QUANTIFYING IMPACT ON WATER ENVIRONMENT BY USING FUZZY SET THEORY

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ABSTRACT

Assessment of the impact of developmental activities on water environment is difficult to measure as numbers of parameters are involved in the overall assessment of water quality. Efforts have been taken to develop Water Quality Index to measure water quality (WQI) by considering various parameters involved in measuring quality of water. The impact can be measured by analyzing difference between quality of water before and after the project. Due to limitation involved in present indices more rational approach is needed to find quality of water. The parameters involved in calculating indices to measure water quality are different in all the cases. Due to limitation of the theory based on Crisp set on which these indices are based we need more advanced technique which can handle vague, fuzzy and imprecise values with a better approach. In order to minimize ambiguity, vagueness, uncertainty and subjectivity fuzzy inference system proved to be a more rational approach. In present work fuzzy set theory is used to analyze water quality. The difference between water quality before and after the project is designated as Fuzzy Impact on Water Environment (FIWE).

KEYWORDS: Fuzzy Impact on Water Environment, Fuzzy Water Pollution Index & Water Quality Index

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INTRODUCTION

As quality of water is worsening, it is one of the most important environmental issue in present era. Different characteristics of water have various indicators of water quality. For drinking purpose regulating agencies have set different standard values as acceptable and permissible values. To find index of water quality crisp set theory is used in all the indices, which involves standing boundary conditions. However, there is no index of water quality which is acceptable to all. In some of the indices weightage factors are used for different parameters.[1]

CRISP WATER QUALITY INDEX

A complete picture of water quality cannot be assessed as the analysis reports of water quality are too technical and detailed. To solve this problem different indices to find water quality are developed all over the world.[Liouet al., 2004; WEP, 1996; Cude, 2001; Mitchell and Stapp, 1996; SAFE, 1995; Said et al., 2004]. U.S. National Sanitation Foundation have developed number of indices to find quality of water [NSF, 2005]. The toxic and hazardous pollutants for example hydrocarbons, pesticides, heavy metals are ignored in most of the indices. The Index equation of water quality are influenced by some parameters dramatically and don't give satisfactory final report. However, uncertainty ambiguity involved in complex environmental issues remains unaddressed and However, the most critical deficiency of these indices is the lack of dealing with uncertainty and this is major deficiency with the present indices [Mpimpas et al., 2001; Chang et al., 2001; Silvert, 2000].

As numbers of discrepancies are involved with present indices an advanced and rational approach in designing of water quality index is needed. The parameters involved in finding WQI are diverse in all the cases. Due to these restrictions of crisp set theory more rational computation method is needed which requires to be capable of managing vague, imprecise and fuzzy values in decision making on monitoring and reporting the water quality. In present work an attempt is made to quantify impact on water environment by using fuzzy set theory.

WATER POLLUTION INDEX BY USING FUZZY SET

Fuzzy set is conceptually easy to understand and it is based on natural language. It is used in modeling non-linear functions and in handling imprecise data [Romano et al., 2004; Pham and Pham, 1999; Zadeh, 1996; Ross, 2004]. This characteristic is successfully applied to solve environmental problems related with water quality. [McKone and Deshpande, 2005; Vemula et al., 2004; Liou and Lo, 2005; Sadiq and Rodriguez, 2004; Ghosh and Mujumdar, 2006].

In order to avoid uncertainties involved in obtaining quality of water method based on fuzzy set theory is projected. Keeping the significance of vagueness handling in the assessment of water quality and usefulness of the fuzzy theory in the assessment making in the vague environment', the contamination level of water is classified by fuzzy set based index.[1]

Out of so many chemical, biological and physical characteristics certain imperative parameters namely Fluoride, total hardness (TH), total dissolved salts (TDS), pH, total alkalinity (TA), and iron are taken under consideration for the Fuzzy inference system approach as recommended earlier by [Garg et al. 1998 and Dahiya et al. 2005, 2007] for the assessment of water quality for domestic need. Fuzzy set theory might be considered as simplification of theory of classical. A fuzzy set can be defined with respect to its membership function, which outline sits domain of interest onto the interval [0, 1]. The truth value is represented by membership function, weightage factor, belongingness or the degree, that the value under consideration belongs to the particular set. On basis of expert opinions and guidelines directed by WHO (1984), BIS (1991), fuzzy membership functions were intended for all concerned parameters. For ease in operation the parameters involved in assessing water quality are divided in two groups In first group total alkalinity, total dissolved solids; pH were considered that results in Group-1 Water Pollution Index Fuzzy based as an output. In second stage of model output of group_1 issued as an input.

