Fuzzy logic to predict Pb content in ex tin-mined pond in Bangka regency

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Abstract. The presence of Pb is one of the constraint to utilize ex tin-mined ponds for various purposes. Information about Pb content in ex tin-mined ponds is useful for determining the kind of utilization and ponds development. This research was conducted to provide an alternative way of predicting Pb content in ex tin-mined ponds through generating a prediction model using fuzzy logic with mamdani inference. Two fuzzy input variables, namely pH and turbidity, and one output variable namely Pb content were gained from measurement of water samples from eighteen ponds in Bangka regency. Sampling technique used was purposive sampling at three kinds of ponds i.e young, medium, and old ponds. These three variables were defined respectively at three fuzzy sets i.e. low, medium, and high. From eighteen data testing, sixteen prediction shown true values. This imply that fuzzy prediction model provide a high degree of accuracy, namely 88.9%.

1. Introduction

The number of ponds in Bangka island is predicted will increase due to the increasing of tin mining activities. On the other hand, ponds have a great of potential utilization and big benefit. Ex tin-mined ponds can be used as planting media of water hyacinth that able to decrease amount of Pb and produce electricity [1]. Furthermore it can be harnessed for various purposes, which is development of tourism destination, supplier for availability of drinking waters, aquaculture commodity, supporting agriculture, and others need.

One of constraints that found for utilizing ex tin-mined ponds are the existence of heavy metals at ponds that harmful for living perpetuity of human, animal, and plants. At various kind of ponds (young, medium, and old) at Bangka Island were found some metals i.e. Pb, Cd, and Fe [2]. The content of Fe, Cu, Cd, and Pb at Kacang pedang pond retention exceed from normal standard [3]. At five lakes former tin mining sites at Malaysia contained high concentrations of Pb compared to As, Cu, and Zn [4]. In the mining water at Nigeria all the selected metals namely Cu, Cr, Mn, Cd, and Fe were detected except for cadmium and were within the WHO permissible limit [5].

The presence of heavy metals as a pollutant associated with water quality. Water quality is one of the important factors to determine changes and levels of environmental pollution due to human activities [6]. The reduce water quality is mainly due to the increase in pollutants, nutrients, and heavy metals [7]. Heavy metal release under varying pH condition, a pH increase significantly decrease the leachability of Zn, Cd, and Pb [8].

Fuzzy logic has a more appropriate and accurate approach to evaluate the concentration of cadmium in soil and product regarding the attention that is paid to the impact of all the characteristics of soil and...
the complex relationship among the parameters and plant type [9]. An adaptive Neuro-Fuzzy Inference System (ANFIS) methodology produce very successful findings and has the ability to predict Cd concentration in water resources. ANFIS also provide more information, simulation, and prediction about heavy metal concentration in natural aquatic ecosystems. Therefore, ANFIS can be used in further researches on water quality monitoring [10]. ANFIS simulates and predicts mercury speciation for biological uptake and mercury adsorption to sediments. Modeling of mercury bioavailability for biota and adsorption to sediments shows strong correlation of more than 98% between simulation results and experimental data [11]. Technically, Pb metal is usually measured using tools, namely AAS (Atomic Absorption Spectroscopy). In case there wasn’t the tool, it is needed an alternative way to determine content of Pb so that provide many benefits. Fuzzy logic system was an powerful tool to creating models on predicting the content of Pb metal at ex tin-mined ponds.

2. Material and Methods

2.1. Study Area and Sampling

Study area of this research were three kinds of ponds (young, medium, and old) at Bangka regency. The determination of pond samples was done used purposive sampling at seven districts in Bangka Regency, namely Belinyu, Riau Silip, Pemali, Sungailiat, Merawang, Mendo Barat, and Bakam districts (Figure 1). The water samples were collected from eighteen ponds between Maret until Juni 2019. The coordinates of sampling locations were gained using GPS (Global Positioning System) device. Variables of pH and turbidity were measured onsite using pH meter and turbidity meter, respectively. Pb content was measured at Laboratory of Environmental Agencies of Bangka Belitung Province and refers to Indonesian National Standard number 6989.08:2009.

