World Applied Sciences Journal 12 (3): 293-298, 2011
ISSN 1818-4952

Evaluating Overall Efficiency of Sewage Treatment Plant Using Fuzzy Composition

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INTRODUCTION

Ever increasing pollution levels are primarily responsible for impairing natural environment. The permissible limits prescribed by the regulatory agencies allow industries and residences to discharge their wastewater in the receiving water bodies (such as stream, rivers and alike). Depletion of water flows in rivers over a period of time and the ever increasing pollution load in the natural bodies is a matter of serious concern. In the absence of adequate dilution, the wastewater treatment plants, that has been discharging its wastes within the permissible norms also contributes its share towards the overall environmental degradation. With a view to improve environmental quality the regulatory agencies have laid down pollution norms. However, the discharge from every wastewater treatment plant to stream is within the pollution norms do not stop rivers getting polluted. It is great concern in the developing countries in the recent past [1]. The surface water bodies have been polluted to such an extent that they have been converted to natural effluent channels. In order to protect and preserve the limited water bodies, the formulation of appropriate pollution abatement strategies is essential. One of the steps in this direction is, to develop, a methodology for finding integrated efficiency of wastewater treatment plant. The efforts detailed herein could possibly be a step forward in this direction. Urbanization and rapid industrial growth has further aggravated the situation in the recent time. Expressing permissible limits of pollution parameters on dichotomous scale (Yes/No) needs a paradigm shift from crisp (Permissible OR Not Permissible) to fuzzy values (Permissible AND Not Permissible) According to Hipel *et al.* [2], a decision problem is said to be complex and difficult, if there exist multiple criteria-both qualitative and quantitative in nature, multiple decision makers, uncertainty, risk and vagueness surrounding the decision-making. An attempt has been made to formulate a fuzzy model employing fuzzy multiple criteria decision making (FMCDM) technique to evaluate integrated efficiency for sewage treatment plant.

In this study, an uncertainty in input variables and its impact on result are characterized with an application of fuzzy set theory [3]. Fuzzy set theory, proposed by Zadeh [4], has been widely applied to solve, with uncertain information, decision making problems. It is proposed to apply fuzzy set theory to the field data. This study focuses on evolving a methodology to develop an overall efficiency for sewage treatment facilities. This can be linked to the policy matters related to pollution taxes and the efforts detailed herein could possibly be a step forward in this direction. The methodology for the study deals with fuzzy weights, expert's perception and decision making under multi criteria environment. Methodology to evaluate overall efficiency for wastewater treatment plants is also a complex multi criteria decision making problem in which primary and secondary treatment processes are evaluated on the basis of it' s pollution potential against large number of decision criteria or pollution parameters.

Needs and Relevance: Different types of efficiency and their measurement, exist. Efficiency is measured as the ratio of some quantity of output to some quantity of input. Usually, here larger the ratio, the greater the efficiency. Some measures invert the relationship to a ratio between input and output so that the smaller the ratio, the greater the efficiency the input may be labor, energy, raw material, or money (also intangibles such as knowledge and know-how). The outputs include intermediate goods, finished products, power and cash value. The power may be thermal, chemical, electrical or mechanical. Various units of measurement are used. Many ratios are given special names such as: labor productivity, yield, energy efficiency, EROI, mechanical efficiency (engineering

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Table 1: Some Measures of Efficiency

Input	Output	Name of Measure
power (electrical)	Power (mechanical)	Mechanical efficiency e.g. drill
Power (electrical or thermal)	Standard quantity of thermal energy removed per annum	Energy consumption (inverse of performance efficiency)e.g. refrigerator (840 kW.h/a)
Work supplied	Heat delivered	Coefficient of performance e.g.heat pump (>1.0)
Power thermal	Power thermal	Thermal efficiency e.g.hot water boiler (85%)
Energy	Energy	EROI energy return on investment e.g. oil extraction
Raw material	Finished product	Yield e.g. Steel
Cost of production	Cost of product	Cost efficiency (micro economics)
Message or information	Speed, accuracy and comprehensibility of information	Commutation efficiency
Man-hours	Mass of finished goods value of product	Labor productivity
Pollution load in waste water treatment plant	Pollution load in waste water treatment plant	?