MODEL DEVELOPMENT OF MODEL TO CALCULATE WATER POLLUTION INDEX GROUP-1 FUZZY BASED (FWPI-GROUP-1) MODEL_1 CONSIDERED INPUT VARIABLES

Total Dissolved Solids, pH and Total Alkalinity are considered as input variable to calculate Water Pollution Index fuzzy based. Trapezoidal shape is considered as nature of the membership function. Membership function for pH, linguistic variable "Desirable" is assigned 4 values (6,6.5,8.5,9) that reflects the truth value (MF ie membership function) and it ranges from 0 to 1 between 6 and 6.5, for 6.5 to 8.5 it is considered as absolute 1 and between 8.5 to 9 it is considered 1 to 0.

pH**Table 1: Ph with Truth Value (MF)**

S N	MF	pH
1	Unaccepted (Low)	(0,0,5,6.5)
2	Desired	(6,6.5,8.5,9)
3	Unaccepted(High)	(8.5,9,14,14)

Figure 1: Input Variable "Ph" (Fuzzy Set)**TDS****Table 2: TDS with Truth value (MF)**

Sr. No	MF	TDS mg/l
1	Desired	(0,0,500,600)
2	Accepted	(500,600,1900,2100)
3	Unaccepted	(1900,2100,2500,2500)

Figure 2: Input Variable TDS in mg/l (Fuzzy Set)**Total Alkalinity****Table 3: TA with Truth Value (MF)**

Sr. No.	MF	TA mg/l
1	Desired	[0,0,175,225]
2	Accepted	[175,225,575,625]
3	Unaccepted	[575,625,1000,1000]

Figure 3: Input Variable TA (Fuzzy Set)

Truth Value (MF) of Output Variable FWPI-Group-1

Table 4: MF for FWPI-Group-1 Variables

Sr. No.	MF	Index
1	Desired	(0,0,30,40)
2	Accepted	(30,40,60,70)
3	Unaccepted	(60,70,100,100)

Figure 4: Variable FWPI-Group-1 (Fuzzy Set)

Water quality is defined on the basis of the concentration of any input variable. For example, on basis of the Total Alkalinity's concentration, it can be defined as Desired, Accepted, and Unaccepted. It is reflected in Figure 3 that set of Total Alkalinity for Accepted range water varies between 175 and 625 mg/l. The 1st value 175 mg/l is least as zero as membership value, it increases to 1 at 225 mg/l and remains constant upto 575 mg/l and comes back to zero at 625 mg/l. The truth value as membership function for Total Alkalinity is given on Y axis. It is apparent that value of Total Alkalinity 595 mg/l is in both sets: Accepted and Unaccepted, but its truth value as membership varies in both the set.

RULE FORMATION FOR FWPI-GROUP-1

A mathematical expression derived by algebraic operations is used in the crisp set to calculate WQI and later it is converted into descriptors for information.

In order to obtain WQI by using Fuzzy Inference System rules are formed by using expert knowledge. Rules are formed by using propositions of antecedent which consists attributes for input variables.

Attributes have linguistic expression for example Desired, Accepted, and Unaccepted. The linguistic descriptions are perpetually imprecise and have insufficient information on the health aspect of each parameter on the user and the combined effect of entire parameters on the human physical condition. Additional uncertainty is also added in the system due to field data error. (Ross, 1997).

Rules are articulated as IF antecedent, THEN consequent, as natural language. For example,

Rule 1: **IF** pH is not desired OR TDS is unaccepted OR TA is unaccepted

THEN FWPI-Group-1 is harmful.

For FWPI-Group-1 pollutants by using OR/AND operators rules are formed to enfold set of all possible grouping of TA, TDS and pH. Rules are as below in Table 5.

