Classification and Assessment of the Water Quality using Fuzzy Inference in Shrimp Aquaculture Systems

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Abstract. Nowadays, there is a lack of effective tools for assessing the status of the environment in aquaculture systems, laws and standards policies does not establish measurements rules in water quality treatment. Systems based on fuzzy inference theory, have demonstrated to be useful in the treatment of environmental problems. Water quality is an important factor in faming aquaculture, and the detection of early environmental problems offers the opportunity for stopping potentially danger situations into the ponds. This study proposes a new method for evaluating the water quality in shrimp ponds based on fuzzy inference system (FIS), this method has been developed proving the importance and potentiality of the fuzzy logic theory in this area. FIS's are used to establish a relationship among the physical-chemical variables that affect the shrimp habitat. The developed model can classify the water quality status in four levels; *excellent*, *bad*, *regular* and *poor*. This work gives an alternative tool that is used in the treatment of the water management.

Keywords: Water quality, fuzzy logic, aquaculture, artificial intelligence.

1 Introduction

The water quality in oceanic research is a problem that affects daily the activities of many people that practice fishing activities. The quantity of biological data is increasing day by day and it is needed to create models of the environment conditions and to use some functional features.

The shrimp farming is an important economical activity in several countries. The farming shrimp is made in different ways; in intensive, semi intensive or extensive ponds. The shrimp production is determined by two main factors: 1) the capacity of maturing in organisms and 2) the capacity of the environment. The capacity of the environment is referred to the conditions that allow a growing and reproduction, whose would be the best in good environment conditions. The water quality into the farming ponds determines the capacity of the environment that makes influence in the life of the organism [7].

Water quality indicators have been grouped in three categories: physical, chemical and biological, each of them contains a significant number of water quality variables.

© G. Sidorov, M. Aldape, M. Martinez, S. Torres. (Eds.)
Advances in Computer Science and Engineering.
Research in Computing Science 42, 2009, pp. 337-346

Received 15/03/09
Accepted 27/04/09
Final version 08/05/09

There are variables that have more significance because they can highly affect the growing and the surviving of the organism (Table 1).

An equilibrated environment in the pond generates good growing and reproduction, a bad controlled habitat generates high stress levels in the organisms, low growing and low resistance for sickness; for example, for shrimp maturation and spawning [9], [10], [11] almost all hatcheries require availability of oceanic-quality water on a 24-h basis.

Table 1: Physical-chemical variables in a shrimp system.

High Impact	Low Impact
- Temperature	- Hydrogen Sulfide
- Oxygen dissolved	- Non Ionized Hydrogen Sulfide
- Salinity	- Nitrates
- PH	- Total inorganic Nitrogen
- Non ionized ammonia	- Silicate
	- Phosphorus
	- Chlorophyll A
	- Total suspension solids
	- Potential redox
	- Alkalinity
	- *Dioxide of Carbon*
	- Total Ammonia
	- Turbidity

2 Environmental Problems

There are a lack of methodologies that asses the water quality giving an index about its status. Some standards have been established as the NOM-001-ECOL-1996 (maximum limits of pollutants in water discharges on coastal water in Mexico) and the CE-CCA-001/89 (water quality criteria) [2], [3], [4]. However, these standards do not establish an index of the degradation status in fresh water or coastal water. International standards has been created giving a solution in this area as the ACA and NSF, however, the methodologies given by them can be only applied by fresh water bodies [5], [6]. The Canadian Council of Ministers of the Environment proposes a method that can be used in coastal water, it is based on calculate the number of failed value tests in a set of environmental variables, obtaining a water quality index (CWQI) [9]. However the ACA, NSF and CWQI indices have a number of weak points, where the lack of a reasoning process in the classification of environmental patterns is the main problem.

