Advances in Engineering Software 42 (2011) 787–796

Contents lists available at ScienceDirect

Advances in Engineering Software

journal homepage: www.elsevier.com/locate/advengsoft

A Cascaded Fuzzy Inference System for Indian river water quality prediction

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ARTICLE INFO

Article history:
Received 26 November 2009
Received in revised form 6 December 2010
Accepted 11 May 2011
Available online 28 June 2011

Keywords:
Fuzzy Inference System (FIS)
Cascaded Fuzzy Inference System (CFS)
Water quality index (WQI)
Membership function
Fuzzy numbers
MATLAB

ABSTRACT

Now-a-days, Fuzzy Inference System (FIS) is considered as an effective tool for solution of many complex engineering systems when ambiguity and uncertainly is associated with the systems. Mamdani and Takagi, Sugeno and Kang (TSK) models poses simplicity in modeling but their system performance prediction capability is severely affected as complexity of the problem increases. In a multi-input, multi-output situation where a system consists of many subsystems and different outputs are desired from each subsystem, an improved version of FIS must be adopted rather than developing FIS for each subsystem. When dealing with such a system, it is prudent to use cascading systems rather than developing models for individual systems. To this end, a new Cascaded Mamdani Fuzzy Inference System is proposed in this paper and its performance is evaluated with the help of prediction of Indian River water quality index (WQI). In general, WQI value is a dimensionless number ranging from 0 to 100 (best quality) and plays an important role in evaluating the water quality of rivers. The proposed model is designed to predict WQI for five rivers in India. The cascaded fuzzy system simplifies and speeds up the computation of WQI as compared to the currently existing standards. In this paper, the proposed model is compared with three International water quality criteria and it is found that the designed model results in accurate prediction.

1. Introduction

Quality of water plays a vital role in all aspects of human and ecosystem survival. All living and industrial activities are controlled by physical, chemical, biological, and microbiological conditions that exist in watercourses and subsurface aquifers. Water quality generally refers to the composition of a water sample. The interpretation of data to assess water quality may be difficult and often requires a lengthy procedure. Evaluations of water quality parameters are necessary to enhance the performance of an assessment operation and develop better water resources management and plan. Water quality modeling involves the prediction of water pollution using mathematical simulation techniques. All the water quality models treat water quality index (WQI) as a function of pH, Biological Oxygen Demand (BOD), Dissolve Oxygen (DO), Fecal Coliform (FC), Electric Conductivity (EC), Ammonical Nitrogen and Temperature, etc. present in the sample. Usually, these parameters are measured in laboratory and best fitting models are applied to predict WQI. Mathematical models are generally complex and pose difficulty in implementation in real time systems. Additionally, they fail to predict the future parameters from current and past measurements.

However, quality is a vague term that cannot easily be described using crisp data, for example good quality water cannot simply be described as having a pH value of 7.0 or above. Instead, it makes sense to consider water quality data to be a fuzzy set that provides the mathematical foundation to express the quality in linguistic terms such as very poor, poor, decent, good, and very good [1]. One way of simplifying a complex system is to allow some degree of uncertainty in its description. For example, water quality can best be described based on its degree of potability and potential usages rather than saying pH = 6.0, TDS = 255 ppm, total hardness = 216 ppm, and so on. Fuzzy based methods have already been demonstrated to address uncertainty and subjectivity in environmental problems [2]. The technique can be used to classify and quantify environmental effects of a subjective nature and provides formalism for missing data [3] and determination of water quality [4–6]. Fuzzy reasoning technique has also been applied in ground and surface water quality forecasting [7,8]. Some of the artificial neural network as well as multivariate analysis methods are also found to be more useful when determination of water quality is conducted based on fuzzy and principal component analysis (PCA) techniques [9,10]. Due to these limitations of deterministic and WQI approach, an advanced classification method is required,

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doi:10.1016/j.advengsoft.2011.05.018

which is capable of accounting for imprecise, vague and fuzzy information in decision-making on drinking water quality. Sii et al. [11] have discussed the uncertainties involved in water quality using fuzzy membership with values ranging from 0 to 1 to form an applicable fuzzy set instead of the conventional scale of 0–100 in WQI methodology. Soft computing techniques viz. Fuzzy Logic Systems, Artificial Neural Network, Radial Basis Functions, etc. have proven to be useful to reduce computational burden and improve prediction accuracy. Fuzzy logic was introduced as a mathematical way to represent vagueness in linguistics and can be considered as a generalization of classical set theory. Fuzzy theory had supplemented conventional technologies in many scientific applications and engineering applications. Very few articles have been reported on application of soft-computing techniques, especially Fuzzy Logic Systems on predicting WQI [12–14].

