Fuzzy Logic Application as A Tool for Classifying Water Quality Status in Gajahwong River, Yogyakarta, Indonesia

Novita Ayu Dewanti1*, Agus Maman Abadi2

1Postgraduate Program, Yogyakarta State University, Yogyakarta.
2Department of Mathematics Education, Yogyakarta State University, Yogyakarta.

*Corresponding author: novitaayu.2017@student.uny.ac.id

Abstract. The growth of manufacturing and waste disposal in the Gajahwong River watershed has resulted in decreasing river water quality. Therefore this study aims to develop a fuzzy logic system in classifying water quality status in Gajahwong River. There are 11 parameters used for classifying water quality status, namely temperature, potential hydrogen (pH), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), free chlorine, nitrate, nitrite, oil and fat, lead and Escherichia coli (E. Coli). These parameters are used to assess the Gajahwong River water quality at three different stations during the period of 2007 to 2017. The application process of fuzzy logic begins with the use of 11 parameters consisting of physical, chemical and biological parameters as input, with the Mamdani method as the fuzzy inference system. The output of this application is in the form of water quality status which is categorized as normal (N), lightly polluted (LP), moderately polluted (MP) and heavily polluted (HP). The classification is expected to facilitate the public in reading information about the quality of river water from the environmental agencies D.I. Yogyakarta, thus, the public can be aware of maintaining watersheds.

1. Introduction

The Gajahwong river is one of the big rivers in Yogyakarta and it flows through the main city of Yogyakarta. As time went by, many human activities had a direct impact on the river, such as factory and household waste disposal. This caused the river to be polluted by hazardous materials. Thus we need a classification of river water quality to see the level of pollution that occurs in a river.

Criteria for river water quality can be determined using physical, chemical and biological parameters. The parameters used in this study are physical parameters, namely temperature (temp); chemical parameters, namely potential hydrogen (pH), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), free chlorine, nitrate, nitrite, oil and fat, and leads; and biological parameters, namely Escherichia coli (E. coli). The value limit for each parameter has been determined. If the parameter exceeds the predetermined limit, it will be dangerous for human health [1]. The value limit has been explained in the form of water quality index (WQI). WQI is the most effective way to declare the status of overall water quality at a given location and time based on the parameters used [2].

Several studies on WQI have been carried out before. Research on the assessment of WQI in several drill holes has been carried out around disposal sites in Nigeria [3]. The parameters used are 23 types, including pH, turbidity, DO, BOD, COD, E. Coli, etc. The classification standards used are based on the National Sanitation Foundation (NSF). In that study has 5 category descriptors, namely excellent, good, medium, bad and very bad.
Assessing water samples using WQI was also carried out in several areas in Chandrapur City, India [4]. The physicochemical parameters used in this study were 10 types (pH, chlorides, DO, BOD, etc.). WQI assessments in that study were carried out using the Weighted Arithmetic Index Method. The water quality produced from the WQI assessment has 5 categories, namely excellent, good water, poor water, very poor water and unsuitable for drinking.

Similar research on the use of WQI in the form of case studies for water quality assessment has also been carried out in Metro Manila [5]. The parameters used was less than the previous research, which were 4 types (pH, DO, BOD, and total coliform). The classification standard used in that study is based on the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI). The category descriptor on the WQI is more detailed than the previous research, namely with 6 descriptors in the form of excellent, very good, good, fair, marginal and poor.

In the meantime, river water quality in Indonesia has been regulated in Peraturan Pemerintah No. 82 of 2001. Determination of river water quality is carried out through WQI assessments. These assessments can be determined through the method of Pollution Index (IP) or Storet [6]. The category standard for Storet method consists of 4 categories, namely fulfilling quality standards or normal, lightly polluted, moderately polluted, and heavily polluted. In this study, the Storet method will be used to compare with the results of the FIS method.

Fuzzy logic has long been designed for environmental indices because it can solve complex problems such as ambiguity, subjective judgment, and interpretation of a complex set of multidimensional data [7]. Research on the use of fuzzy logic in WQI assessments has been carried out. Research on the use of fuzzy logic has been done to evaluate the quality of drinking water [1]. The study uses 5 input parameters and output divided into 4 types using 10 rules that are formed.

Research at Sorocaba river, Brazil also developed fuzzy water quality using 9 input parameters [8]. The development process is done by comparing two inference systems. Moreover, other studies on fuzzy logic to analyze WQI have also been carried out [9]. Research has been carried out on watersheds in Sao Paulo State, Brazil. The inputs used are 8, output and 3125 rules are formed. In Malaysia, research on the development of fuzzy logic for WQI has been carried out in Semenyih river [10].