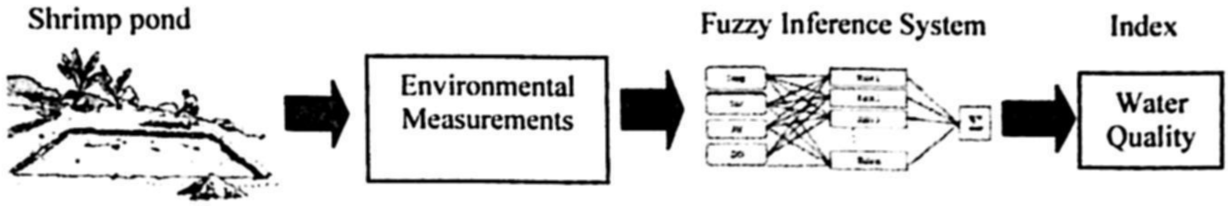

Fig. 1: The measurements of the environment will be analyzed by a model that describes the relationship between variables, obtaining a status of water quality.

3 Methods

3.1 Data Collection

Data collection was made on the shrimp farms from Sonora, Mexico. Almost 97 days were used to measure 9319 patterns; all patterns were obtained in a farming period using manual techniques and electronic devices (sensors). In the aquaculture systems, the environmental variables measured were pH, temperature, salinity and dissolved oxygen; non ionized ammonia can be estimated with pH concentrations, thus was not measured.

The environmental variables were measured with a period of 15 minutes, having a total of 96 measurements by day. The regular behaviors of each variable in one day are showed in figure 2.

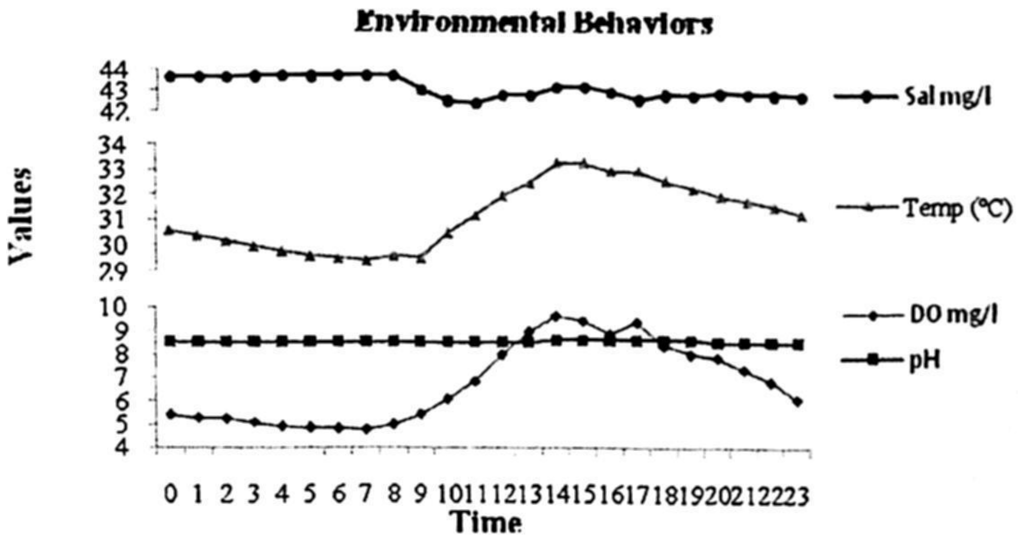

Fig. 2: Measurements one day of the physical-chemical variables in a shrimp system.

3.2 Pattern Classification

Physical-chemical variables can be classified in levels, whose represents the ecological impact in shrimp ponds, those levels are showed in Table 2.

Table 2. Ranges of classification of the environmental variables.

Variables	Hypoxia Acid	Low	Normal	High	Alkaline
Temp (°C)	------	0 - 23	23 - 30	30 - ∞	-----
Salt (mg/L)	------	0 - 15	15 - 25	25 - ∞	-----
DO (mg/L)	0 - 3	3 - 6	6 - 10	10 - ∞	-----
PH	0 - 4	4 – 6.5	6.5 - 9	9 - 10	10 - 11

In general, the environmental variables have nonlinear relations, which have been observed and proven experimentally, the equations that represent them, have been formulated, which is very hard to do. There are various equations that pretend to describe the environment, however for each local place the conditions of the environment changes and the equations created are not the indicated for that case [2], [3], [4], [5].

The water quality can be represented as a relationship between variables as follows:

$$\text{Water quality} = f(\text{Temp}, \text{Salt}, \text{DO}, \text{pH}) \qquad (1)$$

where f is the nonlinear function, *Temp* is temperature; *Salt* is salinity and *DO* is dissolved oxygen.

