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Performance Assessment of ETP of Sugar Industry by Using Fuzzy-TOPSIS

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ABSTRACT: India is second largest producer of sugar in world. Sugar industry plays an important role in country's economic growth. Also it comes in category of highly polluting industry. So, there is need of effective ETP (effluent treatment plant) in sugar industry to bring pollution parameter to the permissible limit. Indian government follows very strict rules and regulation for effluent discharge to protect the environment. Expressing permissible limits of pollution parameters now needs a paradigm shift from crisp (Permissible OR Not Permissible) to fuzzy values (Permissible AND Not Permissible) as strict discharge standard unnecessarily increases the pollution potential of the industry. An attempt has been made to evaluate the performance of ETP based on fuzzy approach.

The performance assessment of effluent treatment plant (ETP) of sugar industry is complex process as number of parameters like seasonal variation, temperature, non-uniformity in sampling and characterization of process, unskilled labour, old technologies, ignorance toward operation and maintenance cost etc are involved. In present study, an attempt has been made to calculate the efficiency of effluent treatment plant using fuzzy-TOPSIS (technique for order preference by similarity to the ideal solution). Six effluent treatment plant (ETP) of sugar industries in Maharashtra are taken and there are evaluated on basis on parameters like BOD, COD, pH and TSS etc. Based on analysis, ETP 5 scored first rank which indicates that its efficiency is highest among all six effluent treatment plant whereas ETP 4 scored last rank which indicate lowest efficiency. The present study shows that Fuzzy-TOPSIS is an effective tool in calculating the efficiency of ETP of sugar industry in both qualitative and quantitative approach.

KEYWORDS: Fuzzy logic, MCDM, TOPSIS, Sugar industry, efficiency etc

I. INTRODUCTION

India is second largest producer after the Brazil nearly producing 15 and 25% of global sugar and sugarcane respectively (Solomon 2014). It plays an important role in country's economic growth that's why sugar crop is called as cash crop (Awasure, Bhosale, and Chavan 2015). It is the second largest agro-based industry in India. It mainly contribute in development of rural population. Sugar industry and integrated industries provide millions of employment to both skilled and un-skilled persons.. Sugar industry co-products i.e. bagasse, press mud, molasses can be used to produce bio-electricity, bio-ethanol, bio-manure, fuel ethanol, bio-butanol, bio-plastic, bio-diesel, paper and pulp, distillery and chemicals etc. All these contribute about 1.1% to the national GDP. (Solomon 2014). All these indicates that sugar industry have important place in the Indian economic development. But sugar industry comes in category of highly polluting industries. If sugar industry wastewater is discharged without being treatment, it may produce unpleasant smell and can also create pollution problem in both terrestrial and aquatic ecosystem [2]. To reduce the concentration of polluting parameters ETP (Effluent treatment Plant) is used in many sugar industry. Generally wastewater treatment plant (WWTP) consist of chemical, physical and biological processes to removal all types pollutant like solid, liquid and gaseous from the wastewater. Moreover, Indian government follows very strict rules and regulation for effluent discharge to protect the environment. Even though industries are discharging their effluent in permissible limits, they are still contributing in environmental degradation. Expressing permissible limits of pollution parameters on dichotomous scale (Yes/No) now needs a paradigm shift from crisp (Permissible OR Not Permissible) to fuzzy values (Permissible AND Not Permissible)

Performance evaluation of effluent treatment plant is required 1] to know the quality of existing effluents. 2] to check whether the treatment plant is able to handle higher organic and hydraulic loading. So that improvement can be done in operation and maintenance units. In case of developing countries, parameters like unskilled manpower, inadequate