In this paper, an attempt has been made to develop a Cascaded Fuzzy Inference System model for prediction of Indian River water quality. The data assembled through surveys, measurement or knowledge to predict WQI is often imprecise or speculative. Since fuzzy system is a good prediction tool for imprecise and uncertainty information, the approach would be the most appropriate technique for modeling the prediction Indian River water quality.

2. Introduction to water quality index (WQI)

Water quality index is an attempt at an imperfect answer to non-technical questions about water quality. It is a unit less number ranging from 1 to 100; a higher number is indicative of better water quality. Multiple constituents are combined and results aggregated over time to produce a single score for each sampling site [15–17]. WQI rating scale is as follows: 91–100: excellent water quality, 71–90: good water quality; 51–70: medium or average water quality; 26–50: fair water quality; 0–25: poor water quality [15]. The parameters used in defining WQI are described as follows:

2.1. WQI parameters

2.1.1. Biochemical Oxygen Demand

The Biochemical Oxygen Demand (or BOD) is a measure of the amount of food for bacteria that is found in water. Bacteria utilize organic matter in their respiration and remove oxygen from the water. The BOD test provides a rough idea of how much biodegradable waste is present in the water (biodegradable waste is usually composed of organic wastes, including leaves, grass clippings, and manure).

2.1.2. Dissolved Oxygen

The Dissolved Oxygen test measures the amount of life-sustaining oxygen dissolved in the water. This is the oxygen that is available to fish, invertebrates, and all other animals living in the water. Most aquatic plants and animals need oxygen to survive; in fact, fish will drown in water when the Dissolved Oxygen levels get too low. Low levels of Dissolved Oxygen in water are a sign of possible pollution.

2.1.3. Fecal Coliform

Fecal Coliform is a form of bacteria found in human and animal waste.

2.1.4. Nitrates

Nitrates are a measure of the oxidized form of nitrogen and are an essential macronutrient in aquatic environments. Nitrates can be harmful to humans, because our intestines can break nitrates down into nitrites, which affect the ability of red blood cells to carry oxygen. Nitrites can also cause serious illnesses in fish.

2.1.5. pH

The pH level is a measure of the acid content of the water. Most forms of aquatic life tend to be very sensitive to pH. Water containing a great deal of organic pollution will normally tend to be somewhat acidic. Water with a pH of 7 is considered neutral. If the pH is below 7, it is classified as acidic, while water with a pH greater than 7 is said to be alkaline. The pH of tap water in the US is usually between 6.5 and 8.5.

2.1.6. Temperature change

The water temperature of a river is very important, as many of the physical, biological, and chemical characteristics of a river are directly affected by temperature. Most waterborne animal and plant life survives within a certain range of water temperatures, and few of them can tolerate extreme changes in this parameter. Using the same thermometer, the water temperature should be checked at the test site and at a similar site one mile upstream. Care should be taken when taking the temperature upstream to ensure that the amount of sunlight and the depth of the river are similar to the original test site.

2.1.7. Total dissolved solids

This is a measure of the solid materials dissolved in the river water. This includes salts, some organic materials, and a wide range of other things from nutrients to toxic materials. A constant level of minerals in the water is necessary for aquatic life. Concentrations of total dissolved solids that are too high or too low may limit growth and lead to the death of many aquatic life forms.

2.1.8. Turbidity

Turbidity is a measure of the dispersion of light in a column of water due to suspended matter. The higher the turbidity, the cloudier the water appears. If water becomes too turbid, it loses the ability to support a wide variety of plants and other aquatic organisms.

In India, once the overall WQI score is known, it can be compared against the scale given in Table 1 to determine how healthy the water is on a given day. Some countries provide water quality criteria classes for finding WQI. Here, two WQI criteria classes followed in Malaysia and US are shown in Table 2 and 3 respectively.

3. Fuzzy expert system – an introduction

Fuzzy expert system based on fuzzy set theory was introduced in 1965 by Zadeh [18] as a new way to represent vagueness in

Table 1
Indian water quality criteria classes (Central Pollution Control Board (CPCB)) [28].

S. no.	Parameters	Requirement for waters of class		
		A-excellent	B-desirable	C-acceptable
(I)	pH	7.0–8.5	6.5–9.0	6.5–9.0
(II)	DO (% saturation)	90–110	80–120	60–140
(III)	BOD, mg/l	Below 2	Below 3	Below 6
(IV)	EC, umhos/cm	1000	2250	4000
(V)	$(NO_2 + NO_3)$-Nitrogen, mg/l	5	10	15
(VI)	Suspended solid, mg/l	25	50	100
(VII)	Fecal Coliform, MPN/100 ml	20 per 100 ml	200 per 100 ml	2000 per 100 ml
(VIII)	Bio-assay (zebra fish)	No death in 5 days	No death in 3 days	No death in 2 days