The water quality status is obtained using a vector of the variables concentrations, for example in day one (Fig. 2) we have the vector v[Temp, Salt, DO, pH] = [23, 35, 3, 8], this vector is used as an input of the FIS, that calculates the water quality status (Fig 1).

3.3 Fuzzy Inference Systems (FIS)

The Fuzzy inference systems (FIS) theory was applied in this study providing a non-linear relationship between input sets (Physical-chemical variables) and output set (Water Quality Index) [10], [4]. Fuzzy inference systems (Fig. 3) uses propositions that are represented with a true or false level, while a Boolean logic proposition is only true or false [12].

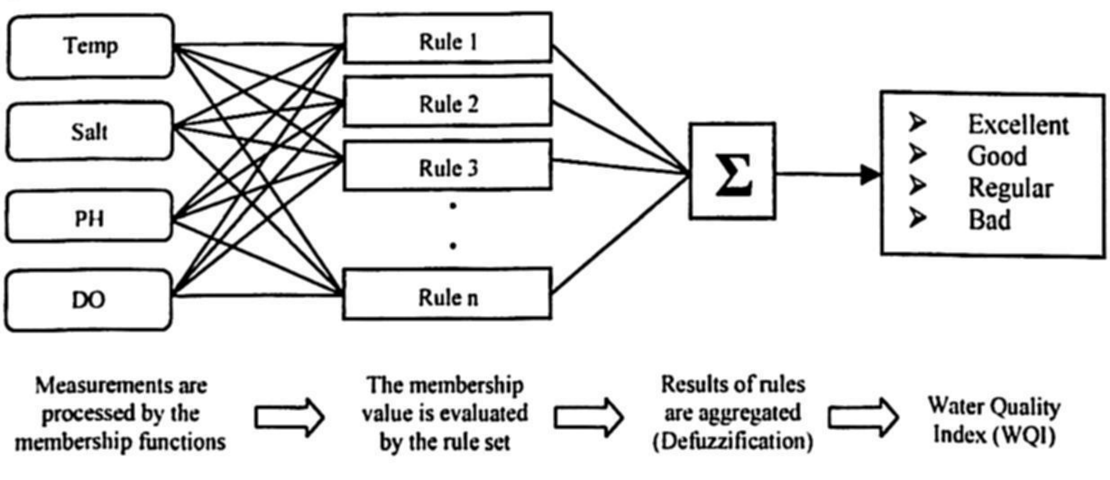

Fig. 3: Architecture of the Fuzzy Inference System applied to the water quality problem in shrimp farms.

The fuzzy logic operators can be used as the basis of the inference systems. Such inference methods have been studied by the expert system community. The fuzzy logic involves three important concepts: membership functions, fuzzy set operations and inference rules.

A membership function is a curve that maps an input real value in a membership value (μ) between 0 and 1. The input space is called universe of discourse (X). A fuzzy set is represented as a set of ordered pairs that assigns a membership level to each element x of the universe X.

$$A = \{x, \mu_A(x) | x \in X\} \quad (2)$$

where $\mu_A(x)$ is the membership function x in A. The election of the curve is arbitrary and it depends of the context of the problem. The operations that define de basis on fuzzy logic can be defined as:

Union (OR) $$\mu_{A \cup B}(x) = max\{\mu_A(x), \mu_B(x)\} \quad (3)$$

Intersection (AND) $$\mu_{A \cap B}(x) = min\{\mu_A(x), \mu_B(x)\} \quad (4)$$

Complement (NOT) $$\mu_{\bar{A}}(x) = 1 - \mu_A(x) \quad (5)$$

Fuzzy systems are based on knowledge rules If – Then. A fuzzy rule is a condition which some words are characterized for having a membership function. The inference process uses the fuzzy rules "IF – Then" creating a relationship between the fuzzy input set (membership values) and the output set. A fuzzy rule has the form:

If DO if low, then WQI is regular

where DO is the membership level of the measured concentration and WQI is the final membership function to analyze. There are some expressions that are frequently used by experts in water quality, that expressions will be helpful for the construction of the FIS, they structure are the follows: if dissolved oxygen is low and the salinity is high, then the water quality is regular. This kind of expressions built the fuzzy language of the FIS and it is represented as follows:

Rule 1: If Temp is normal and Salt is normal and pH is normal and DO is normal then WQI is Excellent
Rule 2: If Temp is normal and Salt is normal and pH is normal and DO is low then WQI is Good
Rule 3: If Temp is normal and Salt is High and pH is normal and DO is low then WQI is Regular

The size of the set rule depends of the number of rules that are involved in the environment; a total of 139 rules have been used in this case.

