e-ISSN No.: 2582-4228

Journal of Indian Association for Environmental Management

Journal homepage: www.http://op.niscair.res.in/index/php/JIAEM/index

Evaluation of Treated Wastewater Reuse Alternatives using Fuzzy – Multi-criteria Decision Making Techniques

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Submitted: April 29, 2020 Revised: May 23, 2021 Accepted: May 25, 2021

Abstract: India is second country after China in which untreated wastewater is largely used to fulfil various water demands. Such practice results in ecological deterioration. This study initiates encouragement of treated wastewater reuse in Aurangabad city by giving best possible reuse alternatives using fuzzy logic. It can help to reduce pollutant loading into nearby streams, widen the range of water availability and accessibility. The ambiguity related to the reuse patterns is defined by Triangular Fuzzy Numbers (TFN). The alternatives Urban reuse, Industrial reuse and Environmental and Recreational reuse are evaluated on the basis of 6 criterions; namely as Quality of reclaimed i.e. treated wastewater, Production /treatment Cost, Demand, Water tariff, Social acceptance and Reliable source. The alternatives assessment is performed with the help of Multi Criteria Decision Making (MCDM) techniques i.e. Fuzzy Analytic Hierarchy Process (F-AHP) for estimation of weights and Fuzzy Technique for Order Preference by Similarity to Ideal Situation (F-TOPSIS) for aggregation outcome. The F-AHP gave the results by pair wise comparison and the F-TOPSIS results were computed to give the order of preference of the best alternative.

Keywords: *Treated wastewater (TWW), reuse alternatives, fuzzy analytical hierarchy process (F-AHP), fuzzy Technique for Order Preference by Similarity to Ideal Solution (F-TOPSIS), Multi criteria decision making (MCDM).*

I. Introduction

Water is bliss to the mankind only if it is available in abundance. Water is present on mother earth since its evolution. Amongst which lesser amount is useful to the mankind. Despite knowing this fact, humans have always exploited this blessing of nature. The Human nature realizes the importance only in the scarce situation. The stress on the existing water supplies due to water scarcity, draught, water pollution like problems has drawn attention towards the need of an option to water source.

The National Water Policy (2012) stated that the rise in water demands due to economic development, emergent population, rapid urbanization and brisk industrialization enlarged the need of utilizable water due to limited water accessibility [1].

Worldwide Alternatives of Fresh Water

Water is very much valued asset of every country as every well-being is dependent on it. Therefore Some Middle Eastern countries and waterless parts of USA, Mexico, Spain and Namibia have chosen the recycled wastewater to complete their water thirst. In various countries agricultural, industrial and commercial applications has been practiced with treated wastewater reuse (Manual on sewerage and sewage treatment systems, 2013). The extensive initiatives are taken to minimize the water scarcity problems and the wastewater recycling projects were promoted to mitigate the adverse environmental and ecological impacts.

Since 1970s, Israel practicing water reuse for irrigation and now treated wastewater has been essential part of water wealth of the country by reusing more than 70% of the sewage. Australia preferred the treated wastewater reuse in agriculture to combat with the unpredictable natural challenges such as floods and droughts. To surpass the challenge of freshwater availability and demand- supply gap of water various states of USA adopted recycling and reuse strategy. Arizona, California, Florida and Texas; these four states of USA reuse almost 90% of recycled water. California uses largest recycled water for agriculture and natural systems reuse purpose whereas urban reuse consumes more percentage of recycled water in Florida. Both the states uses reclaimed (recycled) water for industrial reuse and ground water recharge. Singapore, a water deficient state is inclined towards making it a self-sufficient by the NEWater recycling and reuse program. NEWater i.e. reclaimed water is one of the four main tap waters including water imports from Malaysia, desalination and rainfall.

Reuse of TWW: need of the hour

Recycling and reuse of treated wastewater is helpful step towards improving environment quality and to cope with increasing water demands affected by over population and water shortages. The substantial benefit of reusing treated wastewater is to make it an alternate, reliable source of water which is cheaper as compared to the cost of producing equal quantity of fresh water. The guidelines for water reuse 2012 discussed various countries using treated and untreated wastewater to fulfil their water necessities by applications through treatment, recycling and reuse. But this study concentrates on the treated wastewater reuse as it is sustainable alternative of water for the society. The article 9.3.4 of USEPA 2012 described the benefits of water reuse which says- water reuse is most convenient and environmentally sound alternative. The benefit of water reuse is decrease in treated or untreated wastewater release into the streams resulting in minimal environmental pollution. Through water reuse, reclaimed water can be continuous source, even during draught periods as it is produced where people live. This can nullify the search of tapping new water sources.

