# Fuzzy Logic Water Quality Index and Importance of Water Quality Parameters

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**Abstract:** Determination of status of water quality of a river or any other water sources is highly indeterminate. It is necessary to have a competent model to predict the status of water quality and to advice for type of water treatment for meeting different demands. One such model (UNIQ2007) is developed as an application software in water quality engineering. The unit operates in a fuzzy logic mode including a fuzzification engine receiving a plurality of input variables on its input and being adapted to compute membership function parameters. A processor engine connected downstream of the fuzzification unit will produce fuzzy set, based on fuzzy variable viz. DO, BOD, COD, AN, SS and pH. It has a defuzzification unit operative to translate the inference results into a discrete crisp value of WQI. The UNIQ2007 contains a first memory device connected to the fuzzification unit and containing the set of membership functions, a secondary memory device connected to the defuzzification unit and containing the set of crisp value which appear in the THEN part of the fuzzy rules and an additional memory device connected to the defuzzification unit. More advantageously, UINQ2007 is constructed with control elements having dynamic fuzzy logic properties wherein target non-linearity can be input to result in a perfect evaluation of water quality. The development of the fuzzy model with one river system is explained in this paper. Further the model has been evaluated with the data from few rivers in Malaysia, India and Thailand. This water quality assessor probe can provide better quality index or identify the status of river with 90% perfection. Presently, WQI in most of the countries is referring to physic-chemical parameters only due to great efforts needed to quantify the biological parameters. This study ensures a better method to include pathogens into WQI due to superior capabilities of fuzzy logic in dealing with non-linear, complex and uncertain systems.

**Keywords**: water quality index, biological parameter, fuzzification, water treatment, water quality monitoring, fuzzy inference system and water quality software

## Introduction

The current method of determining water quality index which is in practice utilizes statistical approach and is not precise in most of the time. Nowadays environmental protection and water quality management has become an important issue in public policies throughout the world. More than that government is concerned about the quality of their environmental resources because of the complexity in water quality data sets.[1] Many countries have introduced a scheme for river water quality monitoring and assessment, examining separate stretches of fresh water in terms of their chemical, biological and nutrient constituents and overall aesthetic condition. General indices are used as comprehensive evaluation instruments to assess conditions at the earliest stage by regulatory agencies dealing with pollution abatement problems.[2]

Water quality indices are computed for classification of water wherein the integration of parametric information on water quality data and the expert's knowledge base on their importance and weights are considered. Considerable uncertainties are involved in the process of defining water quality for designated uses. One of the most effective ways to communicate information on environmental trends and river water quality in particular is with indices. The aggregation of indices represents the integrated effect of individual concentration of water quality parameters was proposed[3] using Delphi technique as a tool in a formal assessment procedure.

In United States National Sanitation Foundation (NSF) guidelines for defining water quality, Water Quality Index (WQI) is used. It is a weighted linear system of the sub indices (WQI a) or a weighted product aggregation function (WQI m). Conceptually similar methods are used in other countries for defining water quality.[4] Malaysian DOE has followed their own interim national water quality standards

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(INWQS) for evaluating water quality of the river for intended purposes. Environmental protection agency (EPA) defines comprehensive sets of determinants to monitor water quality. In order to protect the ecological status, as declared in the Water Framework Directive;[5] not only environmental concentrations of chemicals in rivers are being used to assess water quality, but also their effects on tropic chains. The Catalan Water Agency (Catalonia, Spain) uses 150 chemical indicators to survey the condition of water.[6] One of the difficult tasks facing environmental managers is how to transfer their interpretation of complex environmental data into information that is understandable and useful to technical and policy individuals as well as the general public. This is particularly important in reporting status of the environment. Internationally, there are number of attempts to produce a method that meaningfully integrates the data sets and converts them into information.[7] In modeling complex environmental problems, researchers often fail to make precise statements about input and outcomes, but fuzzy logic could help.[8] Conventional water quality regulations contain quality classes which use crisp sets, and the limits between different classes have inherent imprecision.[9]

In Malaysia, the classification of rivers by the Department of Environment (DOE) is based on water quality index (WQI). A water quality index relates a group of water quality determinants to common scale and combines them into a single number in accordance with a chosen method or model of computation. The WQI was established based on the results of an opinion poll of a panel of experts who determined the choice of determinants and weights assigned to each chosen water quality determinant. DOE-WQI consists of six determinants: dissolved oxygen (0.22), biological oxygen demand (0.19), chemical oxygen demand (0.16), ammoniacal nitrogen (0.15), suspended solid (0.16) and pH (0.12). Weight factors are given in parentheses.

