Analysis of agriculture land pollution in Pangkal Baru village, Sintang district using Sugeno method

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Abstract. In Indonesia, the condition of the land of each region is different. It depends on the type of soil and the geographical location of a place or area so that it affects the quality of the soil. For farmers, especially in the countryside, to understand the knowledge of good soil quality is certainly difficult and requires a relatively long time to determine the right type of vegetation, which fits the soil condition, especially for farmers. The purpose of this paper is to help the process of disseminating information and knowledge through calculations using fuzzy logic. In this study, the processed data are the aspect data of the soil as a benchmark in determining whether or not the soil is polluted including pH or acidity of the soil, soil minerals, soil structures and soil nutrient elements. At this time the analysis of fuzzy calculations is performed using the Sugeno method. This paper show that the results obtained by the Sugeno method are not in accordance with the actual data. This is because among the six data, only five data match the actual data, then the percentage of errors with the Sugeno method is 16%.

1. Introduction

Especially for the agricultural sector, good and uncontaminated land is very much needed. In the agricultural sector, land is an important factor in determining agricultural business. In Indonesia, the condition of the land of each region is different that it depends on the type of soil and the geographical location of a place or an area that affects the quality of the soil in the area [1]. Therefore, the quality of soil is maintained and preserved in its function for the maintenance of health and human welfare and protection for other living creatures. In addition to the community, healthy soil is also one of the success determinants for the agricultural sector, because many cases of agricultural business fail only due to contaminated or unhealthy soil problems [2]. This can occur as a result of a lack of understanding about the criteria for good soil or uncontaminated land. The majority of farmers only rely on how to plant well without paying attention to the quality of the land.

For farmers, especially in the countryside, to understand the knowledge of good soil quality is certainly difficult and requires a relatively long time to determine the right type of vegetation which fits the soil condition, especially for farmers [1]. In this study, we will explain how to predict land that is not polluted and safe for both the community and the agricultural sector in helping to make decisions through the selection of healthy and uncontaminated soil types.

Besides that, it can help the process of disseminating information and knowledge through calculations using fuzzy logic. Fuzzy forecasting system can capture the pattern of the past data to project data that will come and some fuzzy logic has frequently been used to assist in the completion of a wide variety of predictions [3]. The data in this paper were calculated using fuzzy logic with the Sugeno method to overcome several data values that compare the uncertainty of data, which were
obtained by the researchers through various sources from every aspect of tested soil samples [4]. This research was conducted at Yogyakarta State University. There are several relevant studies on fuzzy logic which are applied to predict soil conditions, including research by Ahmad Nidomudin that discusses about expert system for determining soil fertility levels using fuzzy logic [4]. Another research within this field was conducted by Jimmi Martin that discuss about pH-based control and soil moisture fuzzy logic using microcontrollers [5]. Added to this, relevant research on fuzzy which is applied to predict pollution includes an existing study discussing about detection system for polluted air pollution in Lapindo mud area using fuzzy logic by Reza Hastuti [6]. The advantages of this study are compared with those of previous research predicting the contaminated soil condition using manual calculation, namely the Sugeno method. It is expected to examine whether or not the system is necessarily used, while the manual calculation is more easily adapted to the actual soil conditions.

2. Method
In this paper, data will be processed by fuzzy models. Fuzzy models have supplanted more conventional technologies in many scientific applications and engineering systems. The property that makes fuzzy set theory particularly interesting is its ability to handle the imprecision inherently present in a system [7]. There are many kinds of fuzzy models such as the Sugeno method has a similar reasoning to the Mamdani Fuzzy model in terms of processing data. However, if the output of reasoning with the Fuzzy Sugeno model is in the form of a constant or linear equation, the Fuzzy Mamdani model is in the form of a Fuzzy set [8]. Here is the flowchart of the research method.

![Flowchart Sugeno Method](image)

3. Data Analysis
As mentioned above, the data which had been processed are the agriculture land data from Yulianto’s study about land condition in Pangkal Baru village, Sintang district [1]. These data achieved the aspect which could categorise soil into several types and could determine whether or not the soil is contaminated by using the fuzzy method. There are aspects of land elements that become input variables and those elements will be sorted into 3 main aspects:

3.1 Variable Degrees of Acidity or pH of Soil

One of the soil parameters that affects soil fertility is the degree of acidity (pH) which can be expressed in the range of 1 to 14 [8]. The pH value of neutral soils is 7, but the pH value of normal and healthy soil is above 5.5, thus the soil which has less than pH 5.5 is said to be acidic, and more than 7 is said to be alkaline. Almost all plants can grow and prefer to develop in slightly acidic and slightly alkaline soils between pH 5.5 - 7.5 depending on the type of plants [1].
3.2 Variables in Soil Nutrients

Nutrients are important in plants that can foster their growth. Nutrients usually require water as a solvent in taking and transporting substances [9]. However, nutrient elements often gradually diminish and even disappears when a lot of waste, both factory waste and residential waste, are approaching soil. This can be measured based on the proximity or absence of the plants, or the settlement of residential areas, or the large percentage of organic carbon in soil [1].