Benefits of water reuse given by the Reuse of Treated Wastewater Guidance Manual, Department of Environmental Protection: Reuse helps to diminish contaminant loading to surface waters. It reduces load on precious ground water supplies used for essential purposes like drinking water and irrigation. Reuse may adjourn costly development investment of new water sources and supplies and allows numerous uses of treated water along with providing aesthetic value.

Indian Outline of Water Reuse

The USEPA 2012 report shows that many countries including India have cultivated greatest area through untreated and diluted wastewater. India is the second country after china which irrigates larger area with untreated wastewater i.e. greater than 1 million hectare [2]. This is due to rapid population increase which results in the greater wastewater generation and lacking in subsequent wastewater treatment facility. Thus much of the wastewater remains untreated and used by small –scale farmers and other consumers compromising with the quality of water. There is a need to address the inadequacy of resources, pathways for implementation and accountability and mechanisms for equitable resource allocation.

Present Study: Aurangabad Scenario

Coming home to Aurangabad, tourism capital of Maharashtra and one of the major industrial cluster in India the circumstances are unaltered. Central Pollution Control Board (CPCB) declared Aurangabad city as one of the critically polluted areas with Comprehensive Environment Pollution Index (CEPI) of 77.44. In the show-cause notices Maharashtra Pollution Control Board (MPCB) expressed concern over adverse impact on public health due to release of untreated sewage water i.e. 103 million litres per day (MLD) in total. Out of which only 11.50 MLD was treated by the Salim Ali and CIDCO sewage treatment plant (STP) amongst 2.75 MLD was used for watering gardens (compliance audit of urban local bodies, 2016). The untreated 91.50 MLD sewage was being discharge into the river Sukhana and Kham which further enters into the Jayakwadi dam, polluting the only source of potable water for Aurangabad City and surrounding areas.

Therefore, this study initiates to give sustainable option of reuse of treated wastewater by utilizing the potential of 161 MLD treatment capacity of Kanchanwadi STP in Aurangabad city to improve the devolved status of surrounding rivers by quantifying best possible reuse alternatives.

II. Materials & Method

Multi Criteria Decision Making using Fuzzy logic

MCDM is the act of choosing one option from many. The decision making in MCDM is attained through the structuring of multiple criteria to achieve the expected outcome. The functioning basis of any MCDM technique is selection of criteria and alternatives, aggregation method selection and finally selection of alternatives based on weights obtained through aggregation method [3].

System Development

The philosophy behind application of fuzzy based MCDM is to assess the criteria which will affect the selection of reuse alternative. It deals with the reasoning that is approximate rather than fixed or exact. It is multi-valued logic that allows intermediate values to be defined between conventional evaluations like true/false, yes/no, high/low etc.

The Indian case study of selection of logistics service integrated two MCDM techniques namely fuzzy –AHP and fuzzy- TOPSIS [4]. Fuzzy AHP method is used as method for calculating criteria weights and also for ranking the alternatives [5], [6], [7]. Fuzzy AHP and fuzzy TOPSIS incorporated to calculate weights and final rankings for weapon selection are done in case paper [8]. A study [9] compared two MCDM processes; F-AHP and F-TOPSIS to analyse wastewater treatment processes in the industrial estates of Iran.

Therefore present study adopted Fuzzy AHP method for criteria weighing in Fuzzy TOPSIS and for ranking [10]. Further the comparison of pairwise comparison of criteria and alternatives in fuzzy AHP and the relative closeness to ideal solution in fuzzy TOPSIS concluded the optimal alternative.

In multi-criteria decision making environment, weight assessment of criteria and evaluation of alternatives with reference to weighted criteria may lead to uncertainty. Fuzzy sets are completely described by membership functions which indicate the degree of belongingness of a particular element.

Triangular membership function: A fuzzy number with triangular membership function Ã is characterized by (a_1, b_1, c_1), $a_1 \prec b_1 \prec c_1$ as shown in figure1. The table1 represents features of membership function.