funds, ignorance toward operation and maintenance, old technologies etc. effects the efficiency of effluent treatment plant (ETP). Also, performance evaluation of effluent water treatment plant (ETP) depends on various parameters that are involved in operation parameters like seasonal variation, temperature, non-uniformity in sampling and characterization process etc. Evaluating the performance of effluent treatment plant is a complex process as number of parameters are involved in it. Evaluating should be done either with help of logical or mathematical tool to make it simple. Logic tool could be best approach when multiple outcomes are governed by multiple input parameters. When the probabilities of the outcomes are unknown, decisions are made under uncertainties, which is the prime domain of fuzzy decision making. Fuzzy multi-criteria decision making is concerned with structuring and solving decisions and planning problems involving multiple criteria. The characterization of wastewater involves different parameters, which are dependent or non-dependent on each other; but are more important when deciding treatment and evaluating the performance of treatment plant. An attempt has been made to make a model which employs Fuzzy-TOPSIS (TOPSIS (technique for order preference by similarity to the ideal solution)). TOPSIS is one of the most popular MCDM method, developed by Hwang and Yoon. By its simplicity, computational efficiency and comprehensive mathematical concept, it has been thoroughly adopted in many cases.

II. RELATED WORK

Several MCDM methods are available with its application for calculation of efficiency of wastewater treatment plant. Some popular MCDM methods include analytical hierarchy method (AHP), analytical network process (ANP), weighted sum method (WSM), weighted product method (WPM), simple additive weighting (SAW), technique for order preference by similarity to ideal solution (TOPSIS), preference ranking organization method for enrichment evaluation (PROMETHEE) etc. Many researchers used MCDM methods to evaluate the efficiency of wastewater treatment plant as there are number of conflicting criteria's which affects the efficiency. Performance evaluation of existing treatment plant is required 1) to know about the treatment plant whether it is possible to handle hydraulic and organic loadings. 2) to assess the existing effluent treatment to meet higher load. Application of Fuzzy-TOPSIS is an effective approach where there are imprecision and vagueness in decision making process.

III. METHODOLOGY

For this study, six effluent treatment plant (ETP) with almost equal capacities are selected in Maharashtra. Three sugar industries were from Pune district while other three from Dhule district. The data of one year is collected to carry out the analysis shown in table 2. As BOD, COD, TSS, TDS, SS, pH, Sulphate, Chloride are most important indicative characteristics of the effluent. Here, pH, COD (chemical oxygen demand), BOD (biological oxygen demand) and TSS (total suspended solids) are used as criteria to carry out the performance evaluation of effluent treatment plant (ETP) of sugar industries. All six ETP (Effluent Treatment Plant) are considered as alternatives. Modified delphi method is used to calculate criteria weights wherein opinion from environmental experts (EE) was taken into consideration. Here, opinion of fourteen environmental experts are taken in form of linguistic variables. Using linguistic variables make the evaluation process more realistic [9]. In this group, seven are academic experts and rest are industrial experts. First linguistic variable is defined after that the expert opinion was taken for different criteria's in the form of linguistic variables. Here, four linguistic variables like most important, important, average important, less important, not important are taken to make it easy for expert to distinguish. Linguistic variables with corresponding fuzzy number and are tabulated in the table 1

I. Table 1- Linguistic variables with corresponding fuzzy number

Linguistic Variables		Fuzzy number
Most important	(MI)	(0.7, 0.8, 0.9, 1.0)
Important	(I)	(0.4, 0.5, 0.6, 0.7)
Average Important	(AI)	(0.2, 0.3, 0.4, 0.5)
Less important	(LI)	(0.0, 0.1, 0.2, 0.3)
Not important	(NI)	(0.0, 0.0, 0.1)

Table 2- Characteristics of treated effluent treatment plant .

Alternatives Criteria	ETP 1	ETP 2	ETP 3	ETP 4	ETP 5	ETP 6
COD	25.36 - 89.7	26.12 - 87.78	25.55 -88.25	23.33-91.25	21.56-88.96	20.15 -85.32
BOD	2.98 - 47.93	4.15 -47.93	3.5 - 48.93	3.63 - 52.96	5.89 - 48.96	8.32 - 53.69
TSS	24.12 - 39.28	16.69 -39.65	17.25 - 39.65	27.12 - 43.25	15.85 - 35.86	16.88 - 32.46
pH	0.80 -11.93	2.36 - 10.89	3.56 - 11.63	2.85- 12.56	4.28 - 11.47	5.86 - 13.69

Table 3- Characteristics of treated effluent treatment plant - average value.