Trapezoidal membership functions define these fuzzy sets (Fig. 4), they are represented as:

$$\mu(x) = min\left\{\frac{x-a}{b-a}, 1, \frac{d-x}{d-c}\right\} \quad (6)$$

Fig. 4 shows the membership functions used in the fuzzyfication process and the output membership function.

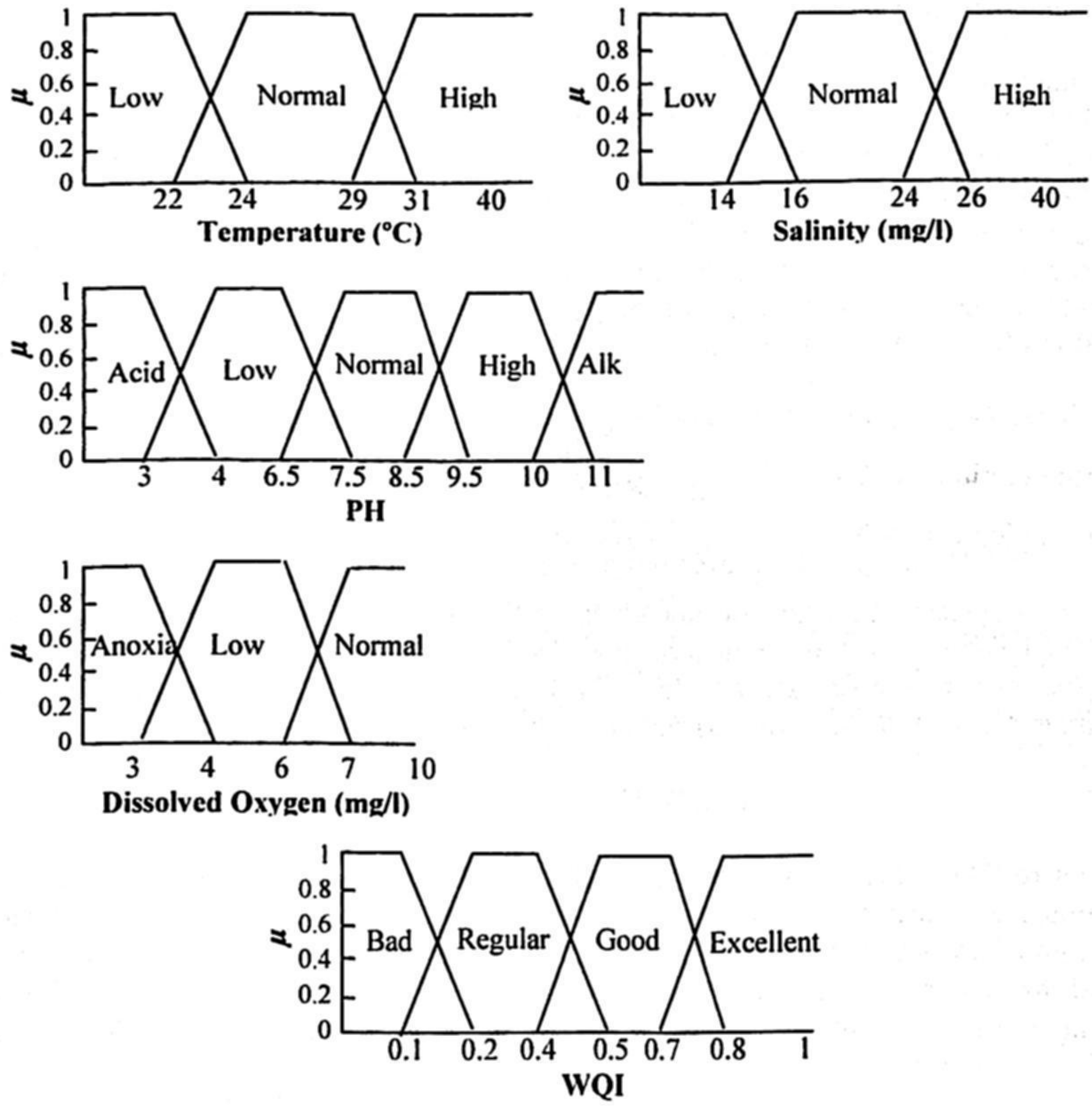

Fig. 4: Membership functions for temperature, salinity, dissolved oxygen, pH and WQI.

The output membership function is the water quality indicator (WQI). The output of the FIS is expressed in a [0, 1] range, where 0 means "poor" and 1 "excellent", the "good" and "regular" status are involved within the range, this is represented in Fig. 4.

The fuzzy outputs of the if-then rules in a real world value are joined by the aggregation process (Fig. 5) [10]. When the final membership function is obtained $\mu_{out}(x)$, the gravity center is calculated using the following equation:

$$WQI = \frac{\int x\mu_{out}(x)\,dx}{\int \mu_{out}(x)\,dx} \tag{7}$$

If we assume that it is necessary to evaluate the WQI in a shrimp pond, using the rule 1 and having the variables Temp, Sal, pH and DO with values 25.0, 20.0, 8.0 and 6.3 respectively, we can calculate using the membership functions proposed in the Fig. 4. For "R1" and "R2" we can calculate:

$$R_1: \mu_{out}(x) = \min\{\mu_{Temp-n}(x), \mu_{Salt-n}(x), \mu_{pH-n}(x), \mu_{DO-n}(x)\} = \min\{1,1,1,0.3\} = 0.3$$

$$R_2: \mu_{out}(x) = \min\{\mu_{Temp-n}(x), \mu_{Salt-n}(x), \mu_{pH-n}(x), \mu_{DO-l}(x)\} = \min\{1,1,1,0.7\} = 0.7$$

Where n is normal, l is low and μ_{out} is the membership value calculated in R1 and R2. Calculating the aggregation functions:

$$\mu_{R1}(x) = \min\{\mu_{out}(x), \mu_{excellent}(x)\} = \{0.3, \mu_{excellent}(x)\} = 0.3$$

$$\mu_{R2}(x) = \min\{\mu_{out1}(x), \mu_{good}(x)\} = \{0.7, \mu_{good}(x)\} = 0.7$$

Calculated the output membership functions (fuzzy outputs), the aggregation of these functions will generate one membership function, this is showed in Fig. 5. The WQI is evaluated using the centroid method (Eq. 7) and replacing the membership functions:

$$WQI = \frac{\int_{0.4}^{0.47}(10x-4)x\,dx + \int_{0.47}^{0.53}(0.7)x\,dx + \int_{0.53}^{0.77}(-10x+8)x\,dx + \int_{0.77}^{1}(0.3)x\,dx}{\int_{0.4}^{0.47}(10x-4)\,dx + \int_{0.47}^{0.53}(0.7)\,dx + \int_{0.53}^{0.77}(-10x+8)\,dx + \int_{0.77}^{1}(0.3)\,dx} = 0.663$$

2.4 Postprocessing

The results evaluated by the defuzzification method is one step for the assessment of the WQI, however, even the membership functions of WQI has a domain [0,1], the process cannot obtain the limit values, if the result of the output function is fully excellent, the highest value calculated is the media of the length of the output function and the final value never is obtained, this is represented using the following equations:

$$\mu_{excellent}(x) = \frac{\int x\mu_{Excellent}(x)\,dx}{\int \mu_{Excellent}(x)\,dx} = 0.873 \quad (8)$$

$$\mu_{Bad}(x) = \frac{\int x\mu_{Bad}(x)\,dx}{\int \mu_{Bad}(x)\,dx} = 0.0777 \quad (9)$$

For scaling the FIS output, the following operation fits the final value in a [0, 1] range:

$$X_{out} = \frac{X - \min(X)}{\max(X) - \min(X)}$$

Where X is the original vector and X_{out} is the linear scaled vector. The final levels of the WQI index are 1 for *excellent*, 0.66 for *good*, 0.28 for *regular* and 0 for *bad*.

