

CRediT authorship contribution statement

Shubham Dutt Attri: Conceptualization, Formal analysis, Visualization, Writing – original draft. **Shweta Singh:** Investigation, Formal analysis, Writing – original draft. **Atul Dhar:** Conceptualization, Methodology, Writing – review & editing, Supervision. **Satvasheel Powar:** Conceptualization, Methodology, Validation, Resources, Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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