Alternatives Criteria	ETP 1	ETP 2	ETP 3	ETP 4	ETP 5	ETP 6
COD	57.53	56.95	56.9	57.29	55.26	52.73
BOD	25.45	26.04	26.215	28.29	27.42	31
TSS	31.7	28.17	28.45	35.18	25.85	24.67
pH	6.365	6.625	7.595	7.7	7.8	9.77

Now, Opinion of fourteen environmental experts in form of linguistic variable for each sub-criteria is tabulated in tab3

Table 4- Weights allocation by experts with references to Linguistic variables

SR.NO	pH	TSS	COD	BOD
AE1	MI	I	I	MI
AE2	MI	MI	I	MI
AE3	I	I	MI	I
AE4	I	MI	I	AI
AE5	I	MI	MI	MI
AE6	I	I	AI	MI
AE7	MI	AI	MI	MI
IE 1	I	I	MI	MI
IE 2	MI	I	AI	I
IE 3	I	AI	I	MI
IE 4	MI	I	MI	AI
IE 5	I	MI	I	MI
IE 6	MI	I	AI	I
IE 7	MI	I	AI	I

Table 5- Fuzzy number corresponding to linguistic variables.

SR.NO	pH	TSS	COD	BOD
AE1	0.85	0.55	0.55	0.85
AE2	0.85	0.85	0.55	0.85
AE3	0.55	0.55	0.85	0.55
AE4	0.55	0.85	0.55	0.35
AE5	0.55	0.85	0.85	0.85
AE6	0.55	0.55	0.35	0.85
AE7	0.85	0.35	0.85	0.85
IE 1	0.55	0.55	0.85	0.85
IE 2	0.85	0.55	0.35	0.55
IE 3	0.55	0.35	0.55	0.85
IE 4	0.85	0.55	0.85	0.35
IE 5	0.55	0.85	0.55	0.85
IE 6	0.85	0.55	0.35	0.55
IE 7	0.85	0.55	0.35	0.55

Now, a decision matrix was formed by comparing table 1 and table 3. A decision matrix is formed by replacing the linguistic variable with corresponding fuzzy number.

The average fuzzy numbers for all the environmental experts' opinion can be expressed as

Ck is developed with the equation:

$$A^{kij} = (1/p)(a_{i1}^k + a_{i2}^k + a_{i3}^k + \dots + a_{ip}^k) \text{ for } j = 1, 2, \dots, p$$

Where A_{ij}^k be the fuzzy number (weight) assigned to an alternative A_i by DM_j (Decision Maker j) for the decision criteria C_k and p is the number of environment experts involved in the evaluation process. The linguistic variables as assigned by the experts are converted to fuzzy numbers used in the above expressions. Now, the defuzzified values for the sub-criteria are obtained by the equation below.