Table 5: Rules Formation for FWPI – Group- 1

Rules	IF					THEN
S. No	pH		TDS		TA	FWPI_Group-1
1	Not Desired	OR	Unaccepted	OR	Unaccepted	Unaccepted
2	Desired	AND	Desired	AND	Desired	Desired
3	Desired	AND	Desired	AND	Accepted	Accepted
4	Desired	AND	Accepted	AND	Desired	Accepted
5	Desired	AND	Accepted	AND	Accepted	Accepted

ESTIMATION OF FWPI-GROUP-1

Fuzzy inference system based on Mamdani concept is used in model to operate fuzzy numbers. In first step all rules are identified in which value of each parameter falls. Output fuzzy set based on these truth value using operators OR/AND can be implicated. The resultant output of all the rules is finally aggregated and then defuzzified to find the value of FWPI-Group-1 and its class. All the parameters considered to determine water quality Index by using Fuzzy Set were not accommodated in first model (Model_1), therefore, rest of the parameters Fluoride, Iron and total hardness are considered in second model (Model_2). The output of Model_1, **FWPI-Group-1**, was taken as an input in Model_2 in order to accommodate the effect of 'total dissolved solids, 'total alkalinity' and 'pH' to find FWPI as final index [1]

DEVELOPMENT OF MODEL TO CALCULATE WATER POLLUTION INDEX FUZZY BASED FWPI (MODEL-2) INPUT AND THEIR TRUTH VALUE (MF)

FWPI-Group-2, Iron, Total Hardness and Fluoride were considered as variable for input to calculate Water Pollution Index Fuzzy based as Final value. The shape of membership functions was selected trapezoidal. Membership function of Total hardness, “Desired” as linguistic variable has fore values i.e. (0,0,275,325), that represents that truth value (MF) which varies from 0 to 0 for 0 to 0 mg/l, between 0 to 275 it is 1 and between 275 to 375 mg/l, it varies between 1 to 0.

Water Pollution Index Fuzzy Based Group 1 (FWPI-Group-1)

Truth Value (MF) for FWPI-Group-1 is as in Table 4 and its fuzzy set is given in Figure 4.

Total Hardness

Table 6: Truth Value (MF) of Total Hardness

Sr. No.	Membership Function for TH	mg/l
1	Desired	(0,0,275,325)
2	Accepted	(275,325,575,625)
3	Unaccepted	(575,625,800,800)

Figure 5: Input Variable Total Hardness (mg/l) Fuzzy Set

Fluoride**Table 7: Truth Value (MF) Fluoride**

Sr. No	MF for Fluoride	mg/l
1	Desired	(0,0,0.2,0.3)
2	Accepted	(0.2,0.3,1,1.5)
3	Unaccepted	(1,1.5,2.5,2.5)

Figure 6: Input Variable Fluoride (mg/l) Fuzzy Set**Iron****Table 8: Truth Value (MF) of Iron**

Sr. No.	Membership Function for Iron	mg/l
1	Desired	(0,0,0.75,1.25)
2	Accepted	(0.75,1.25,1.5,2)
3	Unaccepted	(1.5,2,3,3)

Figure 7: Input Variable “Iron” mg/l Fuzzy Set**TRUTH VALUE (MF) OF OUTPUT VARIABLE
FUZZY WATER POLLUTION INDEX (FWPI)****Table 9: Truth Value (MF) Of FWPI**

Sr. No.	MF for FWPI	Defuzzified Index
1	Desired	(0,0,30,40)
2	Accepted	(30,40,60,70)
3	Unaccepted	(60,70,100,100)

Figure 8: Output Variable FWPI Fuzzy Set

It is seen in Figure 7 that fuzzy set for iron for “Accepted” water ranges from 0.75 to 2 mg/l. The Ist value (0.75 mg/l) is least with zero truth value, next 1.25mg/l with unit truth value which goes up to 1.5 mg/l and then truth value goes down to 0 at 2 mg/l. The MF for this set can be seen on Y axis. It is quite obvious that the value 1.8 mg/l falls in both sets: “Accepted” and “Unaccepted”, but its degree of Truth in both the set differs. This type of categorization is more relevant for unfolding the water quality as it takes inconsistency into thought. Undoubtedly the conventional classical set doesn’t take into consideration unpredictability/subjectivity of data. Likewise fuzzy set of FWPI as final value is given in Figure 8.