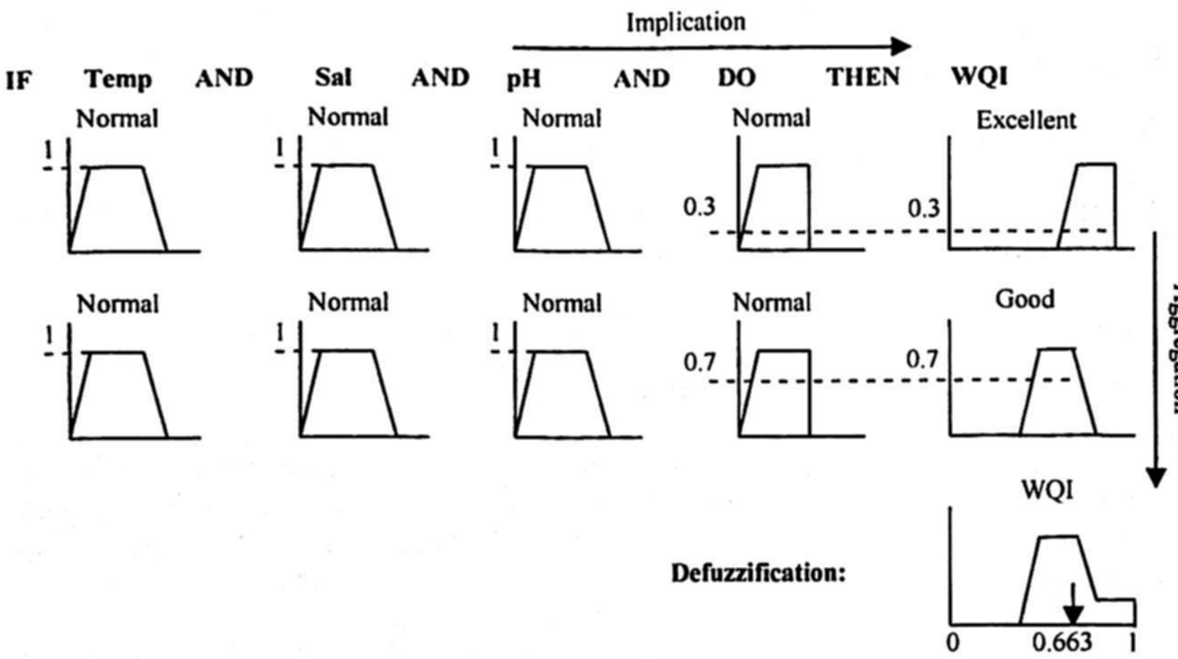

Fig. 5: Defuzzification process where the final membership functions are obtained using the aggregation of the fuzzy outputs.

4 Results

A set of measurements have been evaluated for proving the WQI. Input data extracted from shrimp farms databases have been used to assess water quality the 2007 farming period.

The validation of an index is not an easy task; although indexing processes can miss information their benefits are significant when measuring environmental impacts.

The real validation process is done when the model is proved with real values; however, the most relevant aspect to highlight here is the methodology used in this work to develop the WQI index. A comparison of the performance between deferent methodologies is proposed in this investigation. In Fig. 6, the WQI index is compared with the CCME. A comparison of the performance for the WQI and the CCME index used in environmental assessment could remark some interesting things.

The analysis of Fig. 6 shows the results of the assessment of the CCME and the WQI proposed with a data set of tree days, each day corresponding to different months of the farming period. The CCME and the WQI indices report different behaviors into the pond; the treatment of the information within the FIS influences the final score.

