J. Environ. Res. Develop.
Journal of Environmental Research And Development **Vol. 8 No. 3, January-March 2014**

PREDICTING EFFICIENCY OF TREATMENT PLANT BY MULTI PARAMETER AGGREGATED INDEX

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Received October 25, 2013 *Accepted January 17, 2014*

ABSTRACT

The efficiency of treatment plant is predicted with MPAI v/s efficiency graph. Quality for raw and treated wastewater is judge by Multi Parameter Aggregated Index (MPAI). Wastewater index is evaluated with fuzzy multi criteria decision making approach. Considerable uncertainties are involved in the process of defining the treated wastewater quality for specific usage, like irrigation, reuse, etc. The paper also discuss, predicting MPAI from measured BOD of treated wastewater.

Key Words : Wastewater quality, Uncertainty, Fuzzy set theory, MPAI, Efficiency

INTRODUCTION

Surat has more than 45 lacs population. Total eight sewage treatment plants are designed, out of which six are treating wastewater and two are under construction phase. The prime usage of water is for agriculture, domestic and industrial. For all the above mentioned usages, the required water should be of the different and specific quality. The quality of water is checked by measuring various parameters like pH, Total Dissolved Solids (TDS), Suspended Solids (SS) etc. It is difficult for the authority to make any decision based on these different parameters. But water quality index provides a single number (like a grade) that expresses overall water quality at a certain location and time based on several water quality parameters. The objective of an index is to turn complex water quality data into information that is understandable and useable by the public. This index was originally developed by the National Sanitation Foundation (NSF). Water quality indices aim at giving a single value to the water quality of a source reducing great amount of parameters into a simpler expression and enabling easy interpretation of monitoring data.[1] Rakesh[2] has developed water quality index for Chakkamkan dam Lake, India, where the parameters considered are pH, dissolved oxygen, turbidity and ammonia. Overall quality of water can be assessed mathematically by water quality index which is calculated by assigning certain weight age to important water quality parameters. Mittal[3] studied to assess the drinking water quality at Moga, Punjab (India) as where consumption of fertilizers and pesticides is the highest in the state. Developing the WWQI on the line of WQI is expected to be more practical in implementation and can become effective decision making tool for authority.[4] Based on this concept new wastewater quality index has been developed in name of Multi Parameter Aggregated Index (MPAI), which represent the wastewater quality in terms of numeric i.e. 0 to 1. The MPAI can be the important tool for decision makers.

The wastewater is generated from any type of usage of water but for discharge of wastewater, particularly into the rivers, two approaches or systems are adopted, i.e. Effluent standards as well as stream standards. In India Effluent Standards are followed for disposal of wastewater, where different limits are given for different parameters. The current legal requirement is that all the values of parameters specified in the consent must be satisfied prior to the discharge. Developing the MPAI on the line of WQI is expected to be more practical in implementation and can become effective decision making tool for authority. The index is good tool for rapid comparison of water quality, rapid evaluation of treatment

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options and rapid evaluation of the improvement in water quality.Water indices are mainly used in order to evaluate pollution level.[5,6] No general indices have been defined for checking normative standards and nor for rapid assessments of the quality achieved by wastewater reclamation. At present Gujarat Pollution Control Board (GPCB) monitors the discharge norms of temperature equal to or less than 40^0 C, Biochemical demand (BOD) equal to or less than 30 mg/L. Instead of evaluating individually all parameters, MPAI has been developed by considering all the parameters together defined in statutory norms. The fuzzy approach is applied that there is fuzziness in quality and quantity of parameters. The methodology for the study deals with fuzzy weights, expert's perception and decision making under multi criteria. The study discussed here : the selection of the main parameters, the introduction of their weights, the selection of the normalization curves for the transformation of their values in fuzzy numbers, and the adoption of an aggregation function for the final multi criteria aggregated index.