RULES FOR FWPI

In conventional set based system of WQI, the assessment of index is done by its algebraic operations of various input values using a consequential mathematical expression, which is later distorted into instructive descriptors. In a system based on fuzzy rule, the arithmetical value of FWPI is calculated based on rules framed on expert knowledge. Each rule consists of antecedent’s propositions which include attributes to frame input variables. In this paper Attributes have been used as linguistic expression for example Desired, Accepted, and Unaccepted. These linguistic descriptions are perpetually vague considering the insufficient information on the health insinuation of all the parameter on the concerned people and the included effect of each parameter on health of people and others. Furthermore the information collected from the field also has errors ensuing into further ambiguity into the structure.

Rules are expressed in the form of Natural language is used for expressing the rules eg: IF antecedent, THEN consequent. eg:

Rule Number 1: **IF**[FWPI_Gr_1 is desired AND Fluoride is desired AND Total hardness is desired AND Iron is desired]

THEN [water is desired]

For selected pollutants rules are framed to find FWPI with OR / AND operators to include all possible set of grouping of Fluoride, TDS, TH pH TA, FWPI_Group-1 and Iron and are given in following Table 10.

Table 10: Rules to Calculate FWPI

Rule	IF							THEN
	FWPI_Gr_1		TH		Fluoride		Iron	FWPI
1	Unaccepted	OR	Unaccepted	OR	Unaccepted	OR	Unaccepted	Unaccepted
2	Desired	AND	Desired	AND	Desired	AND	Desired	Desired
3	Desired	AND	Desired	AND	Desired	AND	Accepted	Accepted
4	Desired	AND	Desired	AND	Accepted	AND	Not Unaccepted	Accepted
5	Desired	AND	Accepted	AND	Desired	AND	Desired	Accepted
6	Desired	AND	Accepted	AND	Desired	AND	Accepted	Accepted
7	Desired	AND	Accepted	AND	Accepted	AND	Not Unaccepted	Accepted
8	Accepted	AND	Desired	AND	Desired	AND	Not Unaccepted	Accepted
9	Accepted	AND	Desired	AND	Accepted	AND	Not Unaccepted	Accepted
10	Accepted	AND	Accepted	AND	Not Unaccepted	AND	Not Unaccepted	Accepted

Mamdani type fuzzy inference system is used to operate the Fuzzy Inference System. Initially all the rules are identified in which value of all the parameters fall. On the basis of these Truth values and operators (AND/OR), the fuzzy set of output is obtained. The obtained output result of each rule is later aggregated and finally defuzzified to find final FWPI and its category.

QUANTIFYING IMPACT ON WATER ENVIRONMENT

The output obtained by the model developed to find water Quality (Program_1& Program_2) measures FWPI. FWPI, thus measured can be considered as a baseline status of the water environment. On the other hand, there may be changes in water environment due to developmental activities. The change will depend upon various factors such as existing value of FWPI, requirement of water by developmental activity and visible qualitative impact to a stakeholder such as taste of water, colour of water, smell of water etc. So as to find the impact of developmental activity on water environment, it is necessary to consider requirement of water by developmental activity and qualitative impact in model designing. As a result in next model (Program_3) ‘Water requirement’, and ‘Qualitative Impact’ were acknowledged as input variables and a scale for their approximate measurement was prepared, defining their universe of discourse between “0” to “100”. In subsequent step these input variables were fuzzified by assigning truth value to design their membership function and linguistic variables were introduced. To measure the impact of developmental activity on water environment (Fuzzy Impact on Water Environment FIWE) base line FWPI is also considered as input variable so that the water environment before the project and after the project can be determined. [1]

DEVELOPMENT OF MODEL TO CALCULATE IMPACT ON WATER ENVIRONMENT USING FUZZY SET (PROGRAM-3) INPUT VARIABLES AND THEIR TRUTH VALUE

Fuzzy Water Pollution Index (FWPI)

Truth Value (MF) to find (FWPI) is given in Table 9 and its fuzzy set is given in Figure 8.