Table 2. Variable of Soil Nutrients

| Category | Percentage of Organic C (%) |
|----------|----------------------------|
| Less     | [0,1.5]                    |
| Enough   | [1.5,3.0]                  |
| Normal   | [>3.0]                     |

Based on Table 2, it is clear that ‘less’ category of soil nutrients has interval percentage of organic carbon from 0 - 1.5%, for example, in the real data organic carbon consumes 1%; thus, it is considered as ‘less’. ‘Enough’ category of soil nutrients has interval percentage of organic carbon from 1.5 - 3%, for example, in the real data organic carbon consumes 2.5%; thus it is considered as ‘enough’. ‘Normal’ category of soil nutrients contains organic carbon up to 3%, for example, in the real data organic carbon consume 10%; thus it is considered as normal.

3.3 Variable of Soil Mineral Content

The soil mineral content can usually help plants become fertile and not easily withered. This is because it is needed by microorganisms and fungi that support soil fertility. However, if soil does not contain any fungi or microorganisms, it does not contain minerals. Healthy and uncontaminated soil refers to the soil that contains minerals which can be measured from a large proportion of total potassium per gram in the soil sample taken [1].

Table 3. Variable of Soil Mineral Content

| Category | K Total (mg/100gr) |
|----------|-------------------|
| Less     | [0,20]            |
| Enough   | [20,40]           |
| Normal   | [>40]             |

Based on Table 3, we can see that ‘less’ category of total potassium per 100gram land has interval from 0-20, for example, in the real data potassium amount is 18mg; thus it is considered as ‘less’. ‘Enough’ category of total potassium per 100gram land has interval from 20-40, for example, in the real data of potassium amount is 34mg; thus, it is considered as ‘enough’. ‘Normal’ category of total potassium per 100gram land is up to 40mg, for example, in the real data potassium amount is 85mg, thus, it is considered as ‘normal’.
4. Analysis of Membership Degrees (Fuzzification)

4.1 Membership Function of Variables in the Degree of Soil Acidity

Membership functions of the soil acidity degree is used to calculate the value of $x$ degree of soil acidity, which can be expressed as follows:

$$\begin{align*}
[x_{ac}] &= \begin{cases}
1, & 0 < x < 4.4 (1) \\
\frac{4.5-x}{4.5-0}, & x \geq 4.4
\end{cases}
\end{align*}$$

$$\begin{align*}
[x_{ac}] &= \begin{cases}
0, & x < 4.4 \\
\frac{5.5-x}{5.5-4.4}, & 4.4 \leq x < 5.5 \\
1, & 5.5 \leq x < 6.0 \\
\frac{6.0-x}{7.5-6.0}, & 6.0 \leq x < 7.5 \\
0, & x \geq 7.5
\end{cases}
\end{align*}$$

$$\begin{align*}
[x_{ac}] &= \begin{cases}
0, & x \leq 6.0 \\
\frac{7.5-x}{7.5-6.0}, & 6.0 \leq x < 7.5 (3)
\end{cases}
\end{align*}$$

4.2 Membership Functions of Soil Nutrients

Functions to calculate the membership value of soil nutrients can be expressed as follows:

$$\begin{align*}
[x_{sn}] &= \begin{cases}
1, & x = 0 \\
\frac{1.5-x}{1.5-0}, & 0 < x < 1.5 (4), [x_{sn}] \\
0, & x \geq 1.5
\end{cases}
\end{align*}$$

$$\begin{align*}
[x_{sn}] &= \begin{cases}
0, & x \leq 1.5 \\
\frac{3.0-x}{3.0-1.5}, & 1.5 < x < 3.0 \\
1, & x = 3.0 \\
\frac{3.1-x}{3.1-3.0}, & 3.0 < x < 3.1 \\
0, & x \geq 3.1
\end{cases}
\end{align*}$$

$$\begin{align*}
[x_{sn}] &= \begin{cases}
0, & x \leq 3.1 \\
\frac{3.1-x}{3.1-3.0}, & 3.0 < x < 3.1 \\
1, & x \geq 3.1
\end{cases}
\end{align*}$$