Multi Criteria Decision Making (MDM)

MCDM provides a structured (organized) approach to decision making. Values, beliefs and perceptions are the force behind almost any decision- making activity. They are responsible for the perceived discrepancy between the present and a desirable state. Fuzzy multi criteria decision making is one of the well-known branches of decision making. According to many authors, for example,[7] MCDM has two important paradigms : Multi objective decision making (MODM) and Multi attribute decision making (MADM). Decision makers are often required to consider multiple as well as conflicting objectives in making decisions. MCDM means a structured approach to decision making. In MCDM, relevant alternatives are evaluated according to a number of criteria. Each criterion includes a particular ordering of the alternatives. The number of criteria in multi-criteria decision making is virtually assumed to be finite.[8,9] The general discussion of the particular MCDM models–the Analytical Hierarchy Process (AHP) and the Simple Multi Attribute Rating Technique (SMART) given in selection of MCDM mode. Balteiro and Romero[10] utilized a sustainability aggregating model in search an index to natural systems sustainability. Chen et al.[11] utilized fuzzy MCDM approach and fuzzy AHP for selecting the best environment-watershed plan in Taiwan. Georgopoulou et al.[12] utilized electre Triin defining national priorities for greenhouse gases emissions reduction in the energy sector in Greece.

Selection of MCDM models

A number of different models have been proposed to structure and solve MCDM problems. In spite of on-going research in this area, there is still no satisfactory theoretical framework that supports the selection of a specific MCDM model for a particular application. The selection of the models is based on the following evaluation criteria suggested by Dodgson et al.[13]

- Internal consistency and logical soundness
- Transparency
- Ease of use
- Data requirements are consistent with the importance of the issue being considered
- Realistic time and manpower resource requirements for the analytical process
- Ability to provide an audit trail
- Software availability, where needed

The Analytical Hierarchy Process (AHP)

The AHP developed by Saaty[14] is a technique for analysing and supporting decisions in which multiple and competing objectives are involved and multiple alternatives are available. The method is based on three principles: decomposition, comparative judgment and synthesis of priorities. In the AHP, the first step is that a complex decision problem is decomposed into simpler decision problems to form a decision hierarchy.[15,16] When developing a hierarchy, the top level is the ultimate goal of the decision. The hierarchy decreases from the general to more specific until a level of attributes are reached. Each level must be linked to the next higher level. Typically a hierarchical structure includes four levels: goal, objectives, attributes and alternatives. The AHP provides a proven, effective means to deal with complex decision making.[17] It combines tangible and intangible aspects in order to derive a ratio scale and the

abstract scale of priorities, which is valid to make complex decisions.[18,19] The AHP pair wise comparison enables the decision maker to evaluate the contribution of each factor to the objective independently, thereby simplifying the decision making process[20].However, ambiguity in relative importance, inconsistent judgments by decision maker and the use of 1 to 9 scales can be thought as the disadvantages of this method.

The Simple Multi Attribute Rating Technique (SMART)

Simple Attribute Rating Technique (SMART) is oriented not towards mathematical sophistication of relation between underlying formal structures and practical procedures that implement them, but is towards easy communication and use in an environment in which time is short and decision makers are multiple and busy. The SMART has been successfully applied in many areas such as ordering system in industry[21] and the public health planning.[22] Since the area of multi-criteria decision-making has received widespread attention around the globe, SMART has become the focus of many applications in MCDM. The different scales are converted to a common internal scale using a value function running the model. SMART is a powerful and flexible decision making tool. Because of its simplicity in terms of both responses required of the decision-maker and the manner in which these responses are analysed, SMART has been widely applied. The analysis involved is transparent, so the method is likely to yield an enhanced understanding of the problem.

Fuzzy Multi Criteria Decision Making Model (FMCDM)

Many authors have studied different methods of Fuzzy Multi Criteria Decision Making model in environment during the last three decades. Omero et al.,[23] deal with the problem of assessing the performance of a set of production units, simultaneously considering different kinds of information, yielded by Data Envelopment Analysis (DEA), a qualitative data analysis, and an expert assessment. Hua et al.[24] developed a fuzzy multiple attribute decision making (FMADM) method with a three level hierarchical decision making model to evaluate the aggregate risk for green manufacturing projects. Ling[25] presented a fuzzy MADM method in which the attribute weights and decision matrix elements (attribute values) were fuzzy variables. The author used some fuzzy arithmetic operations and the expected value operator of fuzzy variables to solve the FMADM problem. Xu and Chen[26] developed an interactive method for multiple attribute group decision making in a fuzzy environment. The method could be used in situations where the information about attribute weights were partly known, the weights of decision makers were expressed in exact numerical values or fuzzy numbers. Wu et al.[27] developed a new approximate algorithm for solving fuzzy multiple objective linear programming (FMOLP) problems involving fuzzy parameters in any form of membership functions in both objective functions and constraints. A methodology for hazard ranking of landfills using fuzzy composite programming was developed by Hagemeister et al.[28] The methodology to assess the environmental and public health hazard posed by an unregulated landfill when available data is imprecise, uncertain or subjective was described by Raj and Kumar[29] and concept of maximizing set and minimizing set for ranking alternatives with fuzzy weights was used.