WQI system is to assess water quality trends for management purposes even though it is not an absolute measure of degree of pollution or the actual water quality.[10] DOE-WQI was originally designed to include six determinants designed for making an integrated assessment of water quality conditions in order to meet utilization goals. This classification technique may cause a rough and imprecise approach on data. Because of some parameters being close to or far from the limit, they may have equal importance for evaluation of concentration.[11] The most critical deficiency of this index is the lack of dealing with uncertainty and subjectivity present in this complex environmental issue. In this regard, some alternative methodologies have emerged from heuristic approach. Fuzzy logic has been tested with actual environmental issues.[12] So there is a need for developing a uniform method for measuring water pollution involving biological parameters and is recognized by the scientific community and by general public long time before. Fuzzy logic can be considered as a language that allows one to translate sophisticated statements from natural language into a mathematical formalism.[13] Fuzzy logic can deal with highly variable, linguistic, vague and uncertain data or knowledge and therefore has the ability to allow a logical, reliable and transparent information stream from data collection to data usage in environmental application system. A suitable environment application of inference system based on fuzzy reasoning to integrate water quality determinants has been shown.[14] Fuzzy logic provides a framework to model uncertainty, the human way of thinking, reasoning and perception process. Fuzzy systems were first introduced by Zadeh.[15] Fuzzy logic could be applied to the development of environmental indices in a manner that solves several environmental problems, including the incompatibility of observations, uncertainty, imprecision in criteria and the need for implicitly of value judgments.

## Study Area

The Semenyih river, which is one of the tributaries of Langat river flows southwards towards districts of hulu Langat and Sepang. Semenyih river has been adversely impacted by urban and industrial wastes since the early 1990s. Semenyih basin lies between longitude 101° 47’450”E to 101° 53’034”E and latitude 02° 53’ 021”N to 04° 57’200” N. The average annual rainfall in the area is about 3000 mm. Semenyih basin is located south to the nation’s captial Kuala Lumpur. Currently, more than 1 million people intake for drinking water from Semenyih river. Water quality in the Semenyih is monitored by Department of Environment (DOE). Three sampling station are located in the basin SP9, SP10 and SP11. In 1997–2004, the Department of Environment initialized observations of water quality determinants in the three sampling stations of the Semenyih river periodically. The observed determinants in the basin are dissolved oxygen (0.22), biological oxygen demand (0.19), chemical oxygen demand (0.16), ammonical nitrogen (0.15), suspended solid (0.16), and pH (0.12). Weight factors are given in parentheses.

## Water Quality Model Development Using Fuzzy Logic

In this study, the fuzzy logic formalism has been used to access river water quality by developing a water quality index based on fuzzy reasoning. Fuzzy inference is the process of formulating the mapping from a given input determinant to an output determinant using fuzzy logic reasoning. Decisions can be made on bases of mapping, or patterns discerned. The fuzzy inference process involves three crucial steps: membership functions, fuzzy set operations, and inference rules. Comparison has been done over conventional method (DOE-WQI). River water quality data from Semenyih river are used to evaluate the fuzzy model. Membership functions of the determinants and fuzzy rule bases were defined. The model was evaluated with data from 1997–2004 of Sememyih river basin based on Mamdani fuzzy inference system. Fuzzy model was developed with physicochemical determinants of their weight assigned and significance ratings curve to evaluate the Semenyih river water quality.[16]