![Figure 1. Three examples of pond](image)

(a) old pond at Belinyu district (b) medium pond at Merawang district (c) young pond at Bakam district

2.2. Fuzzy Method

The procedure of fuzzy process consist of problem identification, fuzzification, fuzzy interference and rule base, deffuzzification, interpretation and verification [12]. There are two variables input namely pH and turbidity, and single variable output i.e. Pb content. For each variable is defined fuzzy set, domain, and parameters. Next step is forming and evaluating fuzzy rules to generate fuzzy model. This fuzzy logic process was carried out in the fuzzy logic matlab toolbox.

3. Result and Discussion

The values of pH, turbidity, and Pb content at eighteen samples pond are shown at Table 1. Generally pH values have range from 3.2 to 8.2, the lowest and highest values of turbidity is 1.78 and 1017, respectively. Pb content measurements indicated values below 0.025, while upper limit of Pb values refers to Indonesian National Standard number 6989.08:2009 is 0.1 mg/L.
Table 1. pH, turbidity, and Pb content values at 18 ex tin-mined ponds in Bangka Regency.

| Samples | pH   | Turbidity (NTUs) | Pb (mg/L) | Measured | Quality standards |
|---------|------|------------------|-----------|----------|------------------|
| 1       | 6.0  | 1.78             | <0.025    | 0.1 mg/L |
| 2       | 6.5  | 3.43             | <0.025    |          |
| 3       | 7.0  | 13.5             | <0.025    |          |
| 4       | 7.0  | 2.27             | <0.025    |          |
| 5       | 3.4  | 3.99             | <0.025    |          |
| 6       | 5.5  | 2.01             | <0.025    |          |
| 7       | 4.5  | 570              | <0.025    |          |
| 8       | 7.0  | 12.51            | <0.025    |          |
| 9       | 5.4  | 1017             | <0.025    |          |
| 10      | 7.5  | 68               | <0.025    |          |
| 11      | 7.8  | 36.51            | <0.025    |          |
| 12      | 8.2  | 10.91            | <0.025    |          |
| 13      | 5.0  | 152              | <0.025    |          |
| 14      | 6.5  | 151              | <0.025    |          |
| 15      | 6.2  | 994              | <0.025    |          |
| 16      | 3.5  | 14.73            | <0.025    |          |
| 17      | 3.2  | 8.87             | <0.025    |          |
| 18      | 7.0  | 5.91             | <0.025    |          |

3.1. Fuzzy Design

Based on table 1 defined the membership function for each variables as shown in table 2.

Table 2. Membership function of pH, turbidity, and Pb content.

| Function | Variable | Fuzzy set | Domain | Subdomain | Parameters |
|----------|----------|-----------|--------|-----------|------------|
| Input    | pH       | Low       | [0 9]  | [0 3]     | [0 1.5 3]  |
|          |          | Medium    | [2.5 6.5] | [2.5 4.5 6.5] |           |
|          |          | High      | [6 9]  | [6 7.5 9] |            |
| Turbidity| Low      | [0 1020]  | [0 400] | [0 200 400] |            |
|          | Medium   | [300 700] | [300 500 700] |           |
|          | High     | [600 1020] | [600 800 1020] |          |
|          | Low      | [0 0.1]   | [0 0.04] | [0 0.02 0.04] |          |
| Output   | Pb       | Medium    | [0.03 0.07] | [0.03 0.05 0.07] |          |
|          | High     | [0.06 0.1] | [0.06 0.08 0.1] |          |

Fuzzy rules based on fuzzy set (pH, turbidity, and Pb content) consist of nine rules. These rules defined relationship between input and output variables. Following are the rules:

[R1] IF (pH is low) and (Turbidity is low) THEN (Pb content is medium)
[R2] IF (pH is low) and (Turbidity is medium) THEN (Pb content is medium)
[R3] IF (pH is low) and (Turbidity is high) THEN (Pb content is high)
[R4] IF (pH is medium) and (Turbidity is low) THEN (Pb content is low)
[R5] IF (pH is medium) and (Turbidity is medium) THEN (Pb content is medium)
[R6] IF (pH is medium) and (Turbidity is high) THEN (Pb content is medium)
[R7] IF (pH is high) and (Turbidity is low) THEN (Pb content is low)
[R8] IF (pH is high) and (Turbidity is medium) THEN (Pb content is low)
[R9] IF (pH is high) and (Turbidity is high) THEN (Pb content is medium)