(Source: Okun. A.," Equality and efficiency")

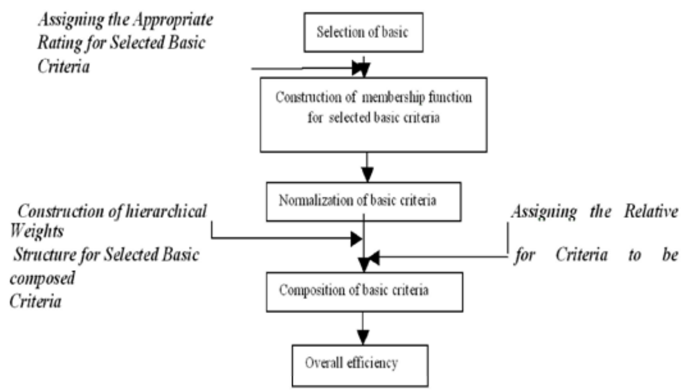

Fig. 1: Schematic Diagram for Study

efficiency), cost efficiency, economy of effort etc. A selection of commonly used measures is presented in the Table below. Efficiency of different input and output, presented in table 1. may be grouped in various ways. The names of the measure are labor productivity, energy consumption, Co-efficient of performance, Thermal efficiency, Yield, Cost efficiency, etc. [5] However for the efficiency of sewage treatment plant measure is undefined. The present trend to monitor the treatment plants is on the basis of removal efficiency of the parametric values. For example, the Biochemical oxygen demand (BOD) removal efficiency of treatment plant is 75% or Chemical oxygen demand (COD) removal efficiency is 68% and so on. This is fair and acceptable when dealing with parametric removal studies. However, the parametric values are not individually separated out when discharges are released into the receiving bodies. Also, the parameters do have interrelationship with one another and so cannot be viewed independently in terms of plant efficiency.

Study Area: Data of wastewater samples for one year was collected from wastewater treatment plant situated at Surat city, applying the prescribed methodology for sampling. These samples were analyzed for eight different physical/bio-chemical wastewater quality parameters as per standard procedure (APHA) [6]. Decision were made on the basis of expert's opinion. Results of present study were taken for the modified FCM model for finding overall efficiency of wastewater treatment plant using parameters namely, pH, Chlorides, BOD, COD, SS, Temperature, TDS and Oil and grease.

Fuzzy Methodology: The efficiency of WWTP is found by using modified fuzzy composite programming. As stated by Gujarat Pollution Control Board (GPCB) parameters were selected for present study. The composite procedure involves a step-by-step regrouping of a set of various basic indicators to form a single indicator [7]. Schematic diagram of study is presented in figure 1.

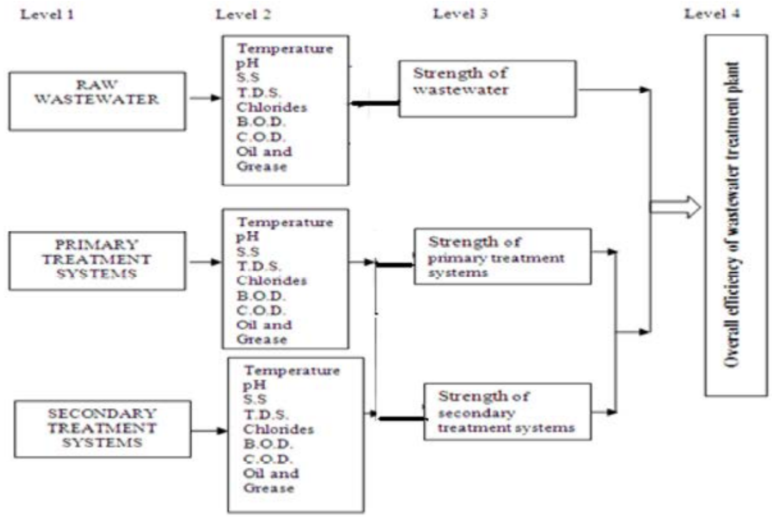

Fig. 2: Hierarchical Composite Structure for Determining Overall Efficiency of Sewage Treatment Plant.