Research has been carried out using 5 input parameters, an output and 86 rules are formed. Fuzzy logic can also be used to measure reservoir water quality as research in Mexico [7]. The study developed a fuzzy logic tool to measure the quality of reservoir water in Lerma River, Mexico. Some fuzzy logic components used are 8 input parameters, an output, and 633 rules.

Therefore, it is necessary to assess the quality of the water index on the Gajahwong river. The assessment is done using fuzzy logic to get the quality status of water. The results of the quality of the water status are expected to be easily understood by the community so as to be able to foster awareness of the community around the river to maintain the blood flow of the river.

2. Method

This study aims to develop a fuzzy logic system for classifying water quality status in Gajahwong River, Yogyakarta. The research method used is a literature study. The data used in this study are secondary data obtained from the website of the Environment Agency of the Yogyakarta Special Region [11]. River water quality is monitored at 3 different station locations, namely in Tanen Bridge, Sleman (Upper), Mujamuju Bridge, Yogyakarta (Central), and Kanggotan Bridge, Bantul (Downstream). Data collected as many as 33 data at the interval 2007 - 2017.

The data analysis technique used is the Storet method. Determination of classification of river water quality status based on the Decree of the Minister of Environment No. 115 concerning Guidelines for Determining Water Quality Status [6]. The classification results of the water quality status are then compared with the results of the Mamdani method fuzzy logic system defuzzification of centroid and the defuzzification of largest of maximum (LOM). This is done in order to get the best way in fuzzy logic applications. The application of fuzzy logic for river water classification consists of 1) input in the form of 11 parameters of river water status consisting of temperature, pH, DO, BOD, COD, free chlorine, nitrate, nitrite, oil and fat, lead and E. coli; 2) output in the form of 4 status of river water.
quality consisting of normal, lightly polluted, moderately polluted and heavily polluted; and 3) the rules used are 32 rules from 33 data.

The steps taken are: 1) identification of river water quality data using storet method, 2) determine input-output, 3) determine universal set of input-output variables, 4) define fuzzy set membership functions in input-output variables, 5) do fuzzification on input and output data, 6) determine rule-base, 7) do fuzzy inference, 8) do defuzzification of centroid and LOM, 9) test data accuracy and 10) conclusion.

| Table 1. Fuzzy Sets Each Variable |
|-----------------------------|
| Function  | Variable | Fuzzy Set | Universe Set | Domain |
| Input     | Temp     | Low       | [15, 35]     | [0 0 20 25] |
|           |          | Mid       | [20 25 30]   |          |
|           |          | High      | [25 30 35 35] |          |
| pH        |          | Low       | [5, 10]      | [5 5 6.5 7] |
|           |          | Mid       | [6.5 7 8.5]  |          |
|           |          | High      | [7 8.5 10 10] |          |
| DO        |          | Low       | [2, 27]      | [2 2 5] |
|           |          | Mid       | [2 5 10]     |          |
|           |          | High      | [5 10 27 27] |          |
| BOD       |          | Low       | [1, 40]      | [1 1 3] |
|           |          | Mid       | [1 3 10]     |          |
|           |          | High      | [3 10 40 40] |          |
| COD       |          | Low       | [2, 55]      | [2 2 25] |
|           |          | Mid       | [2 25 55]    |          |
|           |          | High      | [25 55 55]   |          |
| Free Chlorine | Low | [0, 1]   | [0 0 0.03]   | [0 0 0.03 0.1] |
| Nitrate   | Low      | [0, 15]   | [0 0 10]     |          |
|           | Mid      | [0 10 15] | [0 10 15]    |          |
|           | High     | [10 15 15]| [10 15 15]   |          |
| Nitrite   | Low      | [0, 3]    | [0 0 0.06]   | [0 0 0.06 0.3] |
|           | Mid      | [0 0.06 3]| [0 0.06 3]   |          |
|           | High     | [0.06 3]  | [0.06 3]     |          |
| Oil and Fat | Low | [0, 6000]| [0 0 1000] | [0 0 1000] |
|            | Mid      | [0 1000 6000]|          | [0 1000 6000] |
|            | High     | [1000 6000 6000]| | [1000 6000 6000] |
| Lead      | Low      | [0, 1]    | [0 0 0.3]    | [0 0 0.3 1] |
|           | Mid      | [0 0.3 1] | [0.3 1 1]    |          |
|           | High     | [0.3 1 1] | [0.3 1 1]    |          |
| E. Coli   | Low      | [0, 4600000]| [0 0 100] | [0 0 100] |
|            | Mid      | [0 100 100000]| | [0 100 100000] |
|            | High     | [100 100000 4600000 4600000]| | [100 100000 4600000 4600000] |
| Output    | Water Quality Index | Normal (N) | [-140, 0]| [-2 -1 0 0] |
|           |          | Lightly Polluted (LP) | [-11 -10 -2 -1]|          |
|           |          | Moderately Polluted (MP) | [-31 -30 -11 -10]|          |
|           |          | Heavily Polluted (HP) | [-140 -140 -31 -30]|          |
3. Result and discussion
The fuzzy logic application system will perform calculations using the Mamdani method. The steps taken are:

3.1 Data Input Process
Users of the application entered data on the Gajahwong river in 2007 which was classified as heavy polluted and had the following criteria: temperature = 23.9 °C, pH = 7, DO = 4.7 mg/L, BOD = 5.8 mg/L, COD = 35.3 mg/L, free chlorine = 0.04 mg/L, nitrate = 2.4 mg/L, nitrite = 0.03 mg/L, oil and fat = 1200 μg/L, lead = 0.02 mg/L, E. coli = 107666.7 JPT/100 mL.

3.2 Fuzzification Process
The first step to calculating is to make a fuzzy set for each variable. Fuzzy sets for each variable can be seen in Table 1.

The graph of the fuzzy set membership functions each variable both input and output can be seen in Figures 1 to 6.

![Graph Membership Function of Temperature and pH](image1)

**Figure 1.** Graph Membership Function of Temperature (1a) and pH (1b).

![Graph Membership Function of DO and BOD](image2)

**Figure 2.** Graph Membership Function of DO (2a) and BOD (2b).
Figure 3. Graph Membership Function of COD (3a) and Free Chlorine (3b).

Figure 4. Graph Membership Function of Nitrate (4a) and Nitrite (4b).

Figure 5. Graph Membership Function of Oil and Fat (5a) and Lead (5b).
Based on the membership function of each parameter, the first river data obtained is the degree of membership (DM) for each parameter in Table 2.

### Table 2. The Degree of Membership of the First River Data

| Parameter   | Data   | DM       | Category |
|-------------|--------|----------|----------|
| Temp        | 23.9   | 0.7800   | Mid      |
| pH          | 7.0    | 1        | Mid      |
| DO          | 4.7    | 0.9000   | Mid      |
| BOD         | 5.8    | 0.6000   | Mid      |
| COD         | 35.3   | 0.6567   | Mid      |
| Free Chlorine| 0.04  | 0.8571   | Mid      |
| Nitrate     | 2.4    | 0.7600   | Low      |
| Nitrite     | 0.03   | 0.5000   | Low      |
| Fat and Oil | 1200.0 | 0.9600   | Mid      |
| Lead        | 0.02   | 0.9333   | Low      |
| E. Coli     | 107666.7 | 1       | High     |
| WQI         | -61    | 1        | HP       |

After fuzzification, the rule base will be determined. The rule base that will be used is fuzzy IF-THEN rules [12]. The operator used to connect between inputs is an AND operator. Rules were built using the help of Matlab R2011b and there were 32 rules formed from 33 data. Here are some of the following rules used that been used; [1] If (Temp is Mid) and (pH is Mid) and (DO is Mid) and (BOD is Mid) and (COD is Mid) and (FChlorine is Mid) and (Nitrate is Low) and (Nitrite is Low) and (Oil and Fat is Mid) and (Lead is Low) and (E. Coli is High) then (WQI is HP); [2] If (Temp is Mid) and (pH is Mid) and (DO is Mid) and (BOD is High) and (COD is High) and (FChlorine is Mid) and (Nitrate is Low) and (Nitrite is Low) and (Oil and Fat is Mid) and (Lead is Low) and (E. Coli is High) then (WQI is HP); and [32] If (Temp is High) and (pH is High) and (DO is Mid) and (BOD is Mid) and (COD is Low) and (FChlorine is Mid) and (Nitrate is Low) and (Nitrite is Mid) and (Oil and Fat is Mid) and (Lead is Low) and (E. Coli is Mid) then (WQI is HP).

3.3 Fuzzy Inference System of Mamdani Method

In fuzzy inference systems (FIS), there is a process of converting inputs into output following the IF-THEN rules that have been set on the basis of fuzzy rules [13]. The fuzzy inference system used is the Mamdani Method, also known as the Min-Max Method. There are several methods on fuzzy inference system used, namely: 1) Implications, the implication method used is the MIN method; and 2) aggregation, the aggregation method used in this paper is the MAX method.

3.4 Defuzzification

This defuzzification stage will return the results of fuzzy calculations into variables that correspond to the range at the output. Defuzzifier uses the membership function to map fuzzy set values to variables.
at the output so that obtained crisp value information [14]. The method used is the Centroid Method or the center of the area and Largest of Maximum (LOM).