A membership function is a curve that defines how each point in the input space is mapped to a membership value between 0 and 1. The input space is called the universe of discourse. The output space is called the membership value μ. If X is the universe of discourse and its elements are denoted by x, then a fuzzy set A is defined as a set of ordered pairs. μA(x) is the membership function of x in A. A membership function is an arbitrary curve whose shape is defined by convenience. The standard fuzzy set operations are: union (OR), intersection (AND) and additive complement (NOT). They manage the essence of fuzzy logic. If two fuzzy sets A and B are defined on the universe X, for a given element x belonging to X, the following operations can be carried out: The third concept is the inference rule. An if—then rule has the form: "If x is A then z is C", where A and C are linguistic values defined by fuzzy sets in the universe of discourse X and Z, respectively. The if—part is called the antecedent, while the then—part is called consequent. The antecedent and the consequent of a rule can have multiple parts.

Fuzzy logic comprises, usually, fuzzification, evaluation of inference rules, and defuzzification of fuzzy output results. Fuzzification is process to define inputs and outputs as well as their respective membership function that change the crisp value into a degree of match to a fuzzy set, which explains a characteristic of the variables. After the inputs are fuzzified, the degree to which each part of the antecedent is satisfied for each rule. If the antecedent of a given rule has more than one part, the fuzzy operator is applied to obtain one number that represents the result of the antecedent for that rule. This number is then applied to the output function. The input to the fuzzy operator is two or more membership values from fuzzified input variables. The output is a single truth value. The input for the implication process is a single number given by the antecedent, and the output is a fuzzy set. Implication is implemented for each rule. Because decisions are based on the testing of all of the rules in a FIS and the rules must be combined in some manner in order to make a decision. Aggregation is the process by which the fuzzy sets that represent the outputs of each rule are combined into a single fuzzy set. Finally, the input for the defuzzification process is a fuzzy set (aggregated output fuzzy set) and the output is a single number. As much as fuzziness helps the rule evaluation during the intermediate steps, the final desired output for each variable is generally a single number. However, the aggregate of a fuzzy set encompasses a range of output values, and so must be defuzzified in order to resolve a single output value from the fuzzy set.

A fuzzy model for river water quality assessment has been developed. Different shapes of membership functions can be used, depending upon the type of application.[17] The right prediction of the fuzzy model depends on the number of fuzzy sets used in the mapping process, since it facilitate to give more continuity to the universe of discourse. However, in this research, each of the six input quality determinants have been divided into three categories, and trapezoidal membership functions were assigned as shown in (Fig. 1). Trapezoidal membership functions were used and the parameters are given in (Table 1). Three fuzzy sets have been considered suitable for this study. The amount of overlap, the width and the shape of fuzzy sets