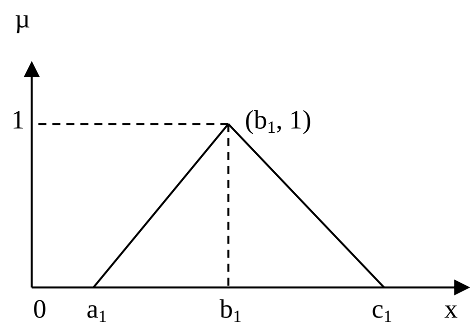

Fig.1: Fuzzy number Ã with triangular membership function

TABLE 1
Features of the triangular membership function

	Membership function	Ranges
	0	$x \prec a_1$
	$\frac{(x-a_1)}{(b_1-a_1)}$	$a_1 \leq x \leq b_1$
$\mu_{\tilde{A}}(x)=$	$\frac{(c_1-x)}{(c_1-b_1)}$	$b_1 \leq x \leq c_1$
	0	$x \succ c_1$

Weighing method – fuzzy AHP

Exercising fuzzy numbers instead of real numbers gave an extension to the standard AHP method as fuzzy- AHP. It uses the concept of fuzzy set theory and solves the problem with the help of hierarchical format to analyse each step of the hierarchy i.e. goal- criteria- alternative independently. The systematic arrangement of hierarchy makes the problem easy to solve. The elements inscribed in the hierarchy are compared with one another. The decision makers have the liberty of using their intuition in comparison of the criteria and alternative while rating on the scale of linguistic importance of the respective variables.

The fuzzy AHP comprises following breakdown:

Step 1: Construction of the hierarchy

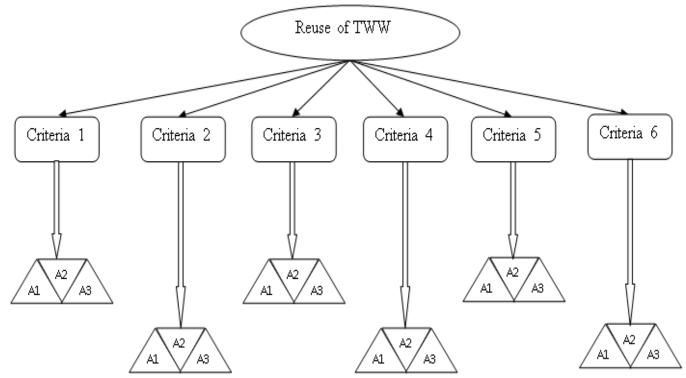

Fig.2: Systematic Hierarchy

TABLE 2
Hierarchy Attributes

First tier (Goal)	**Second tier (Criterion)**	**Third tier (Alternatives)**
Reuse of treated wastewater	Quality of reclaimed i.e. treated wastewater	1.Urban reuse
	Production /treatment Cost	
	Demand	2.Industrial reuse
	Water tariff	
	Social acceptance	3.Environmental and Recreational Reuse
	Reliable source	

Step 2: Pairwise comparison between criteria

Fuzzy triangular scales examined the criteria priorities in the hierarchy reflecting the relative importance among other criteria. Table 3 elaborated the linguistic importance.

TABLE 3
Description of linguistic terms

Saaty scale	**Linguistic terms**	**Fuzzy triangular scale**
1	Equally important (Eq. Imp)	(1,1,1)
3	Weakly important (W. Imp)	(2,3,4)
5	Fairly Important (F. Imp)	(4,5,6)
7	Strongly Important (S. Imp)	(6,7,8)
9	Absolutely Important(A. Imp)	(9,9,9)
2	The intermittent values between two adjacent scales	(1,2,3)
4		(3,4,5)
6		(5,6,7)
8		(7,8,9)

TABLE 4
Pairwise comparison of criteria

A. Imp	S. Imp	F. Imp	W. Imp	CRITERIA	Eq. Imp	CRITERIA	W. Imp	F. Imp	S. Imp	A. Imp
				C_1		C_2			■	
		■		C_1		C_3				
				C_1		C_4		■		
				C_1		C_5				■
				C_1		C_6			■	
				C_2		C_3	■			
				C_2	■	C_4				
				C_2		C_5		■		
			■	C_2		C_6				
				C_3		C_4			■	
				C_3		C_5				■
				C_3		C_6				■
				C_4		C_5			■	
				C_4		C_6		■		
				C_5		C_6				■

Eq.1 represents the pair wise contribution matrix. Triangular fuzzy numbers were used by decision maker k.

$$\widetilde{\boldsymbol{A}}^{\boldsymbol{k}} = \begin{bmatrix} \widetilde{d_{11}^{k}} & \widetilde{d_{12}^{k}} & \cdots & \widetilde{d_{1n}^{k}} \\ \widetilde{d_{21}^{k}} & \vdots & \vdots & \widetilde{d_{2n}^{k}} \\ \cdots & \widetilde{d_{n2}^{k}} & \vdots & \cdots \\ \widetilde{d_{n1}^{k}} & & & \widetilde{d_{nn}^{k}} \end{bmatrix} \qquad \text{…………. (1)}$$

Step 3: Eq. 2 represents fuzzy comparison values of each criterion by resulting in triangular values of geometric mean.