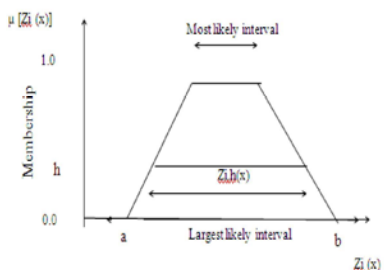

Fig. 3: Fuzzy estimate of ith basic indicator into index Si,h(x)

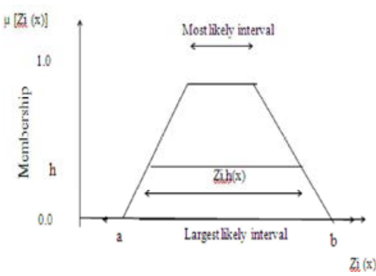

Fig. 4: Transferring actual value Zi,h(x)

Composite structure of the basic indicators is selected for evaluating the overall efficiency of WWTP. The set of basic indicator were grouped in to smaller sub set of second level indicators and at third level the overall efficiency is found due to primary and secondary treatments. A hierarchy structure of a modified fuzzy composite programming for finding overall efficiency is shown in Fig 2. The various components for the entire process will be discussed sequentially

Selection of Basic Criterion: As per the Gujarat Pollution Control Board (GPCB) norms, total eight basic criteria were selected. They were Temperature, SS, TDS, BOD, COD, Oil & Grease, Chloride and pH. These criteria were considered as the input variables for evaluation of the overall efficiency.

Construction of Membership Function: The basic criteria selected for evaluating the overall efficiency of sewage treatment plant contains elements of uncertainty. Several methods, such as probabilistic analysis, fuzzy set analysis and others, can be used to incorporate the uncertainty. Among these, the fuzzy set approach is more useful to solve the uncertainties of criteria than other approaches, particularly in case when input variables are uncertain. Thus in this study, concept of fuzzy set approach is used to characterized the uncertainty, which is inherent to a given set with a degree of membership. In order to evaluate the fuzzy number for different indicators, the most likely and largest likely interval for different parameters is selected. This is presented graphically as trapezoid in fig 3. Experts perception for best and worst values of indicators were selected. A level cut concept is used to define the interval of each basic indicator at various level of confidence. In order to evaluate the overall efficiency of sewage treatment plant with elements of uncertainty, let Z_i (x) be a fuzzy number for the i^{th} basic criterion and lets its membership function μ [Zi (x)] be a trapezoid (Fig.3), where x denotes an element of the discrete set of management alternative being analyzed. If the trapezoid is reduced to a vertical line, it represents a so-called crisp number. A level-cut concept [8] is used to define the interval of each basic indicator at various levels of "confidence". Then the membership function for each of the basic criterion can be constructed as shown in

Fig.2, where $Z_{i,h}$ (x) is an interval value of the ith basic criterion at the confidence level (membership degree) h, [i.e. a= $Z_{i,h}$ (x) =b]. The best and worst value for the basic criterion is determined by expert's opinion. Using the best value of Z_i($BESZ_i$) and the worst value of Z_i ($WORZ_i$) for the i^{th} basic indicator, the actual value $Z_{i,h}$ (x) is transformed into an ith normalized basic criterion value. The actual value $Z_{i,h}$ (x) is transformed into an index value $S_{i,h}$ (x)denoted by (Fig. 4). Since the actual value Zi,h(x) is an interval with lower bound a and upper bound b (Fig. 4), the index value Si,h(x) resulting from Zi,h(x) is also an interval (Fig. 3).

