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Determination of Wastewater Quality Index of Municipal Wastewater Treatment Plant using Fuzzy Rule Base

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ABSTRACT

Seasonal variation, storm water intrusion, ambient temperature etc. are the factors which affects the waste water quality due to which it is difficult to define the quality of wastewater. Wastewater Quality Index (WWQI) is a unit less number ranging within 1 to 100 and able to indicate overall characteristic of wastewater. This index helps to have a competent model to optimize the treatment processes. Present work deals with determination of wastewater quality index using fuzzy rule base approach. Three wastewater treatment plants were studied for a span of a year. Characterization was carried out on the basis of Temperature, Total dissolved solid (TDS), Suspended Solid (SS), Biological oxygen demand (BOD), Chemical oxygen demand (COD), Phosphate, Chloride (Cl^-), pH Sampling and characterization was carried out as per APHA guideline. WWQI was defined in the range of class 1 to class 5.

Keywords: Characterization, class, fuzzy, rule base, WWQI

INTRODUCTION

Municipal wastewater treatment plants (MWWTP) mostly deal with municipal sewage and storm water [1]. The characterization of wastewater treatment plant inlet helps to define treatment units to be introduced and their capacities. Wastewater characterization has become a very significant parameter in waste management process due to changed characteristics of wastewater, regulation laid by state or central pollution control board on discharge policy, etc. A typical wastewater treatment system for WWTPs has three treatment phases. Primary treatment phase to remove solids from wastewater using gravitational settling, flotation, and sedimentation, secondary treatment phase consisting biological treatment using microorganisms, and tertiary treatment phase of disinfection [2].

Fig. 1 elaborates a typical flowchart of different processes adopted sequentially in WWTP. Wastewater characterization has become a very significant parameter in waste management process due to changed characteristics of wastewater, regulation laid by state or central pollution control board on discharge policy, etc. The systematic approach towards wastewater characterization helps to achieve realistic data and will be helpful for efficient treatment mechanism developments. Wastewater is characterized in terms of its physical, chemical and biological constituents, [3]. Determination of these characteristics on daily or hourly basis is necessary for proper control over all the activities.

Optimization in WWTP operation is essentially need to be carried out for better utilization of all the resources involved in the entire system of WWTP. At WWTP resources such as manpower, energy and chemicals are need to be utilised sensibly. In case of manpower these are nontechnical persons running all operative procedures. Such agencies could face difficulty to interpret the observations found regarding waste water characteristic at different Phases of treatment. There is a need of protocol to be developed which could elaborate waste water quality in simplest way which will be easily get interpreted by lay man. Wastewater quality index (WWQI) is the unique numbers which indicate an overall characteristic of wastewater by considering all above mentioned characteristics. This index may facilitate to reduce laborious characterization. A very few approaches were found for determination of WWQI. Many of which had adopted statistical approach to evaluate WWQI. The mechanism of calculating WWQI becomes more complicated as multiple parameters affecting waste water treatments are essentially need to be considered.