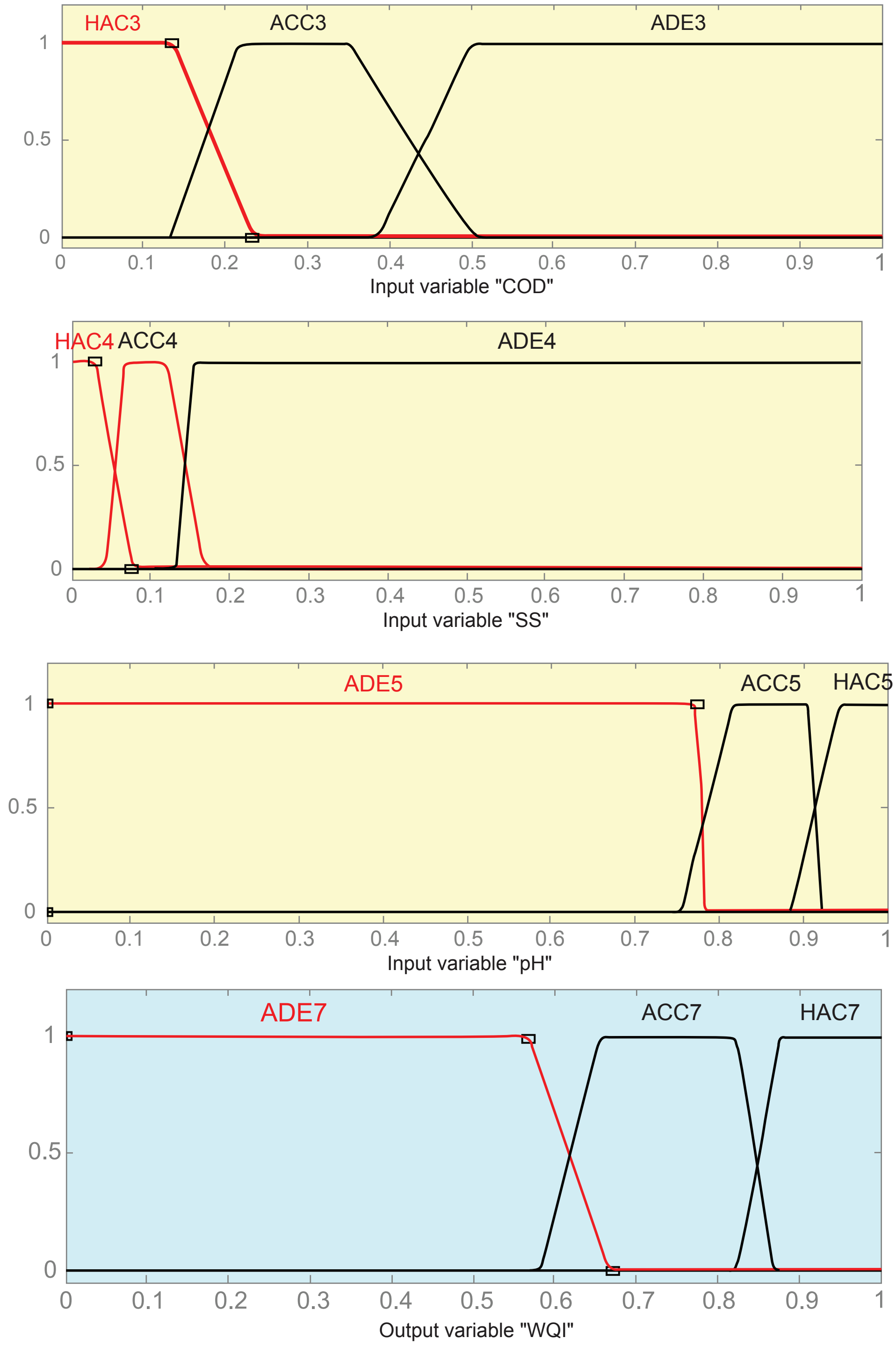


**Figure 1.** Membership functions defined for water quality classification.

should be considered by an expert for each input variable. Ranges for fuzzy sets were based on interim national quality standards (INWQS) for Malaysia. Malaysian rivers are classified in the interim national water quality standards (INWQS) based on water quality criteria and standards for several beneficial uses.[16,18]

Ranges of fuzzy sets used are shown in Table 1. Six quality determinants have been selected to evaluate water quality by means of an aggregated index called fuzzy water quality (FWQ) index. Defuzzification of output is achieved by centroidal method as it is the most prevalent and physically appealing to all available methods.[19] For the

**Table 1.** Parameters for membership functions in the fuzzy inference system.

| Determinant | Adequate ADE | Acceptable ACC | Highly acceptable HAC | Range |
|---|---|---|---|---|
| | a b c d | a b c d | a b c d | |
| DO | 0.13, –0.13, 0.36, 0.50 | 0.36, 0.48, 0.76, 0.87 | 0.79, 0.85, 1.07, 1.13 | 0–1 |
| BOD | –0.45, –0.05, 0.13, 0.20 | 0.13, 0.23, 0.42, 0.50 | 0.36, 0.52, 1.07, 1.47 | 0–1 |
| COD | –0.45, –0.05, 0.13, 0.23 | 0.13, 0.21, 0.35, 0.50 | 0.38, 0.50, 1.02, 1.02 | 0–1 |
| SS | –0.04, –0.03, 0.04, 0.07 | 0.04, 0.06, 0.13, 0.16 | 0.13, 0.15, 1.12, 1.52 | 0–1 |
| pH | 0.0, 0.0, 0.77, 0.78 | 0.75, 0.81, 0.90, 0.92 | 0.88, 0.94, 1.01, 1.04 | 0–1 |
| $NH_3$-N | 0.0, 0.083, 0.089 | 0.06, 0.12, 0.14, 0.41 | 0.33, 0.48, 1.01, 1.01 | 0–1 |
| FWQ | 0.0, 0.56, 0.66 | 0.58, 0.65, 0.82, 0.86 | 0.78, 0.86, 1.05, 1.07 | 0–1 |