1. If $BESZi > WORZ_i$, then

$$S_{i,h}(x) = \begin{cases} 1 & Z_{i,h}(x) \geq BESZ_i \\ [Z_{i,h}(x) - WORZ_i]/(BESZ_i - WORZ_i), & WORZ_i < Z_{i,h}(x) < BESZ_i \\ 0 & Z_{i,h}(x) \leq WORZ_i \end{cases} \quad \ldots\ldots\ldots(1)$$

2. If $BESZi < WORZ_i$, then

$$S_{i,h}(x) = \begin{cases} 1 & Z_{i,h}(x) \leq BESZ_i \\ [Z_{i,h}(x) - WORZ_i]/(BESZ_i - WORZ_i), & BESZ_i < Z_{i,h}(x) < WORZ_i \\ 0 & Z_{i,h}(x) \geq WORZ_i \end{cases} \quad \ldots\ldots\ldots(2)$$

Using the index values of basic indicators, index values, Li, h(x), of second-level composite indicators can be defined by:

$$L_{i,h(x)} = \left\{ \sum_{i=1}^{n_j} w_{ij} \left[S_{i,h,j}(x) \right]^p_j \right\}^{(1/P)} \ldots\ldots \quad (3)$$

Where n_j = The number of elements in the first –level group j;

$S_{i,h,j}$ (x) = The index value for the ith indicator in the first level group j of basic indicators;

w_{ij} = The weight reflecting the importance of each basic indicator in second level group;

P_j = The balancing factor for the second level group j

Where n_j = the number of elements in the second –level group j;

$S_{i,h,j}$(x) = the index value for the ith indicator in the second level group j of basic indicators;

w_{ij} = the weight reflecting the importance of each basic indicator in second level group

P_j = the balancing factor for the second level group j

Weighting coefficients are assessed to reflect the relative importance of each of the indicators.

Determination of Weigh: Weighting coefficients are assessed to reflect the relative importance of each of the indicators. To calculate the weighting coefficient for each of the indicators, the procedure developed by Saaty is

Table 2: Linguistic Measures of Importance, a_{ij}

Sr No.	Definition	Intensity of Importance
1.	Equal Important	1
2.	Weak Important	3
3.	Strong Important	5
4.	Demonstrated Importance	7
5.	Equal Importance	9
6.	Intermediate Values	2,4,6,8

applied. The procedure called the analytic hierarchy process (AHP) can be used to obtain the relative weight of each of the indicators in a group based on a paired comparison of each of the indicator [8]. To compare indicator *i* with indicator *j*, the decision maker assigns value a_{ij} from table 2.

All the first level indicators such as Temperature, pH, SS, TDS, BOD, COD. Chlorides and O&G in Fig.2 are compared in a pair wise manner using Table 2. By following above procedure an 8×8 matrix A. Construction of matrix A is presented below.

A = (4)

	BOD	COD	SS	TDS	pH	Temp.	O & G.	CI
BOD	1	5	7	9	4	6	8	3
COD	1/5	1	3	5	2	8	4	2
SS	1/7	1/3	1	7	2	4	3	6
TDS	1/9	1/5	1/7	1	9	4	6	8
pH	1/4	1/2	1/2	1/9	1	3	2	4
Temp.	1/6	1/8	1/4	1/4	13	1	3	6
O & G.	1/8	1/4	1/3	1/6	1/2	1/3	1	3
CI	1/3	1/2	1/6	1/8	1/4	1/6	1/3	1

$$w = \begin{vmatrix} 0.39 \\ 0.18 \\ 0.15 \\ 0.12 \\ 0.06 \\ 0.05 \\ 0.03 \\ 0.02 \end{vmatrix} \quad (5)$$

By solving eigenvalue problem (4) obtain the unit eigenvector , W corresponding to $Ö_{max}$. The values are 0.39, 0.18,0.15,0.12,0.06,0.05,0.03 and 0.02 for BOD,COD, SS, TDS, pH, Temperature, O&G and Chlorides respectively.