The principal steps in the application of MCDM model, the concepts and procedures have been given by Edwards[30] and also by Dodgson et al.[13] they identify the following sequence of steps in a typical application. The steps involved are as follows :

1. Establish the decision context, the decision objectives (goals) and identification of the decision makers.
2. Identify the alternatives.
3. Identification of the criteria (attributes) that are relevant to the decision problem.
4. Measuring performance of the alternatives by assigning scores to each of the criterion.
5. Based on the above step developing an evaluation matrix.
6. Normalizing or standardizing the scores.
7. Determination of weight for each criterion to determines relative importance.

8. Combining weights and scores to compute an overall assessment measure for each decision alternative.
9. Carrying out the final ranking of the alternatives.

METHODOLOGY

The first step was to identification of environmental experts and the criteria for evaluation of MPAI for determining the performance of treatment plant. The importance weightage for each of the criteria was developed by consulting the environmental experts. The approach for developing MPAI was based on strength of different parameters is somewhat analogous to the procedure suggested by Singh and Tiong.[31] **Fig. 1** portrays an overview of the fuzzy decision framework for evaluating MPAI and performance of treatment plant, which is self-explanatory.

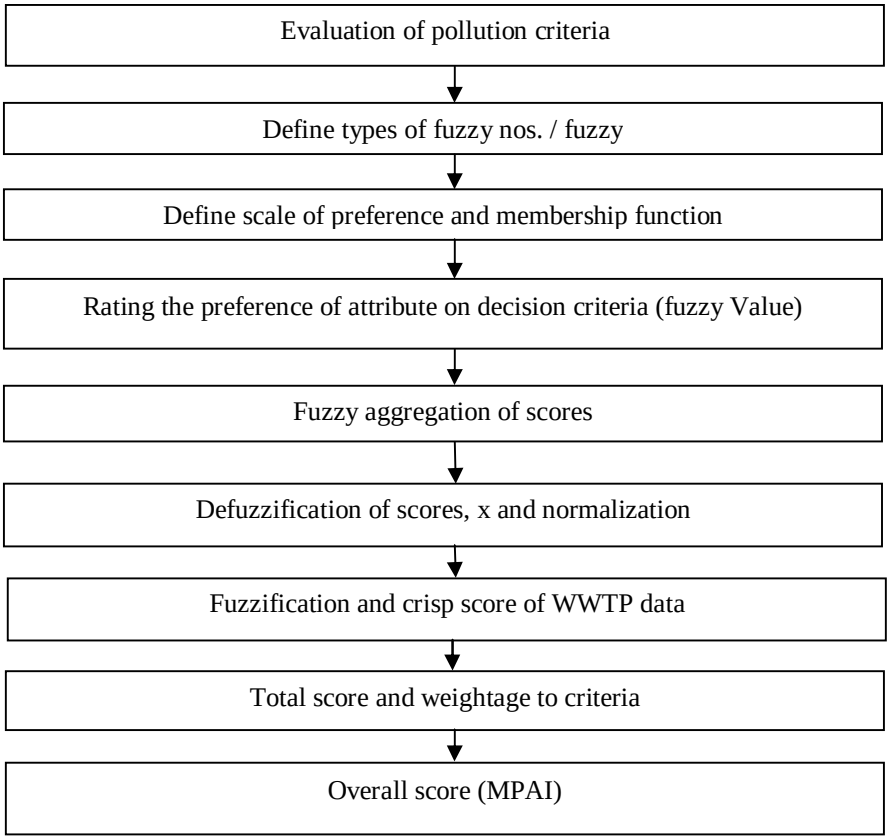

Fig. 1 : Step involved in a MCDM model

To describe the level of performance on decision criteria Saaty[32] has proposed fuzzy numbers for nine linguistic variables. Linguistic variables assigned for the study were five, Highly Significant (HS), Significant (S), Average Significant (AV), Low Significant (LS), and Not Significant (NS).Each were defined with four fuzzy numbers. **Fig. 2** is the graphical presentation of fuzzy numbers for the linguistic variables used by seven environmental experts to develop weight age for each criterion.