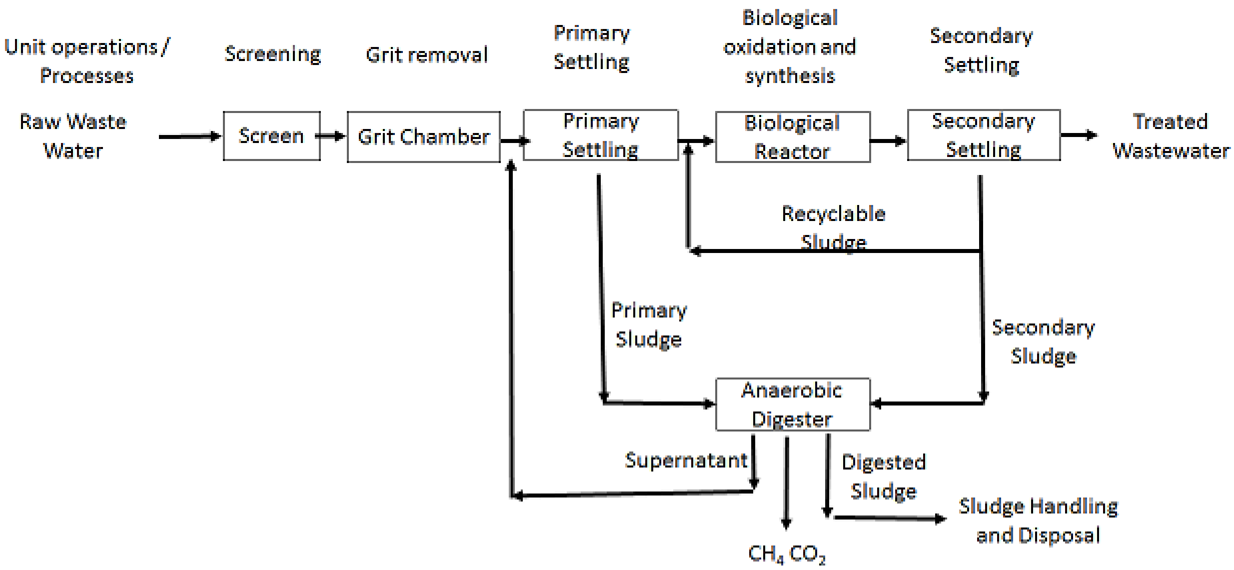

Fig. 1 Typical process flow diagram at MWWTP

For MWWTP quantity of inflow is found unstable. Concentration and dilution varies due to various factors like seasons, festivals, droughts etc. The peak hour concentration is considerably higher than the rest of the period. Thus the data obtained is vague. In such circumstances fuzzy approach will be more suitable. When there is a situation of decision making with multiple inputs and multiple outputs, fuzzy approach is the best optimizing tool. Fuzzy logic is a complex mathematical method that allows solving difficult simulated problems with many inputs and output variables [4]. As all the characteristics are having typical range, the time specific sample need to be identified. In fuzzy approach these characteristics are expressed in the form of linguistic variables [5].

A present work will deal with wastewater characterization and determination of wastewater quality index using Fuzzy approach. This paper focuses on determination of wastewater quality index of municipal wastewater treatment plant using fuzzy rule base approach. A software MATLAB R2015a® was used to run the fuzzy inference system and also to define WWQI. Earlier Bhargava *et al* suggested grouping of water quality parameters for potable purpose and evaluated a water quality index for drinking water supplies [6]. Ahmaid Said *et al* [7]defined a new water quality index for big lost river water shed in Idho to assess water quality for general use. Babaei *et al* developed water quality index for river in Iran by using fuzzy logic to estimate the uncertainties and nonlinear behaviour of the system [8]. Abhishek and Khambete developed a multiple regression formula in order to define wastewater quality based on CCME method [9]. The wastewater quality index of the influent wastewater in the existing treatment plant site at Puducherry (India) was evaluated by Govindassamy [10]. The parameters considered for this study were pH, TDS, TSS, BOD, COD, N as NO_3 and P as PO_4, which were used for the determination of WWQI and statistical analysis. Multiple Linear Regression (MLR) and Artificial Network Analysis (ANN) models were also developed for WWQI and compared.

Mudiya discussed the various methodologies of WQI and WWQI, which can be used for determination of WWQI as well as concept of model and its consideration [11]. RMSE and CCME methods were adopted to evaluate the same. Effluent Quality Index (EQI), is an efficient tool for rapidly evaluation of the quality achieved by different treatment systems for reuse purposes by Nezhad [12]. The index was developed by a weighted average of eight parameters (TSS, BOD5, COD, NH4, PO4, Fecal coliform, TDS, and pH) which obtained from Delphi method and Fuzzy TOPSIS decision making tools. Calculation of water quality rating curves (sub- indices) were based on giving a rating scores of 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100 corresponding to the 5^{th}, 10^{th}, 20^{th}, 30^{th}, 40^{th}, 50^{th}, 60^{th}, 70^{th}, 80^{th}, 90^{th} and 99 percentiles respectively to each parameter observations. Then, the thresholds for different reuses and discharges are defined by using environmental limitations and developed EQI. Finally, the effluent quality of South Waste Water Treatment plant of Tehran for summer and autumn was evaluated using the developed EQI.