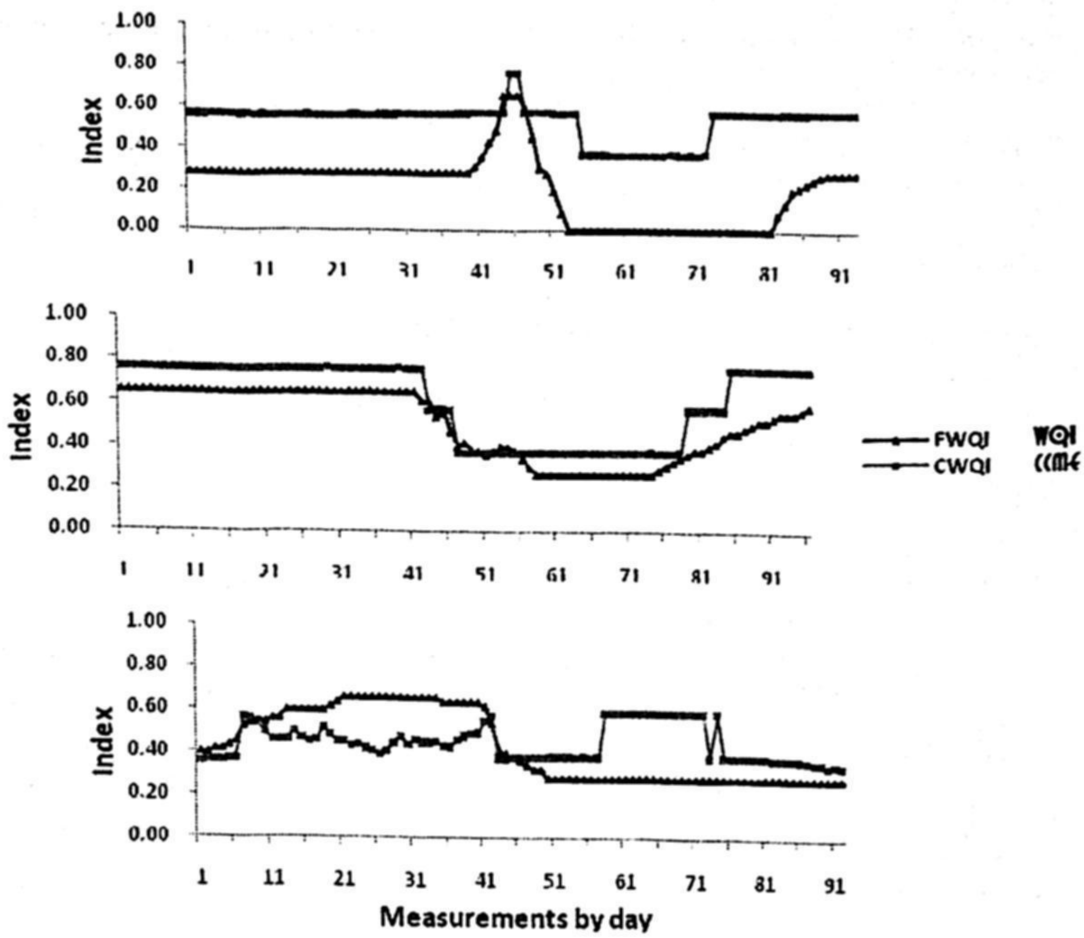

Fig. 6: Comparison of the WQI and CCME indices.

The CCME index shows values between 4.0 (regular) and 8.0 (good) in a non fuzzy environment. The WQI index shows values between 0.0 (poor) and 7.0 (good). The CWQI index is above of the FWQI index; although the final values are similar they have some differences. The main difference is because the WQI is calculated with reasoning cases that affects the status of the water, and the especial situations are processed by the WQI, as an example we can refer the hypoxia situations with the DO

5 Conclusion

An original methodology to evaluate and classify an ecological impact in the habitat of shrimp aquaculture systems has been created. This research establishes an index that asses the status of the artificial shrimp habitat based on four levels; excellent, good, regular and poor.

In this paper, we present a robust tool for water management in shrimp ponds; the methodology is presented in the form of a fuzzy inference system and it is based on a reasoning process implemented to evaluate information data. The necessity to link fuzzy systems and reasoning methodologies to evaluate water bodies has been showed. Studies are now needed to tune the different cases that are presented in the environment.

This model can be adjusted by assessing other aquaculture marine systems that have the necessity of analyze the status of their ecosystem. Nowadays some researchers are evaluating the possibility of use this model for embedding in expert systems or for creating predicting models that allows recognizing undesirable status into the ponds.

Acknowledgements. Authors wish to thank CONACYT and the National Polytechnic Institute for supporting this work.

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