Water Requirement

Qualitative Impact

Table 11: Membership Function for Water Requirement & Qualitative Impact

Sr. No	MF Water Requirement & Qualitative Impact	Index Value
1	Low	[0,0,30,40]
2	Medium	[30,40,60,70]
3	High	[60,70,100,100]

Figure 9: Fuzzy Set for Variable “Water_Requirement” & “Qualitative Impact”

OUTPUT VARIABLES AND THEIR TRUTH VALUE FUZZY IMPACT ON WATER ENVIRONMENT (FIWE)

A scale to measure impact on water environment is designed and its universe of discourse is defined between “0” to “100”. Its linguistic variables were identified as “Insignificant”, “Low”, “Moderate” and “High”.

Table 12: Membership Function for FIWE

Sr. No.	MF for FIWE	Parameters
1	Low	[0,0,20,30]
2	Medium	[20,30,45,55]
3	High	[70,80,100,100]

Figure 10: Output Variable “FIWE” (Fuzzy Set)

So as to find impact on water environment by using fuzzy set theory, that is Fuzzy Impact on Water Environment (FIWE), rules were formed by using AND/OR operators. The input variables FWPI, 'Water_requirement' and 'Qualitative Impact' were taken under consideration. These rules are tabulated in Table 13. [1]

Table 13: Rules To Determine FIWE

Rule	IF					THEN
	FWPI		Water Requirement		Qualitative_Impact	FIWE
1	Desired	AND	Low	-	-	Insignificant
2	Desired	AND	Medium	AND	Not High	Low
3	Desired	AND	Medium	AND	High	Moderate
4	Desired	AND	High	AND	Not High	Moderate
5	Desired	AND	High	AND	High	High
6	Accepted	AND	Low	-	-	Low
7	Accepted	AND	Medium	AND	Low	Low
8	Accepted	AND	Medium	AND	Not Low	Moderate
9	Accepted	AND	High	AND	Not High	Moderate
10	Accepted	AND	High	AND	High	High
11	Unaccepted	AND	Low	-	-	Moderate
12	Unaccepted	AND	Medium	AND	Low	Moderate
13	Unaccepted	AND	Medium	AND	Not Low	High
14	Unaccepted	AND	High	-	-	High

Initially first step is to be identified for each rules in which value of all the parameters falls. On the basis of Truth values and operators (AND/OR), the output is implicated. In next step it is aggregated and defuzzified to find value of FIWE and its category [1]. The model gives Fuzzy Impact on Water Environment (FIWE) as an output. When the water environment is to be studied in isolation, the value of FIWE can be used independently in Environmental Impact Assessment report. In order to find the baseline status of water environment, value of FWPI is used to run the model, assigning value of rest all the input variables “0” as in absence of 'developmental activity' other input variables 'Water_requirement', and 'Qualitative_Impact' will have no impact on Water Environment. In order to predict the water environment after the 'Developmental Activity' the stakeholder's value is assigned to input variables 'Water_requirement', and 'Qualitative_Impact'. The assigned value will depend on knowledge engineering, availability of data and voted-For Distribution technique. Moderate, High, Desirable, Acceptable or Unacceptable, Acceptable, Desirable, High, Moderate are the concepts where no objective criteria applies. However, in the Universe of Discourse, a range of values can be

classified by experts. A group of water environment experts, for example, can be asked about the water requirement by a specific developmental activity and its qualitative impact on a defined universe of discourse. The water environment experts on their experience decide the grade of Truth value in the fuzzy set desired, accepted or unaccepted. In the case of water environment also voting technique can be made acceptable by involving non-experts, to use some defined criteria like desirability, acceptability, significance etc.

In this way, we can assign different values to input variables 'Water_requirement', and 'Qualitative_Impact' to find FIWE after the 'developmental activity'. The difference between value of FIWE before and after the 'developmental activity' is the impact of 'developmental activity' on Water Environment.

CONCLUSIONS

WQI based on Crisp set theory has number of limitations mainly due to slant boundary conditions. The term WQI is also confusing as with increase in quality index quality decreases. Water quality index calculated by using Fuzzy set theory decreases the ambiguity involved. It is termed as FWPI. Increase in FWPI indicates increase in water Pollution. Difference between value of FWPI before and after the developmental activity is termed as Fuzzy Impact on Water Environment (FIWE)

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