The importance weight age factors are computed for eight sub criteria (parameters) of wastewater for raw and treated wastewater. On the basis of the experts' opinion (linguistic variable) or perception, a fuzzy decision matrix for the subcriteria of wastewater was computed. Using the Eq. 1 given below, the average fuzzy numbers for all the environmental experts' opinion can be expressed as

$$A^k ij = \left(1/p\right)\left(a_{i1}^k + a_{i2}^k + a_{i3}^k + + a_p^k\right) \text{for j} = 1, 2, \ldots \text{p} \quad (1)$$

Where a^k_{ij} be the fuzzy number (weight) assigned to an alternative A_i by DM_j(Decision Maker i) for the decision criteria C_k and p is Number of environment experts involved in evaluation process.

The linguistic variables as assigned by the experts are converted to fuzzy numbers used in the above expressions through **Fig. 2**. Now, the defuzzified values for the subcriteria are obtained by the Eq. 2[33].

$$e = (X_1 + X_2 + X_3 + X_4)/4 \quad (2)$$

For details about different types of fuzzy numbers, membership functions, aggregation and defuzzification methods, interested readers may refer to Zimmerman.[7,9,11,33] These linguistic variables for each criteria as assigned by environmental experts were converted to fuzzy number and the normalized weight for each sub criteria was obtained by dividing the scores of each sub criteria (C_{ij}) by the total of all sub-criteria (ΣC_{ij}).

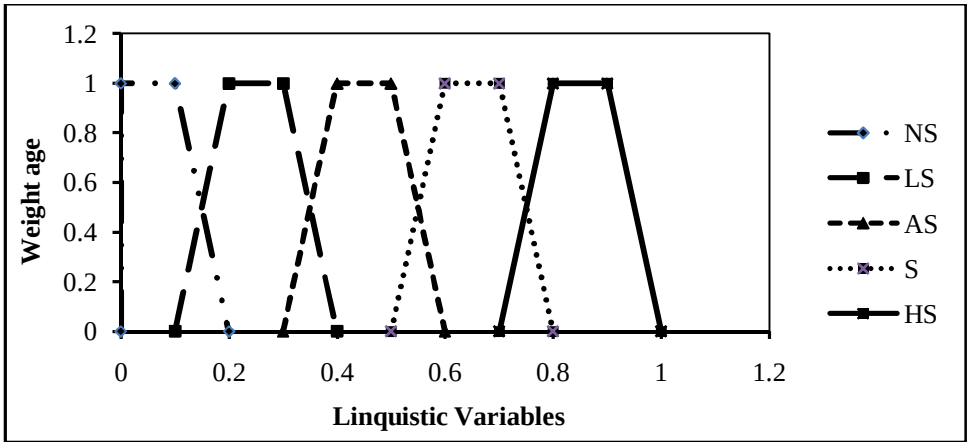

Fig. 2 : Graphical representation of trapezoidal membership function

Case study

The case study relates to the Anjana treatment plant at Surat, Gujarat, India. The samples were collected from inlet and out let point of sewage treatment plant for complete one year. All the samples were collected at fix time i.e. at 1 PM to 1.30 PM. Samples were collected in container rinsed with detergents, nitric acid and finally with distilled water. Immediately after collection some of the parameters like pH, temperate were recorded on the field and letter the samples were refrigerated at 4^0 C prior to further analysis. Total 104 samples were analyzed twice a week for the year 2011.The samples were analyzed in the laboratory with method prescribed in standard methods[34] for wastewater analysis. **Table 1** present the maximum, minimum and average, reading of eight analyzed samples for raw and treated wastewater. These observations were converted in to membership functions with respect to discharge norms set by the GPCB. The normalized membership function will be in the form of [0.1]. **Fig. 3** explains the transferring COD data into fuzzy data. The fuzzy value of 60 mg/L is 0.6 and 100 mg/L and above is one.