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \tilde{d}_{ij}\right)^{1/n}, i = 1,2,\dots,n \qquad \text{……...(2)}$$

Step 4: the geometric mean, $\widetilde{r_i}$ for each criterion and vector summation of $\widetilde{r_i}$ are calculated.

Step 4 a): the reverse power of summation vector is calculated by making inverse of total. Finally the inverse power is arranged in increasing order.

Step 4 b): Each criterion with the help of eq. 3 resulted in fuzzy weights by multiplying each $\widetilde{r_i}$ with reverse vector.

$$\widetilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \cdots \oplus \tilde{r}_n)^{-1} \qquad \text{…………...(3)}$$

$$= \left(lw_i, mw_i, uw_i\right)$$

Step 5: De-fuzzification of $(\widetilde{w_i})$ is performed by using centre of area method.

$$M_i = \frac{lw_i + mw_i + uw_i}{3} \qquad \text{…………(4)}$$

Step 6: Normalization of M_i is done by calculating N_i.

$$N_i = \frac{M_i}{\sum_{i=1}^{n} M_i} \qquad \text{……………(5)}$$

The aggregated results for normalized weights N_i for each alternative according to each criterion are used as input weights in later method.

Method of Aggregation: Fuzzy TOPSIS

Distance based MCDM technique- F-TOPSIS opts for the alternative closer to the fuzzy positive ideal solution and farther to the fuzzy negative ideal solution. This method evaluates numerous alternatives against particular criteria. The result of this aggregation will actually separate the best alternative from the available options.

Step 1a): linguistic importance of alternatives.

TABLE 5
Linguistic importance of alternatives

CRI	C_1	C_2	C_3	C_4	C_5	C_6
A^1	F. Imp	W. Imp	S. Imp	Eq. Imp	S. Imp	F. Imp
A^2	F. Imp	F. Imp	S. Imp	F. Imp	F. Imp	A. Imp
A^3	A. Imp	S. Imp	A. Imp	F. Imp	S. Imp	F. Imp

Step 1b): Fuzzy decision matrix.

Step 2: Computation of normalized decision matrix.

$\tilde{R} = [\tilde{r}_{ij}]_{m\times n,} \quad i = 1,2,\ldots,m; \; j = 1,2,\ldots,n \quad \ldots(6)$

Where,

$$\left.\begin{array}{l} \tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \quad and \\ c_j^* = \underbrace{max}_{i}\, c_{ij} \quad \text{(benefit criteria)} \end{array}\right\}$$

$$\left.\begin{array}{l} \tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right) \quad and \\ a_j^- = \underbrace{min}_{i}\, a_{ij} \quad (cost\ criteria) \end{array}\right\}$$

Eq. 6 gives normalized decision matrix by considering maximum benefit criteria and minimum cost criteria.

Step 3: The construction of weighted standard decision matrix.

The calculations are performed by multiplying $\tilde{r}_{ij}$ with $\widetilde{w}_j$ of the criteria.

$$\left.\begin{array}{l} \tilde{V} = [\tilde{v}_{ij}]_{m\times n,} \quad where: \\ i = 1,2,..,m; j = 1,2,\ldots,n. \\ \tilde{v}_{ij} = \tilde{r}_{ij}(\cdot)\widetilde{w}_j = (a''_{ij}, b''_{ij}, c''_{ij}) \end{array}\right\} \quad \ldots..(7)$$

The weights ($\widetilde{w}_j$) are taken from the fuzzy- AHP procedure. The weights obtained in equation 5 are directly taken as criteria weights.