MATERIAL AND METHODS

Study area was specially selected due to few parameters like, geometric growth of population and infrastructural development in recent decade, inclusion under smart city corridor, lack of efficiency assessment by last so many years, need of optimization in wastewater treatment operation with reference to power consumption and operational cost etc. Three WWTPs with almost equal capacities were selected. The sampling drives for all WWTPs were carried out for a period of twelve months. After every treatment step samples were collected. Each WWTP was sampled three times during the evaluation period. The average values were considered for further decision making process. The characterization was carried out within the criterions, temperature, Total Dissolved Solids (TDS), Suspended Solids (SS), Biological and Chemical Oxygen Demand (BOD and COD), pH, Phosphate and Chlorides. Samples were preserved at 40C while carrying them to the laboratory. Also were immediately analysed for Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD5), pH and turbidity. All the analyses were carried out as per the Standard Methods laid by APHA. Detailed characterization of wastewater samples is summarized in Table -1 with average values of three sampling campaigns.

Fuzzy logic uses variables like extreme low, low, moderately high, high etc. in place, of true/false or yes/no variables. The linguistic variables of a fuzzy set for input are set to be low, moderate, high, and extremely high and that for output are Class 1 to Class 5.

The next step is the normalization of the basic indicators to convert non-commensurate indicators into unit less entities. This is necessary because all basic indicators have different units and are difficult to compare in their respective units. In order to evaluate the fuzzy number of different indicators, the most likely and largest likely interval for different parameters was selected. This graphically presented as trapezoid in Fig. 2. 'Experts' perception of best and worst values of indicators was selected. In order to evaluate the overall efficiency of WWTP with elements of uncertainty, let Zi (x) be a fuzzy number of the ith basic criteria, and lets its membership function μ [Zi (x)] be a trapezoid, Fig. 2, where x denotes an element of the discrete set of parameters alternative being analysed. If the trapezoid is reduced to a vertical line, it represents a so-called crisp number. Alpha level-cut concept is used to define the interval of each basic indicator at various levels of 'confidence' [13].

Fuzzy sets are determined by membership functions. The membership function for each of the basic criteria can be constructed as shown in Fig. 2, where Zi,h(x) is an interval value of the ith basic criteria at the confidence level (membership degree) h, [i.e., a ≤ Zi,,h (x) ≤b]. The best and worst value for the basic criterion is determined by expert's perceptions.

Using the best value of Zi (BESZi) and the worst value of Zi (WORZi) for the ith basic indicators, the actual value Zi,,h(x) is transformed into an ith normalized basic criterion value. Triangular membership functions are used.

Table -1 Characteristics of Inlet Wastewater

	Temp.	TDS	SS	BOD	COD	Phosphate	Cl^-	pH
	Average							
WTP 1	26	572	144	132.67	404.66	6.61	309	7.54
WTP 2	29	559	157	146.12	437	6	303	7.58
WTP 3	28	554	148	141	432	6.15	305	7.49