selected set of six water quality determinants the most prominent 86 rules have been used. For example, fuzzy rules are chosen, "if the levels of organic matter in a river are ADE, and the levels or dissolved oxygen are HAC, then the expected water quality is ACC. In fuzzy description, it could be pronounced as follows: Rule1. If BOD5 is ADE, and DO is HAC then WQ is ACC. In the same way, other rules can be enunciated. Robustness of the system depends on the number and quality of the rules.

## Results and Discussion

The water quality for the Semenyih river has been assessed with the FWQ index. Data sets (1997–2004) from Department of environment (DOE) of Malaysia were used to assess water quality. The calculated FWQ indices according to fuzzy inference system (FIS) are given in (Fig. 2). On the other hand, comparison has been done between FWQ and the actual WQI index. Fuzzy water quality assessment results were compared to present DOE-WQI with respect to aquatic life, water supply, and irrigation. The observations of fuzzy model testing from 1997 to 2004 and are shown in (Fig. 3). In the fuzzy model, DO, BOD, and COD are high showing acceptable and are mainly affected by total suspended solid values and ammonia. FWQ index are acceptable in 1997, 1999, 2003, and 2004. But fuzzy result is adequate in 1998, 2000, 2001, and 2002. It can be observed in (Fig. 2). The sampling stations SP9, SP10, and SP11 exhibit an acceptable water quality in different years. It can also be noticed in Figure 2. Fish and other aquatic animals need oxygen to

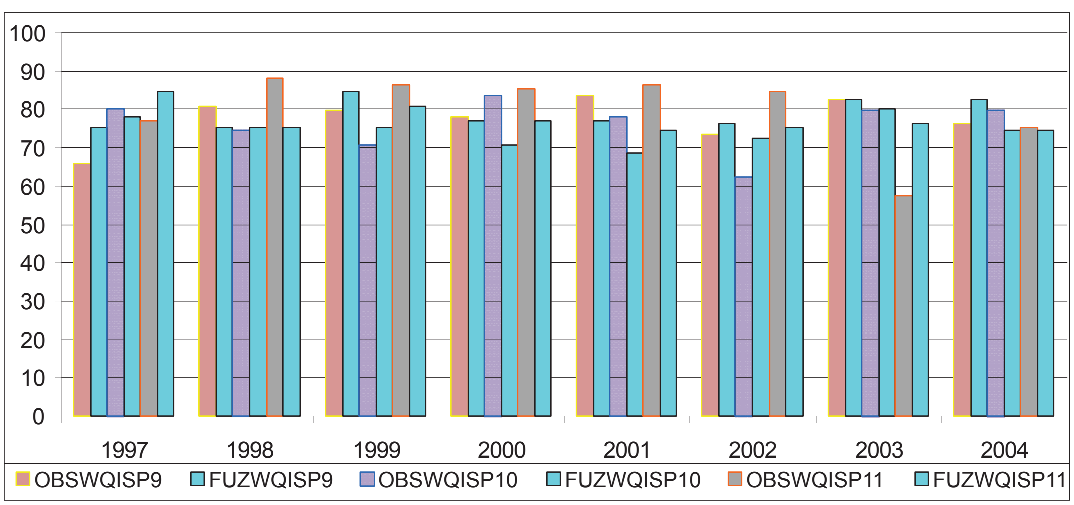


**Figure 2.** Results for the fuzzy water quality index of sampling points.

breathe. They are put under stress when dissolved oxygen falls below 5 mg/L and fish death results if dissolved oxygen falls below 2 mg/L. Cold water can hold more dissolved oxygen than warm water. The DOE-INWQS rating scale considers dissolved oxygen levels from 0 to 5 mg/L as adequate from 5 to 7 as acceptable, and above 7 as highly acceptable. The dissolved oxygen in the Semenyih river is acceptable based on fuzzy model results.