Step 4: The construction of fuzzy positive ideal solution (FPIS), A* and fuzzy negative ideal solution (FNIS), A⁻.

$$\left.\begin{array}{l} A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \ldots, \tilde{v}_n^*) \quad where \\ \tilde{v}_j^* = (c,c,c) \quad such\ that: \\ c = \underbrace{max}_{i}\{c''_{ij}\}, i = 1,2,\ldots,m; j = 1,2,\ldots,n \end{array}\right\} \quad \ldots. (8)$$

$$\left.\begin{array}{l} A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^-) \quad where: \\ \tilde{v}_j^- = (a,a,a) \quad such\ that: \\ a = \underbrace{min}_{i}\{a''_{ij}\}, \; i = 1,2,\ldots,m; j = 1,2,\ldots,n \end{array}\right\} \quad \ldots. (9)$$

FPIS (A*) gives best performance value whereas FNIS (A⁻) derives worst performance value.

Step 5: Calculation of separation measures (d_i^*, d_i^-)

In this step, distance of each alternative from FPIS and FNIS is calculated.

$$d_i^* = \sum_{j=1}^{n} d_v(\tilde{v}_{ij}, \tilde{v}_j^*), \quad i = 1,2,\ldots,m \quad \ldots.. \ldots\ldots (10)$$

$$d_i^- = \sum_{j=1}^{n} d_v(\tilde{v}_{ij}, \tilde{v}_j^-), \quad i = 1,2,\ldots,m \quad \ldots.. \ldots\ldots. (11)$$

Where $d_v(\tilde{a}, \tilde{b})$ is the distance measurement between two fuzzy number $\tilde{a}, \tilde{b}$.

$$d(\tilde{a}, \tilde{b}) = \sqrt{\frac{1}{3}\left[(a-a')^2 + (b-b')^2 + (c-c')^2\right]}$$

Step 6: Calculation of relative closeness (CC_i)

Relative closeness CC_i affects the alternative ranking by assessing the shorter and farther distances d_i^*, d_i^- from the positive and negative ideal solutions.

$$CC_i = \frac{d_i^-}{d_i^- + d_i^*}, \quad i = 1,2,\ldots,m \quad \ldots\ldots (12)$$

III. Result And Discussion

F-AHP Aggregated results for each alternative according to each criterion

TABLE 6
Aggregated Results

Criteria		Scores of Alternatives with respect to Criterion		
	Weights (N_i)	A^1	A^2	A^3
Quality of TWW	0.043	0.077	0.199	0.724
Production Cost	0.0126	0.068	0.220	0.712
Demand	0.038	0.053	0.178	0.769
Water Tariff	0.118	0.134	0.119	0.746
Social Acceptance	0.305	0.363	0.305	0.332
Reliable Source	0.371	0.305	0.362	0.333
Total (Score alt x weight criteria)		**0.246**	**0.259**	**0.382**

Order preference by F-TOPSIS

TABLE 7
Relative Closeness to Ideal Solution (CCi)

	d*	d⁻	CCi	Rank
A^1	0.19690	0.17545	0.47119	1
A^2	0.20250	0.16952	0.45567	2
A^3	0.26782	0.10454	0.28006	3

IV. Conclusion

Comparison of F-AHP and F-TOPSIS:

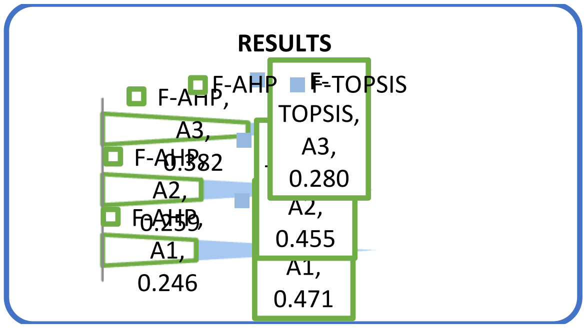

Fig.3: Comparative Results

In order to understand various reuse patterns, global to local attitudes were studied. Which shows that to cope with water scarcity problem treated wastewater is considered as solution. Similarly, in Aurangabad city, water shortages and contamination of local water bodies is not new. Thus the proposed STP can resolve this problem to an extent by the reuse of TWW strategy. This study initiated to look towards the current scenario through reuse perspective. MCDM has helped to illustrate the reuse alternatives through comparative results of two techniques- F-AHP AND F-TOPSIS. To evaluate the reuse options of treated wastewater, Fuzzy- AHP and Fuzzy –TOPSIS analysis results are compared in above graph. The F-AHP method demonstrated that alternative 3 i.e. environmental and recreational reuse as the best option which is highest in ranking. F- TOPSIS adopts alternative 1 i.e. urban reuse as optimal alternative which is closer to Fuzzy Positive Ideal Solution and farther from Fuzzy Negative Ideal Solution.

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