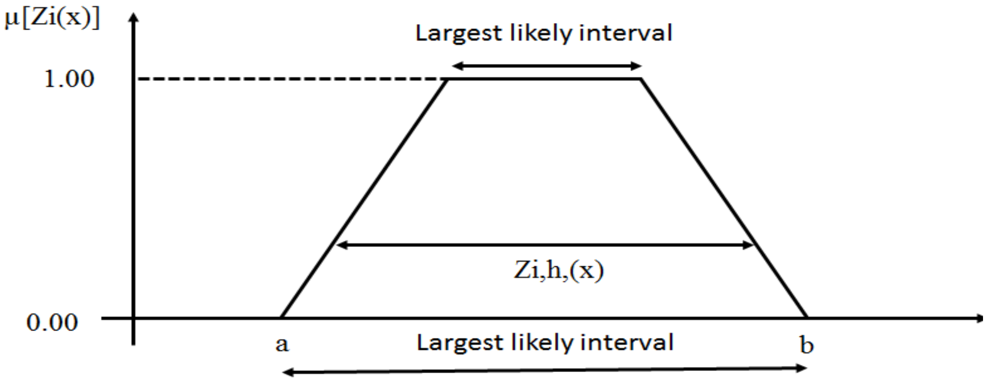

Fig. 2 Fuzzy estimate of ith basic indicator

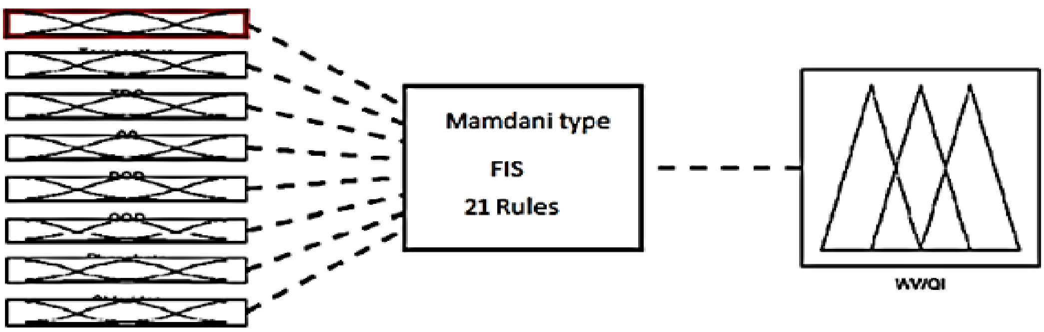

Fig. 3 Fuzzy Inference System

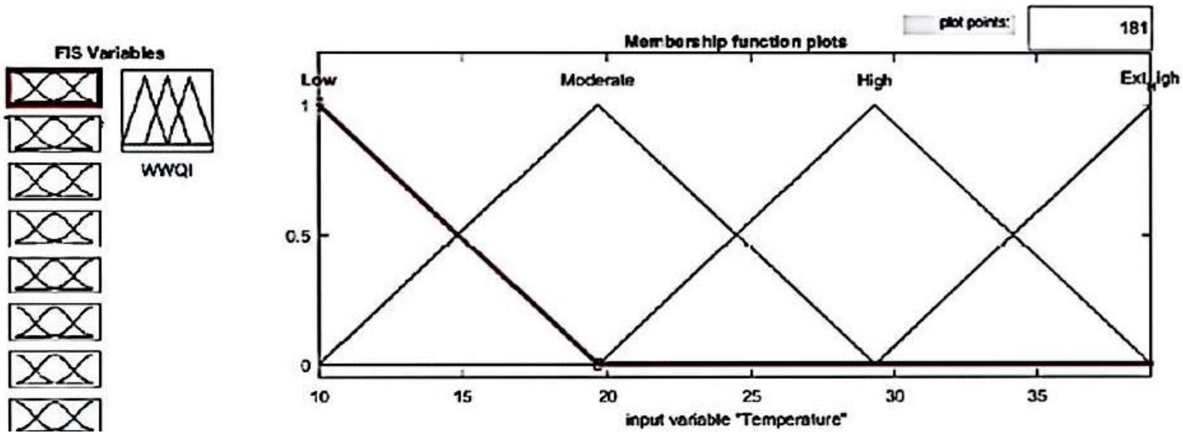

Fig. 4 Membership Function and linguistic variables for input Temperature

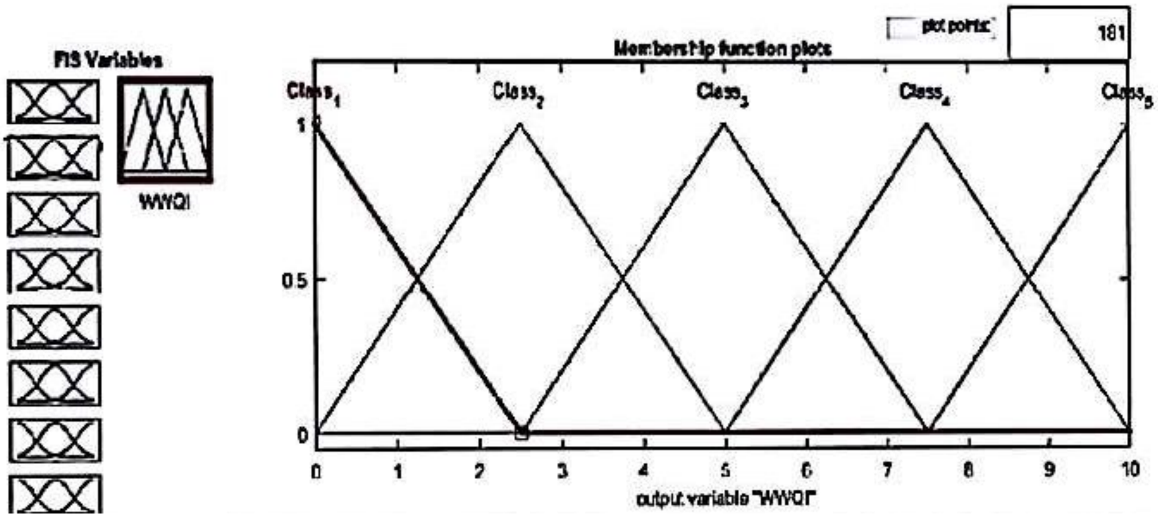

Fig. 5 Membership Function and linguistic variables for output – WWQI

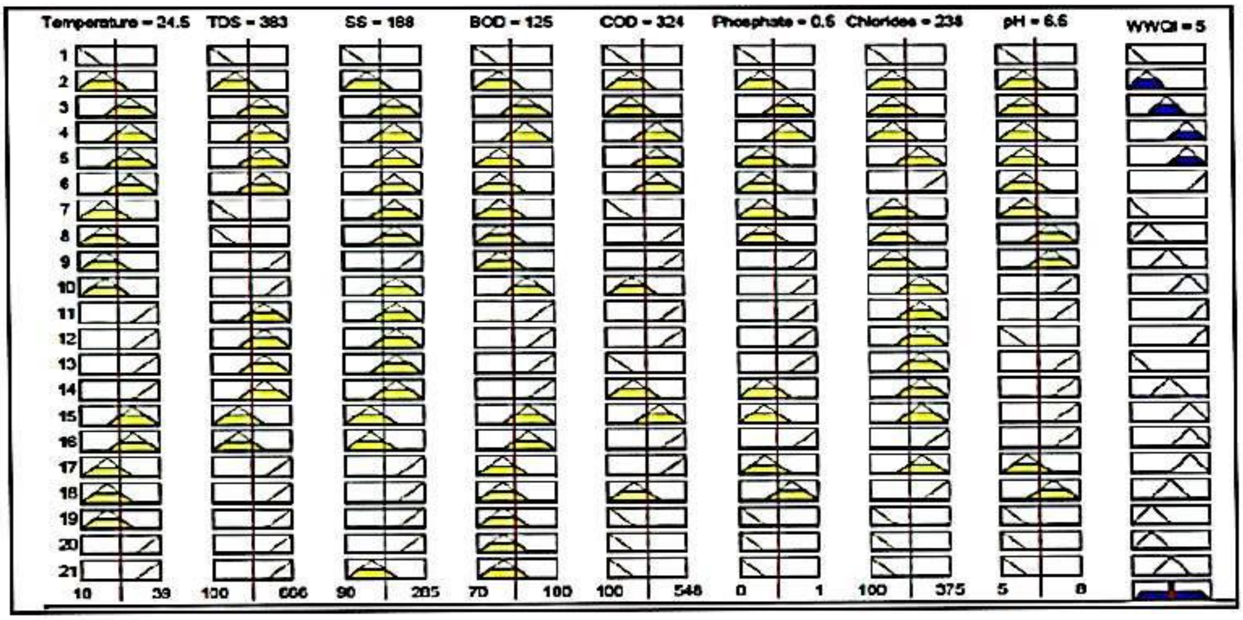

Fig. 6 Fuzzy Output indicating WWWQI

The fuzzy rule based system is structured as IF temp is x_1 AND TDS is x_2 AND SS is x_3 AND BOD is x_4 AND COD is x_5 AND Phosphate is x_6 AND Chlorides is x_7 AND pH is x_8 THEN WWQI is class Y. In Fig. 2, fuzzy inference system designed to calculate WWQI has been elaborated. The system has eights inputs which were with crisp data obtained from laboratory analysis. For each input membership function was defined as shown in Fig. 3. The Mamdani type FIS was adopted and output, WWWQI was in the form of class 1, class 2, class 3, class 4 and class 5. The membership function for the output is same as shown in Fig. 4. The fuzzy approach to calculate WWQI was adopted for the crisp data obtained from two WWTPs i.e. $WWTP_1$ and $WWTP_3$ and the model was calibrated and validated for the characteristics of $WWTP_2$. Calibration and validation is essential to adopt the calculated index universally or at least for same territory.

Rules were constructed in accordance to expert opinion [14]. Experts were chosen from industry, academician, Ph.D. students, plant chemist and technical persons from WWTP. Total 21 rules were applied to inference system so as to get output in the form of WWQI. The fuzzy toolbox uses MIN operator (AND method) for inference of a fuzzy rule. The final output of all rules is a fuzzy set obtained by MAX operator. The centroidal method is used for obtaining crisp output of the model for given set of input parameters. Following equation is used for defuzzification of the fuzzy set obtained by inference of various rule.