Biological oxygen demand (BOD) is a measure of the organic material, both natural (for example, decaying plant and animal material) or human (petroleum products and organic chemicals). BOD in Semenyih is dominated by naturally occurring organic material. It can react with chlorine in water treatment plants to form harmful Disinfectant by-products in drinking water. DOE-INWQS rating scale designates TOC level of 0 to 3 mg/L as highly acceptable, 4 to 5 mg/L as acceptable and above 6 mg/L as adequate. Overall BOD in the Semenyih river is acceptable on bases of fuzzy results. Semenyih river monitoring indicates that TOC is typically in the adequate range. The local water treatment plants closely monitor TOC to control the levels of disinfection by-products and to ensure a safe drinking water for the community.

Chemical oxygen demand (COD) is measure of chemical waste and often be correlated with BOD in water. The organic carbon is oxidized to carbon dioxide by burning or by chemical oxidation in water. The carbon dioxide gas is swept out and by dissolving it in water and measuring the pH change (the gas is acidic). DOE-INWQS rating scale designates COD levels of 1 to 10 mg/L as highly acceptable, 10 to 25 mg/L as acceptable and above 25 mg/L as adequate. COD is acceptable in Semenyih river on the basis of fuzzy results.

Total suspended solids (TSS) are a measure of material that is suspended in the water. Semenyih river monitoring indicates that TSS is in highly acceptable range in the fall, but is acceptable to adequate range in the summer. Most TSS in the Semenyih river is sediment from runoff and bank erosion and makes the water look muddy. The DOE-INWQS rating scale designates 0 to 50 mg/L TDS as Low (rated as highly acceptable), 50 to 100 as Medium (rated as acceptable), and 150 to >300 as High (rated as adequate). Based on adequate fuzzy model results, the TDS levels in Semenyih river are in the adequate range. Most TSS in the Semenyih river is sediment from runoff and bank erosion and makes the water look muddy.

The parameter pH expressed on a scale from 1 to 14, describes the acidity or alkalinity of water. If the value of pH equal to 7 is neutral. Values below 7 are acidic, and values above 7 are said to be basic or alkaline. Fishes live the best in waters with a pH between 6.5 and 8.4. Fish are harmed if pH becomes too acidic (falls below 4.8) or too alkaline (goes above 9.2). The DOE-INWQS rating scale designates a pH between 6.5 and 8.4 as highly acceptable between 4.8 and 6.5 and between 6 and 9 as acceptable, and below 4.8 and above 9.2 as adequate. The pH of the Semenyih River is very stable based on fuzzy results (due in parts to the dissolved carbonate minerals in the water).

The DOE-INWQS rating scale designates 0 to 0.1 mg/L ammonia as Low (rated as highly acceptable), 0.1 to 0.3 mg/L as Medium (rated as