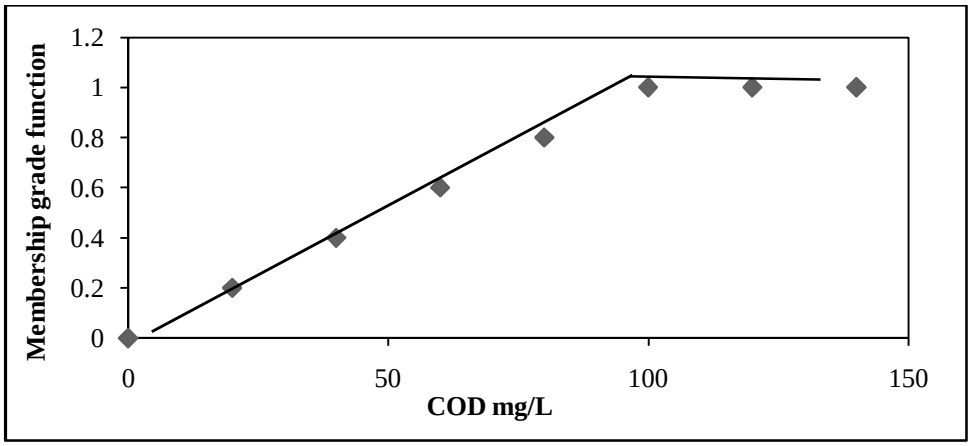

Fig. 3 : Pollution parameter Chemical Oxygen Demand (COD)

The average values of parameters for wastewater **(Table 2)** were converted to the fuzzy numbers (membership functions) based on the specified statutory norms. **Table 1** shows the average values of parameters analyzed as raw and treated wastewater for sample calculation these values were normalized.

Table 1 : Max. Min. and Ave. data of different parameters for raw and treated wastewater at Anjana WWTP

Wastewater		Temp.	TDS	SS	BOD	COD	O&G	pH	Cl^-
Raw	Max.	33.7	1253.0	1132.0	1012.0	2232.0	9.2	7.8	453.0
	Min.	22.0	305.0	136.0	126.0	330.0	0.2	7.0	150.0
	Average	29.0	650.8	543.8	521.0	1035.7	7.4	7.2	275.4
Treated	Max.	39.8	841.0	120.0	27.0	147.0	275.0	8.0	380.0
	Min.	20.7	325.0	15.0	7.0	7.7	0.0	6.8	205.0
	Average	29.4	720.0	34.7	16.5	82.5	2.4	7.6	302.8

RESULTS AND DISCUSSION

The data is normalized as shown in **Fig. 3**. Normalized values for maximum, minimum and average data from Table for all sub criterions for raw and treated wastewater are as shown in **Table 2** below. **Table 3** shows the important weights in terms of linguistic terms assigned to each of sub criteria of raw and treated wastewater by environmental experts. The data was collected trough questioner.

Table 2 : Normalized data for different criterions (X_k)

Wastewater		Temp.	TDS	SS	BOD	COD	O&G	Cl	pH
Max.	Raw	0.8750	0.4014	1.0000	1.0000	1.0000	0.7810	0.6250	0.5733
Min.		0.6200	0.2686	1.0000	1.0000	1.0000	0.6960	0.4083	0.0267
Average		0.7243	0.3205	1.0000	1.0000	1.0000	0.7240	0.4820	0.3000
Max.	Treated	0.8450	0.3771	0.4000	0.7667	1.0000	0.0800	0.6000	0.6999
Min.		0.6125	0.3019	0.0600	0.1667	0.3200	0.0100	0.4667	0.3266
Average		0.7225	0.3486	0.2214	0.4093	0.6781	0.0410	0.5299	0.4666

Table 3 : Linguistic terms by experts

Sub criteria	EE. 1	EE. 2	EE.3	EE. 4	EE. 5	EE. 6	EE. 7
Temp.	AS	AS	AS	LS	AS	NS	S
TDS	S	S	AS	AS	S	LS	LS
SS	S	AS	S	S	HS	AS	LS
BOD	HS	HS	HS	S	AS	HS	HS
COD	HS	S	HS	AS	S	HS	S
O & G	NS	LS	NS	NS	LS	LS	NS
Cl	LS	LS	LS	AS	LS	NS	LS
pH	AS	AS	AS	AS	LS	AS	LS

*NS=Not Significant,LS=Low Significant, AS= Ave.Significant, S=Significant and HS= High Significant

The normalized weight age for each sub criterion is obtained by dividing the score of each sub criterion (C_k) by the sum total of all sub criteria $\Sigma(C_k)$ for raw and treated wastewater. The weight for each criterion depends upon the characteristic of raw and treated wastewater. The normalized weight given by expert's for each criterion is shown below in **Table 4**.