3.2. Fuzzy Logic Procedure in Matlab Toolbox

3.2.1. Membership Function

The membership function of pH variable shown at Figure 2. It represented as triangular membership function with 3 (three) fuzzy sets i.e. low [0 3], medium [2.5 6.5], and high [6 9].
The membership function of turbidity variable shown at Figure 3. It represented as triangular membership function with 3 (three) fuzzy sets i.e. low [0 400], medium [300 700], and high [600 1020].

The membership function of Pb content variable shown at Figure 4. It represented as triangular membership function with 3 (three) fuzzy sets i.e. low [0 0.04], medium [0.03 0.07], and high [0.06 0.1].

3.2.2. Rules Viewer

The result from rules were defined on matlab fuzzy toolbox seen at Figure 5.
3.2.3. Surface Viewer

The surface on Figure 6 indicated that the lower pH and the higher turbidity values, the higher content of Pb.

![Surface Viewer](image)

**Figure 6.** Surface viewer for predicting Pb content based on pH and turbidity variables

3.3. Model Testing

The model testing was applied to determine performance of mamdani fuzzy logic on predicting Pb content. It is worked by comparing values of Pb prediction from fuzzy and eighteen data from survey. Table 3 showed the results.

| Sample | pH  | Turbidity (NTUs) | Pb content | Conclusion |
|-------|-----|-----------------|------------|------------|
|       |     |                 | Measuring output | Fuzzy set | Fuzzy output | Fuzzy set |
| 1     | 6   | 1.78            | <0.025      | low       | 0.02        | low       | true      |
| 2     | 6.5 | 3.43            | <0.025      | low       | 0.02        | low       | true      |
| 3     | 7.0 | 13.5            | <0.025      | low       | 0.02        | low       | true      |
| 4     | 7.0 | 2.27            | <0.025      | low       | 0.02        | low       | true      |
| 5     | 3.4 | 3.99            | <0.025      | low       | 0.02        | low       | true      |
| 6     | 5.5 | 2.01            | <0.025      | low       | 0.02        | low       | true      |
| 7     | 4.5 | 570             | <0.025      | low       | 0.02        | low       | true      |
| 8     | 7.0 | 12.51           | <0.025      | low       | 0.02        | low       | true      |
| 9     | 5.4 | 1017            | <0.025      | low       | 0.05        | medium    | false     |
| 10    | 7.5 | 68              | <0.025      | low       | 0.02        | low       | true      |
| 11    | 7.8 | 36.51           | <0.025      | low       | 0.02        | low       | true      |
| 12    | 8.2 | 10.91           | <0.025      | low       | 0.02        | low       | true      |
| 13    | 5.0 | 152             | <0.025      | low       | 0.02        | low       | true      |
| 14    | 6.5 | 151             | <0.025      | low       | 0.02        | low       | true      |
| 15    | 6.2 | 994             | <0.025      | low       | 0.05        | medium    | false     |
| 16    | 3.5 | 14.73           | <0.025      | low       | 0.02        | low       | true      |
| 17    | 3.2 | 8.87            | <0.025      | low       | 0.02        | low       | true      |
| 18    | 7.0 | 5.91            | <0.025      | low       | 0.02        | low       | true      |

Table 4 showed that from eighteen (18) data testing there are two (2) conclusion indicated false values and the others were true. It means Mamdani fuzzy logic give accuracy until 88.9% to predict Pb content in ex tin-mined ponds. The comparement between observed and predicted Pb content shown at Figure 7.
Figure 7. Comparison of measured and predicted Pb content in ex tin-mined ponds in Bangka

4. Conclusion
Fuzzy logic with Mamdani inference has a high degree accuracy (88.9%) for predicting the content of Pb in ex tin-mined ponds based on pH and turbidity variables.

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