3.5 Fuzzy System Result and Accuracy
The following are the results of the fuzzy logic application system obtained from the Gajahwong river data. In Table 3 we can see the results of a comparison of the classification of water quality status based on the Storet Method, the Mamdani Centroid Method, and the Mamdani LOM Method.

| Year | Location | Storet Skor | Category | Mamdani Centroid Skor | Category | Mamdani LOM Skor | Category |
|------|----------|-------------|----------|------------------------|----------|------------------|----------|
| 2007 | 1        | -61         | HP       | -85.4                  | HP       | -140             | HP       |
|      | 2        | -63         | HP       | -85.4                  | HP       | -140             | HP       |
|      | 3        | -57         | HP       | -85.4                  | HP       | -140             | HP       |
| 2008 | 1        | -30         | MP       | -71.8                  | HP       | -29.4            | MP       |
|      | 2        | -43         | HP       | -85.4                  | HP       | -140             | HP       |
|      | 3        | -33         | HP       | -85.4                  | HP       | -140             | HP       |
| 2009 | 1        | -22         | MP       | -20.6                  | MP       | -29.4            | MP       |
|      | 2        | -49         | HP       | -85.4                  | HP       | -140             | HP       |
|      | 3        | -43         | HP       | -85.4                  | HP       | -140             | HP       |
| 2010 | 1        | -31         | HP       | -80.8                  | HP       | -140             | HP       |
|      | 2        | -33         | HP       | -85.4                  | HP       | -140             | HP       |
|      | 3        | -25         | MP       | -85.4                  | HP       | -140             | HP       |
| 2011 | 1        | -27         | MP       | -20.7                  | MP       | -29.4            | MP       |
|      | 2        | -41         | HP       | -85.4                  | HP       | -140             | HP       |
|      | 3        | -33         | HP       | -83.9                  | HP       | -140             | HP       |
| 2012 | 1        | -39         | HP       | -85.4                  | HP       | -140             | HP       |
|      | 2        | -43         | HP       | -85.4                  | HP       | -140             | HP       |
|      | 3        | -41         | HP       | -85.4                  | HP       | -140             | HP       |
| 2013 | 1        | -27         | MP       | -63.8                  | HP       | -29.4            | MP       |
|      | 2        | -35         | HP       | -85.4                  | HP       | -140             | HP       |
|      | 3        | -35         | HP       | -85.4                  | HP       | -140             | HP       |
| 2014 | 1        | -27         | MP       | -20.6                  | MP       | -29.4            | MP       |
|      | 2        | -41         | HP       | -85.4                  | HP       | -140             | HP       |
|      | 3        | -63         | HP       | -85.4                  | HP       | -140             | HP       |
| 2015 | 1        | -51         | HP       | -85.4                  | HP       | -140             | HP       |
|      | 2        | -45         | HP       | -85.4                  | HP       | -140             | HP       |
|      | 3        | -45         | HP       | -85.4                  | HP       | -140             | HP       |
| 2016 | 1        | -43         | HP       | -85.4                  | HP       | -140             | HP       |
|      | 2        | -63         | HP       | -85.4                  | HP       | -140             | HP       |
|      | 3        | -55         | HP       | -85.4                  | HP       | -140             | HP       |
| 2017 | 1        | -43         | HP       | -77.3                  | HP       | -140             | HP       |
|      | 2        | -55         | HP       | -85.4                  | HP       | -140             | HP       |
|      | 3        | -67         | HP       | -85.4                  | HP       | -140             | HP       |

Accuracy System: 90.90% 96.97%
Based on Table 3, it was found that the FIS of the Mamdani method with defuzzification Centroid has an accuracy system of 90.90%. The FIS of the Mamdani method with defuzzification of LOM has an accuracy system of 96.97%. FIS of the Mamdani method with Centroid defuzzification experienced errors in 3 data, namely in 2008 (location 1), 2010 (location 3), and 2013 (location 1). However, the FIS of the Mamdani method with LOM defuzzification experienced an error in 1 data, namely in 2010 (location 3). Thus, the FIS of the Mamdani method with LOM defuzzification has a higher level of accuracy system compared to the Mamdani method FIS. Therefore, it can be said that the FIS application of the Mamdani method with LOM defuzzification has a higher level of accuracy than the FIS of the Mamdani method with the Centroid defuzzification.

4 Conclusion
Assessing the quality water index of the Gajahwong River by applying fuzzy logic can be done using fuzzy logic applications. The fuzzy logic application method used is the Mamdani method with defuzzification of LOM. This is similar to the statement that fuzzy logic can be used to develop river water classification models [10]. Thus, this fuzzy logic application can be used as a substitute for manual calculations carried out by the Environment Agency.

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