$$E = (X_1 + X_2 + X_3 + X_4)/4.$$

Table 6- Average fuzzy number,

SR.NO	pH	TSS	COD	BOD
AE1	(0.7,0.8,0.9,1.0)	(0.4,0.5,0.6,0.7)	(0.4,0.5,0.6,0.7)	(0.7,0.8,0.9,1.0)
AE2	(0.7,0.8,0.9,1.0)	(0.7,0.8,0.9,1.0)	(0.4,0.5,0.6,0.7)	(0.7,0.8,0.9,1.0)
AE3	(0.4,0.5,0.6,0.7)	(0.4,0.5,0.6,0.7)	(0.7,0.8,0.9,1.0)	(0.4,0.5,0.6,0.7)
AE4	(0.4,0.5,0.6,0.7)	(0.7,0.8,0.9,1.0)	(0.4,0.5,0.6,0.7)	(0.2,0.3,0.4,0.5)
AE5	(0.4,0.5,0.6,0.7)	(0.7,0.8,0.9,1.0)	(0.7,0.8,0.9,1.0)	(0.7,0.8,0.9,1.0)
AE6	(0.4,0.5,0.6,0.7)	(0.4,0.5,0.6,0.7)	(0.4,0.5,0.6,0.7)	(0.7,0.8,0.9,1.0)
AE7	(0.7,0.8,0.9,1.0)	(0.2,0.3,0.4,0.5)	(0.7,0.8,0.9,1.0)	(0.7,0.8,0.9,1.0)
IE 1	(0.4,0.5,0.6,0.7)	(0.4,0.5,0.6,0.7)	(0.7,0.8,0.9,1.0)	(0.7,0.8,0.9,1.0)
IE 2	(0.7,0.8,0.9,1.0)	(0.4,0.5,0.6,0.7)	(0.2,0.3,0.4,0.5)	(0.4,0.5,0.6,0.7)
IE 3	(0.4,0.5,0.6,0.7)	(0.2,0.3,0.4,0.5)	(0.4,0.5,0.6,0.7)	(0.7,0.8,0.9,1.0)
IE 4	(0.7,0.8,0.9,1.0)	(0.4,0.5,0.6,0.7)	(0.7,0.8,0.9,1.0)	(0.2,0.3,0.4,0.5)
IE 5	(0.4,0.5,0.6,0.7)	(0.7,0.8,0.9,1.0)	(0.4,0.5,0.6,0.7)	(0.7,0.8,0.9,1.0)
IE 6	(0.7,0.8,0.9,1.0)	(0.4,0.5,0.6,0.7)	(0.2,0.3,0.4,0.5)	(0.4,0.5,0.6,0.7)
IE 7	(0.7,0.8,0.9,1.0)	(0.4,0.5,0.6,0.7)	(0.2,0.3,0.4,0.5)	(0.4,0.5,0.6,0.7)

the total of all sub-criteria. To calculate normalised value weighted sum method is used.

Table 7- Normalised value

Normalized value						
Alternatives Criteria	ETP 1	ETP 2	ETP 3	ETP 4	ETP 5	ETP 6
COD	0.17	0.17	0.17	0.17	0.16	0.16
BOD	0.15	0.16	0.16	0.17	0.17	0.19
TSS	0.18	0.16	0.16	0.20	0.15	0.14
pH	0.14	0.14	0.17	0.17	0.17	0.21

Next step is to formed weighted decision matrix .

The next step is to convert the parametric values of treated effluent to the fuzzy numbers (membership functions) based on the specified statutory norms. Using simple additive weighing method (Hwang and Yoon, 1981), the overall score (OS) of treated effluent can be calculated using following equation.

$$OS = \sum (X_k \otimes W(C_k)) \text{ for } k = 1, 2, \dots, n$$

Where, $W(C_k)$ = Weight (Importance Value) of the sub criterion k

X_k = Crisp Score (Defuzzied Value) of treated data against the sub criterion k

Table 8- Applying weight

Applying weight						
Alternatives Criteria	ETP 1	ETP 2	ETP 3	ETP 4	ETP 5	ETP 6
COD	13.28	13.14	13.13	13.22	12.75	12.17
BOD	6.78	6.94	6.99	7.54	7.31	8.26
TSS	7.40	6.58	6.64	8.22	6.04	5.76
pH	1.71	1.78	2.04	2.07	2.10	2.63

TOPSIS is based on the concept that chose the alternative which has the shortest distance from positive ideal solution (PIS) and longest distance from negative ideal solution(NIS) following formulae are used to calculate the positive ideal solution and negative ideal solution.

$$PIS = \{ (\text{MAX } t_{ij} : i = 1, 2, 3, \dots, M : j \in J_-), (\text{MIN } (t_{ij} : i = 1, 2, 3, \dots, M) : j \in J_+) \} = t_{wj} : j = 1, 2, 3, \dots, N$$

$$NIS = \{ (\text{MIN } t_{ij} : i = 1, 2, 3, \dots, M : j \in J_-), (\text{MAX } (t_{ij} : i = 1, 2, 3, \dots, M) : j \in J_+) \} = t_{bj} : j = 1, 2, 3, \dots, N$$