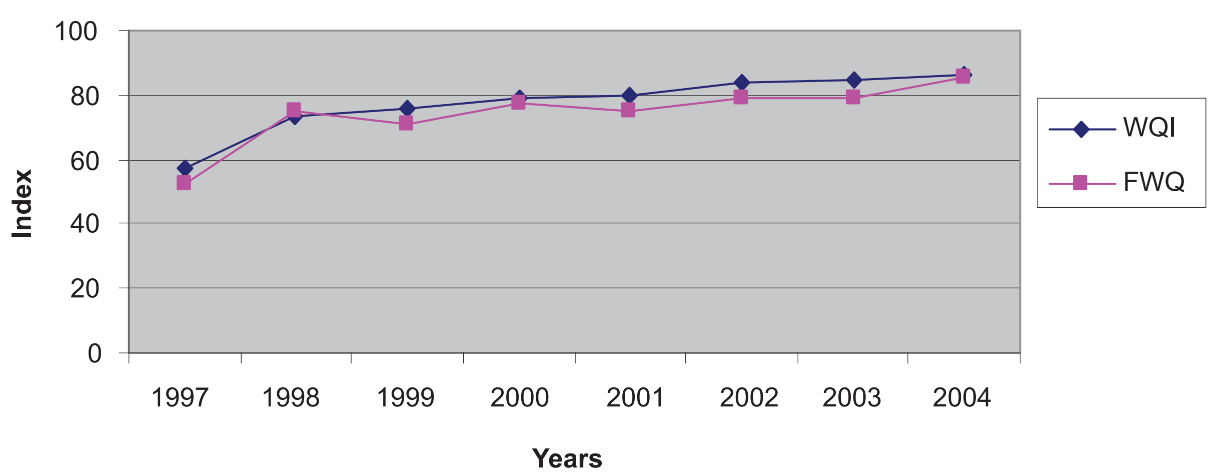


**Figure 3.** Comparison of derived by fuzzy logic (FWQ) and observed (WQI).

acceptable), and 0.3 to >2.7 as High (rated as adequate). Based on fuzzy results the ammonia in Semenyih river is adequate due to sewage deposal and urban runoff. Ammonia is a source of nitrogen (N), an important nutrient for plants and algae and ammonia occurs in a harmless form but at higher temperatures or higher pH, ammonia changes to a gas, a form harmful to fish and other aquatic life. Ammonia is excreted by animals and is produced during decomposition of plants and animals. Ammonia is an ingredient in many fertilizers and is also present in sewage, storm water runoff, certain industrial wastewaters, and runoff from animal feedlots. In m ost rivers and lakes, ammonia exists predominantly in the ionized form ($NH_4^+$). As pH and temperature increase, the ionized ammonia changes to un-ionized ammonia gas ($NH_3$). Ammonia gas can be toxic to fish and other aquatic organisms. If sufficient dissolved oxygen (DO) is present, ammonia can easily be broken down by nitrifying bacteria to form nitrite and nitrate. An analysis of variance (ANOVA) over the FWQ results has shown that there are significant differences between years assessed. It indicates that policies to diminish pollution are not giving optimistic results.

On the other hand, ANOVA shows that there are significant differences between sampling sites. The SP9 exhibits a good water quality, while SP10 is adequate. Differences between SP9 and the other sampling sites are due to the fact that this sampling sites do not have industrial activities. The SP10 and SP11 have small scale industries and small residential area. FWQ index indicated the load exerted on the Semenyih river basin taking into account both natural and anthropogenic factors. FWQ model is built with human language. It is valuable in water management decision processes, in which involved person has no mathematical background. Fuzzy model has been validated with two years independent sets of data.

## Model Validation

The validation results have been shown in (Fig. 3). In Figure 3, the FWQ index is compared with observed WQI index, which is used by Department of Environment (DOE) for river water classification. FWQ results have shown status of water quality in Semenyih river as adequate in some parts and acceptable in some other. FWQ outputs better agree with the real condition reported by DOE-WQI. The results are in perfect agreement with observed values to 90%. Further an expert survey is conducted by selecting most prominent rules out of derived fuzzy rules of the model. The results are shown in (Fig. 4). This is accumulated from 40 respondents involved in the field of study namely graduate researchers of higher learning institutes, Malaysian Department of Environment and its local offices in the state.