Table 4 : Normalized weights by environmental experts

Sub criteria	AFN 1	AFN 2	AFN 3	AFN 4	Average Fuzzy Number (C_k)	Normalized Weight (W_j)
Temp.	0.2571	0.3429	0.4429	0.5429	0.3964	0.1077
TDS	0.3286	0.4286	0.5286	0.6286	0.4786	0.1300
SS	0.4143	0.5143	0.6143	0.7143	0.5643	0.1532
BOD	0.6143	0.7143	0.8143	0.9143	0.7643	0.2076
COD	0.5571	0.6571	0.7571	0.8571	0.7071	0.1920
O & G	0.0429	0.0857	0.1857	0.2857	0.1500	0.0407
Cl	0.1143	0.2000	0.3000	0.4000	0.2535	0.0689
pH	0.2286	0.3143	0.4143	0.5143	0.3679	0.0999
					$\Sigma(C_k)$= 3.6821	$\sum$= 1

Weights determined through expert perception are shown as, $W(C_{11})$ = 0.1077, $W(C_{12})$ = 0.13, $W(C_{13})$ = 0.1532, $W(C_{14})$ = 0.2076, $W(C_{15})$ = 0.920, $W(C_{16})$ = 0.0407, $W(C_{17})$ = 0.0689, $W(C_{18})$ = 0. 0999, are the weights for different criterion.

Using simple additive weighting method (Hwang and Yoon 1981), the total score (TS) for each Sewage treatment plant can be calculated using equation 3.

$TS = \Sigma (X_k \times W (C_{ki}))$ for k = 1, 2, ….n (3)

Where, $W (C_{ki})$ = weight or the importance value of the sub criterion k and

X_k = crisp score of the plant data against the sub criterion k.

Using equation 3, the overall scores for raw and treated wastewater of Anjana wastewater treatment plants can be calculated and on the basis of overall score MPAI for law and treated wastewater of the plant can be determined. On the basis of weight evaluated for the sub criteria, the MPAI was developed for raw and treated wastewater. The next step is to determine total score. Using simple additive method the total score (TS) can be calculated. To obtain the total score the data of fuzzy crisp scores and normalized weights of sub criteria were operated by a matrix as shown below. Matrix (1) presents the total score for raw wastewater in terms of MPAI by academicians.

$$\text{Total score for average data of raw wastewater in terms of } MPAI_{raw} = \begin{bmatrix} X_k \\ 0.7243 \\ 0.3205 \\ 1.0000 \\ 1.0000 \\ 1.0000 \\ 0.7240 \\ 0.4820 \\ 0.3000 \end{bmatrix} \begin{bmatrix} W_j \\ 0.1077 \\ 0.1300 \\ 0.1532 \\ 0.2076 \\ 0.1920 \\ 0.0407 \\ 0.0689 \\ 0.0999 \end{bmatrix} \begin{bmatrix} \text{Sub criteria} \\ \text{Temp.} \\ \text{TDS} \\ \text{SS} \\ \text{BOD} \\ \text{COD} \\ \text{O\&G} \\ \text{Cl} \\ \text{pH} \end{bmatrix} = 0.7651 \quad (4)$$

Similarly, Matrix 2 presents the aggregate score for treated wastewater in terms of MPAI. Total score for treated wastewater by academicians is 0.4570.

$$\text{Total Score for Treated wastewater for Average Data} = \begin{bmatrix} X_k \\ 0.7225 \\ 0.3486 \\ 0.2214 \\ 0.4093 \\ 0.6781 \\ 0.0410 \\ 0.5299 \\ 0.4666 \end{bmatrix} \begin{bmatrix} W_j \\ 0.1077 \\ 0.1300 \\ 0.1532 \\ 0.2076 \\ 0.1920 \\ 0.0407 \\ 0.0689 \\ 0.0999 \end{bmatrix} \begin{matrix} \text{Sub criteria} \\ \text{Temp.} \\ \text{TDS} \\ \text{SS} \\ \text{BOD} \\ \text{COD} \\ \text{O\&G} \\ \text{Cl} \\ \text{pH} \end{matrix} = 0.4570 \quad (5)$$

Efficiency of the treatment plants was also determined by using equation 4.

$$\text{Effciency} = \frac{\text{Input}-\text{Output}}{\text{Input}} \times 100 \quad (6)$$

The efficiency for data of maximum, minimum and average is 19.77%, 61.38% and 40.27% respectively. Reduction in strength is 0.3081. For predicting efficiency of treatment plant, plot between $BOD_{Treated}$ v/s MPAI was plotted as shown in **Fig. 4**.Where R^2 =0.8649 and equation of straight line is Y= 0.0149X + 0.2728.