TABLE 9- PIS AND NIS

	PIS	NIS
COD	13.28	12.17
BOD	8.26	6.78
TSS	8.22	5.76
pH	2.63	1.71

Considering negative and positive ideal solution, a scale is created which indicates the distance of each alternative solution (t_{ij}). The best alternative is one which is obtained by positive ideal solution whereas the worst alternative is one which is obtained by negative ideal solution. The following formulae is used to calculate the best and worst alternative:

$$S_{ib} = \sqrt{\sum_{j=1}^n (t_{ij} - t_{wj})^2}, i=1,2,3,\dots,m$$

$$S_{iw} = \sqrt{\sum_{j=1}^n (t_{ij} - t_{bj})^2}, i=1,2,3,\dots,N$$

Where S_{ib} gives the best ideal solution and S_{iw} gives the worst ideal solution.

Finding out the most efficient industry - Based on closeness coefficient, rank will be given to the different sugar industries and based on given rank most efficient industry will be determined. The closeness coefficient is obtained by following formula.

$$II. R_{iw} = \left[\frac{S_{iw}}{(S_{ib} + S_{iw})} \right] \leq I_{iw} \leq 1, i = 1, 2, 3, \dots$$

Table 10- Closeness coefficient

Alternatives	Closeness coefficient	Rank
ETP 1	0.62	5
ETP 2	0.22	2
ETP 3	0.26	3
ETP 4	0.75	6
ETP 5	0.10	1
ETP 6	0.30	4

While evaluating the performance of ETP (effluent treatment plant) of sugar industries, ranking approach is used. Lower the rank less will be the less will be pollution. Indicate higher the chances to allow to discharge effluent in the environment with having less adverse effect on the environment and human health. From the analysis, ETP 3 has ranked first with closeness coefficient 0.19 which indicate that its efficiency is highest among all six ETP (effluent treatment plant) whereas ETP 4 has ranked first with closeness coefficient 0.83.

Table 11 – Ranking of ETP (effluent treatment plant) of sugar industry.

Ranking of ETP	
Alternative	Rank
ETP 5	1
ETP 2	2
ETP 3	3
ETP 6	4
ETP 1	5
ETP 4	6

IV. RESULTS

After analysing six sugar industries using fuzzy- TOPSIS (Technique For Order Preference By Similarity To Ideal Solution), rank is given to each sugar industry as shown in table.

Table 10– Ranking of ETP (Effluent Treatment Plant) of the sugar industry.

Ranking of ETP	
Alternative	Rank
ETP 5	1
ETP 2	2
ETP 5	3
ETP 6	4
ETP 1	5
ETP 4	6

A deduction can be made for lesser pollution that rank should be higher and thus the treatment process should be more efficient. This can be inferred from the ranking of the sugar industry. ETP 5 can be seen getting the first rank with the score of 18.70 which represents that it is very helpful and efficient in the treatment wastewater of sugar industry among six STP (Effluent treatment plant) while ETP 4 was on rank 6 with score 53.32, this means it is not effective in treating wastewater. The best solution can be said as the one with which is close to the positive ideal solution (PIS) while the worst solution is one which is far away from the negative ideal solution (NIS). We can come to the conclusion that ETP 5 is best from all the treatment plants whereas ETP 4 is the worst in treatment from the sugar industry.

V. CONCLUSION

Conventionally, efficiency of effluent treatment plant is calculated from inlet and outlet characteristics of parameters. But, it fails due to uncertainty and it is entirely qualitative. Whereas the fuzzy approach provides qualitative as well as quantitative evaluation. From the study, ETP 5 has ranked first with closeness coefficient 0.10 which indicates that its efficiency is highest among all six ETP (effluent treatment plant) whereas ETP 4 has ranked last with closeness coefficient 0.75. Use of fuzzy- TOPSIS in environmental field promotes resource optimization, better control over performance activity and cost reduction.

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