The results are also in good agreement with the expert survey for about 75%, indicating that human also makes mistake sometime. They may forget and give wrong responses in expert survey. If the number of respondents is more there is a possibility to get more accurate fit with fuzzy model. The developed fuzzy model determines the water

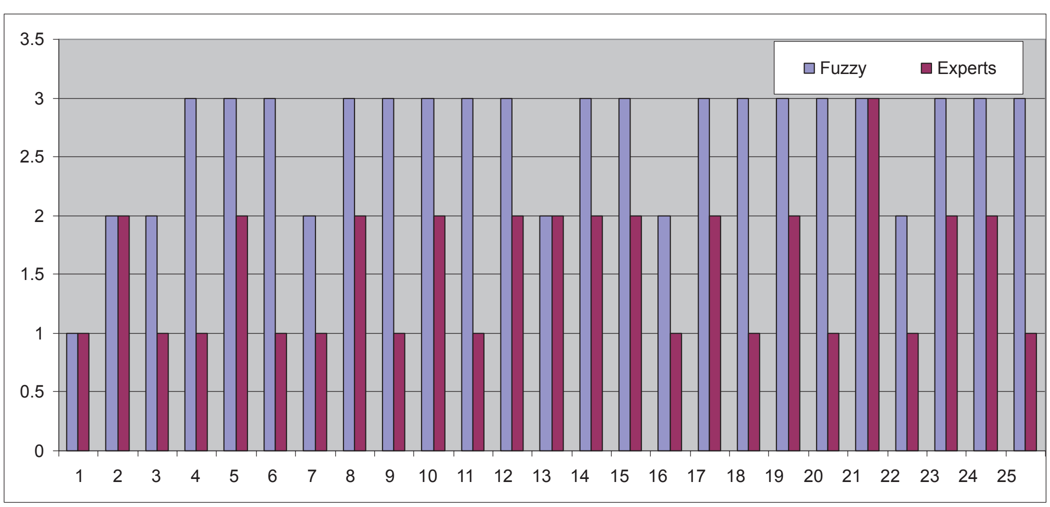


**Figure 4.** Comparison of Fuzzy results with Experts Survey.

**Table 2.** Water quality index and its suggested treatment.

| No. | Class | Intended use | Treatment method |
|---|---|---|---|
| 1 | I | Conservation of natural environment, Water Supply I and Fishery I—very sensitive aquatic species | Practically no treatment necessary |
| 2 | II | Water supply II, Fishery II—sensitive aquatic species and Recreational use with body contact | Conventional treatment required |
| 3 | III | Water supply III, Fishery III—common, of economic value and tolerant species livestock drinking | Extensive treatment required |
| 4 | IV | Irrigation | Advanced treatment methods required |
| 5 | V | None of the above | Must undergo waste water treatment |

**Source:** Department of environment, Malaysia.

quality index (FWI). With FWI, one can get guidance for the type of treatment for which the water has to be subjected to. Some of the criteria are derived through this research and are presented in (Table 2). Thus UNIQ2007 serves the purpose of determining water quality based on fuzzification system and advises for the proper treatment method.

FWQ does not objective at discussing the changes of the strength of a single pollutant or the alternation of a physical parameter. It is used as estimator of status of water quality generated by physiochemical determinants. Fuzzy model has been validated with the two years independent sets of data. The validation results have been shown in (Fig. 3). FWQ results give a water condition in the Semenyih river as some part is adequate, and some part is acceptable. FWQ outputs better agree with the real condition as reported by DOE-WQI.

## Conclusions

Fuzzy logic is the flexible tool to develop classification model with a simple framework and constructed with natural language. In this study, water quality index value was obtained to express the classification of river in order to make water quality assessment more understandable especially in public consideration. It has been demonstrated that computing with linguistic terms within FIS improves the tolerance for imprecise data. We have assessed water quality in the Semenyih river with physicochemical determinants.

Fuzzy model has demonstrated that water quality is below sustainable expected results in the Semenyih river. The new index is believed to assist decision makers in reporting the condition of water quality and investigation of spatial and temporal changes in the river. The authors believe that fuzzy logic concepts, if used logically, could be an effective tool for some of the environmental policy matters. Model based on FIS can be used for future determination of WQI for six parameters. More stringent methodologies are then required to molt the ideas of decision maker and manager to apply fuzzy model in practice.

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## Disclosures

The authors report no conflicts of interest.

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