Determination of Balancing Factors: The balancing factor ($p \geq 1$), was assigned to groups of the indicators to reflect the importance of the maximal deviation, where maximal deviation means the maximum difference between an indicator value and the best value for that indicator.

Table 3: Second Level Fuzzy Value for Basic Indicators for Raw Wastewater

Parameters	S_{ij} Normalized fuzzy value of first level indicator for raw wastewater	w_{ij} Weight factor	p_j Balancing factor
BOD	0.7	0.39	1
COD	1	0.18	1
SS	1	0.15	1
TDS	0.65	0.12	1
pH	1	0.06	1
Temperature	1	0.05	1
O&G	1	0.03	1
Chlorides	1	0.02	1

Solving table 3 with following equation, the strength of raw wastewater is 0.841

Table 4: Second Level Fuzzy Value for Basic Indicators for Treated Wastewater

Parameters	S_{ij} Normalized fuzzy value of first level indicator for raw wastewater	w_{ij} Weight factor	p_j Balancing factor
BOD	0.2	0.39	1
COD	0.5	0.18	1
SS	0.45	0.15	1
TDS	0.5	0.12	1
pH	0	0.06	1
Temperature	0.5	0.05	1
O&G	0	0.03	1
Chlorides	0.24	0.02	1

By solving the data given in table 4, using above equation the overall strength of treated wastewater is 0.3253

Table 5: Strength of Sewage Wastewater for Raw Wastewater And After STS

Strength of wastewater	
Raw	0.841
Treated wastewater	0.325
Reduction in strength	0.516

The larger the value of the balancing factor, the greater the concern with respect to the maximal deviation. When p=1, all deviation are equally weighted. When p=2, each deviation receives its importance in proportion to its magnitude. As the value p becomes larger and larger, the deviation has more and more importance.

Case Study: The case study relates to the field data from sewage treatment plant in Surat city. The effluent discharged were observed , the limit set by governing authority The first level fuzzy indicators for Raw wastewater and STS were determined by using the methodology previously described. Second level indicator values were also determined by same methodology. These values are the strength of pollution in wastewater before treatment and after treatment. With the help of equation (3) the S_{ij} Normalized fuzzy values of first level indicator were determined. Table 3, illustrates the first level fuzzy indicators using best and worst value for each basic indicator for raw wastewater.

While Table 4 indicates the second level fuzzy value for treated wastewater as basic indicator.

Table 5 shows the strength of raw wastewater and treated wastewater.

Determination of Overall Efficiency of WWTP: From above results reduction in strength of wastewater is from 0.841 to 0.325. Total reduction is 0.516 due to primary treatment processes and secondary treatment processes. The overall efficiency is 61.36%.

CONCLUSION

There is no perfect methodology to evaluate the overall efficiency of the wastewater. From present study the strength of waste after treatment has reduced by 0.516 degree of certainty. Ideal situation the strength of treated wastewater should be near zero. If the different indices for the treated wastewater strength are identified depending on its reuse the same waste water can be used for irrigation, bathing or fishery purposes. At present with the same data the conventional efficiency is above 86.00%.The final result may vary with the weights and balancing factors assigned to each indicator and group. Thus, a sensitivity analysis is needed to investigate the effect for the weights and balancing factors. Because the selection of different basic indicators may also lead to different results, care must be taken to select all of the critical system indicators so that other indicator choices will not radically alter the result of the analysis. The modified fuzzy-composite programming method can be a useful decision making tool where there are conflicting objectives; the objectives are of varying degrees of importance; and the values of the basic indicator variables are uncertain.

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