$$x^* = \frac{\sum_{i=1}^{n} x1 \, \mu \, x1}{\sum_{i=1}^{n} \mu \, x1} \tag{1}$$

RESULTS AND DISCUSSIONS

The WWQI obtained through input variables, provides a realistic simulation with the data obtained from $WWTP_3$. Output classes were defined in such a manner that it will be more significant and easy to identify waste water quality. In Fig. 6, WWQI has been developed using MathWorks - MATLAB®. More the WWQI indicates higher organic load. If compared with central pollution control board limits, it will be easier task to regulate the discharge standards using WWQI calculated by this approach. When statistical approaches are adopted for the same kind of evaluation, the results are different, as in case of statistical way, quantitative database affects the reality. There will be no any effect in case of less numbers of field data. This limitation can be overcome in fuzzy rule base approach and hence sensitive. In case of quantitative evaluation also it may be observed that the percentage loading removal with reference to all the characteristics is also considerably more in case of $WWTP_{2.}$ TDS, COD and chlorides are major performance indicators being used by experts. The present WWTP also comprises to these parameters as removal efficiency has been found to about 85%.

Classes defined could able to define treatment strategies and severity of wastewater concentrations without performing detailed characterization. Chloride concentration at extreme high in concern with extreme high concentration of TDS along with extreme high concentration of COD definitely needs to provide WWQI as class 5. If the results correlated with wastewater discharge norms laid by central pollution control board class 1 and class 2 wastewater need to be treated for secondary treatment while class 3, class 4 and class 5 wastewater need to be undergone trough tertiary treatment too.

CONCLUSION

Calculation of WWQI using fuzzy rule base approach has found a more realistic as process involves expert participation and so practical. In entire process a structure of rue base is more significant. Formulation of rules reflects realistic wastewater quality in accordance to Indian scenario, hence results found more practical and model could validate better. A fuzzy approach for WWQI provides a simplest approach to interpret the wastewater quality. The WWQI obtained will define the quality of wastewater and corresponding essential treatment. This will also help to make easy field measurements by layman. WWQI can be displayed at the various location of the plant so that every authority involved will be well aware for treatment strategies. $WWTP_2$ receives a wastewater with quality as described in table 1. Accordingly, it is essential to provide preliminary, primary, secondary as well as tertiary treatments to the waste water. WWQI of class 4.45 for $WWTP_2$ indicates the same wastewater quality.

In continuation of this work, it is possible to calculate WWQI after every treatment stage so that the optimization in every succeeding process can be introduced. The resource optimization on WWTP is very essential and display of WWQI at respective locations will be helpful for better operations on plant.

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