It is possible to predict the efficiency of the treatment plant with the graph between MPAI v/s Efficiency. The graph between MPAI v/s efficiency is presented in **Fig. 5**. The **Fig. 5** helps in predicting the efficiency of treatment plant. The equation for the same is Y = -0.128.41X+98.99. To use treated wastewater for irrigation purpose the MPAI should be 0.4642. The sample of BOD less then14 mg/L can be reused for irrigation purpose.

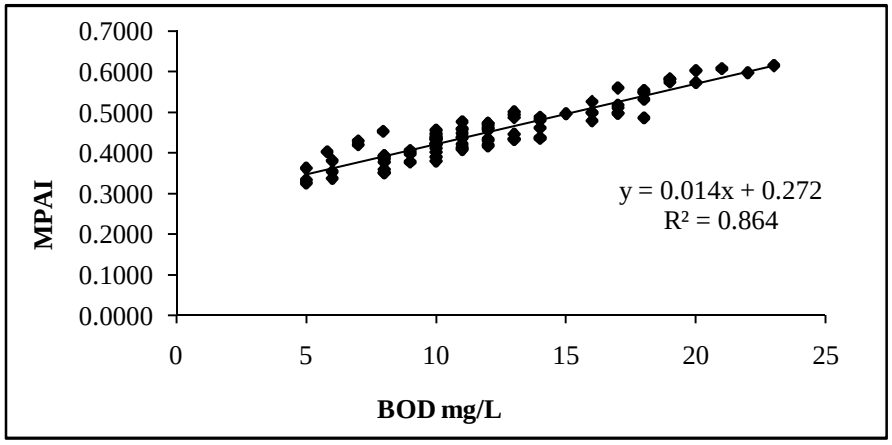

Fig. 4 : $BOD_{Treated}$ v/s MPAI

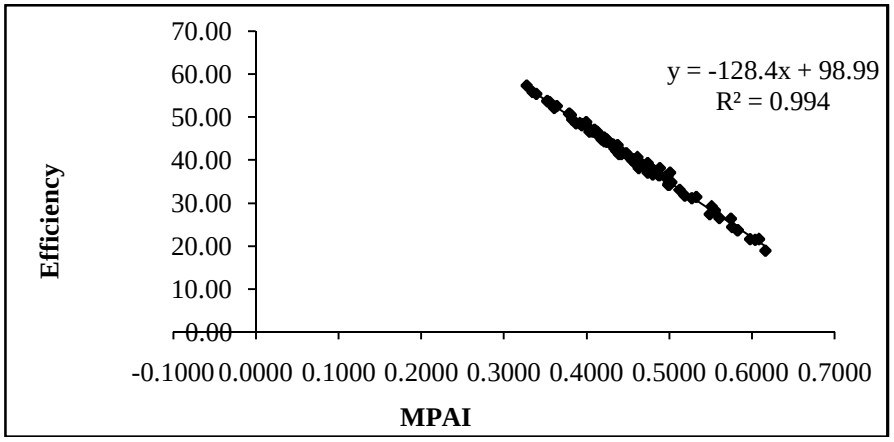

Fig. 5 : MPAI v/s Efficiency

CONCLUSION

In this study, a new index, the Multi Parametric Aggregated Index, (MPAI) has been proposed for comparing the water quality level of an effluent. The MPAI prediction is easy with graph 4 and the predicted MPAI is well within 10 %. At the same time with the help of graph 6 the efficiency can be predicted, where the error in prediction is 15 to 20 %.This index could be of great help to decision makers and environmental managers for evaluating the performance of treatment plant. The decision on environmental issues is invariably based on imprecise parametric data, and the domain experts' opinion in defining the parameters in linguistic terms, which is based on their approximate reasoning and shallow knowledge. Fuzzy logic based approach could be used effectively in environment management systems and evaluating the performance of treatment plant based on pollution potential, in particular.

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