4.3 Membership Functions of Soil Mineral Content

Functions to calculate the value of $x$ soil mineral content can be expressed as follows:

$$\begin{align*}
[x_{mc}] &= \begin{cases}
1, & x = 0 \\
\frac{2.0-x}{2.0-0}, & 0 < x < 20 (7), [x_{mc}] \\
0, & x \geq 20
\end{cases}
\end{align*}$$

$$\begin{align*}
[x_{mc}] &= \begin{cases}
0, & x \leq 20 \\
\frac{40-x}{40-20}, & 20 < x < 40 \\
1, & x = 40 \\
\frac{45-x}{45-40}, & 40 < x < 45 (8), [x_{mc}] \\
0, & x \geq 50
\end{cases}
\end{align*}$$

$$\begin{align*}
[x_{mc}] &= \begin{cases}
0, & x \leq 40 \\
\frac{50-x}{50-45}, & 40 < x < 50 (9)
\end{cases}
\end{align*}$$

5. Fuzzy Rules

Fuzzy Inference Systems (FIS) are based on three components namely rule base, data-base and reasoning mechanism. The rule base consists of the antecedents and consequents of the following form: If $A$ is ‘antecedent’ then $B$ is ‘consequent’ [10]. These rules serve as a tool to analyze the soil conditions.

**Table 4. Fuzzy Rule for Estimating Soil Pollution**

| No | Rule | Acidity (pH) | Nutrient | Mineral | Land Conditions |
|----|------|--------------|----------|---------|----------------|
| 1  | R1   | Acid         | Less     | Less    | Polluted       |
| 2  | R2   | Acid         | Less     | Enough  | Polluted       |
| 3  | R3   | Acid         | Less     | Normal  | Polluted       |
| 4  | R4   | Normal       | Less     | Less    | Resident Safe  |
| 5  | R5   | Normal       | Less     | Enough  | Resident Safe  |
| 6  | R6   | Normal       | Less     | Normal  | Arable Land    |
| 7  | R7   | Base         | Less     | Less    | Resident Safe  |
| 8  | R8   | Base         | Less     | Enough  | Resident Safe  |
| 9  | R9   | Base         | Less     | Normal  | Resident Safe  |
| 10 | R10  | Acid         | Enough   | Less    | Polluted       |
| 11 | R11  | Acid         | Enough   | Enough  | Polluted       |
| 12 | R12  | Acid         | Enough   | Normal  | Polluted       |
| 13 | R13  | Normal       | Enough   | Less    | Resident Safe  |
| 14 | R14  | Normal       | Enough   | Enough  | Resident Safe  |
| 15 | R15  | Normal       | Enough   | Normal  | Arable Land    |
Based on Table 4, we use rules above to predict land condition. For example, if the real data resemble the condition in Rule 1 (R1) which pH is acid, the total soil nutrient is ‘less’ (with organic carbon ranges from 0-1.5%) and total mineral is ‘less’ (total miligram potassium per 100gram land ranges from 0-20). If the real data resemble the condition in Rule 6 (R6) which pH is normal, the total soil nutrients is ‘less’ and total mineral is normal (total miligram potassium per 100gram land reaches up to 40). Therefore, the land is considered arable.

After identifying the fuzzy rules, the application function will then look for the shape of the soil by using the equation of the Order-Zero Sugeno fuzzy model. In general, the equation for the Order-Zero Sugeno fuzzy model as follow [11]:

\[ I(F(x_1 \text{is} A_1) \cap (x_2 \text{is} A_2) \cap \ldots \cap (x_n \text{is} A_n)) \text{THEN} z = k \]

Description: \( x_n \) is the input variable, \( A_n \) is a category [8].

At this time the implication function will be used to determine the minimum function by looking for \( i - \text{rule} \) and it can be stated in the following equation formula [12]:

\[ a_i = \mu_{A_i}(x) \cap \mu_{B_i}(x) = \min(\mu_{A_i}(x), \mu_{B_i}(x)) \]

where:

- \( a_i \) = The minimum \( x \) value of the fuzzy set \( A \) and \( B \) in the \( i - \text{rule} \)
- \( \mu_{A_i}(x) \) = The minimum \( x \) value of the fuzzy set \( A \) in the \( i - \text{rule} \)
- \( \mu_{B_i}(x) \) = The minimum \( x \) value of the fuzzy set \( B \) in the \( i - \text{rule} \)

6. Fuzzy Inference

The composition of the rules using the max function, namely the fuzzy set solution is obtained by selecting the maximum value of the rule [13]. If all propositions have been evaluated, the output will contain a fuzzy set that reflects the contribution of each proposition. In general, it can be written as follows:

\[ U_{sf}[x_i] = \max(U_{sf}[x_i], U_{kl}[x_i]) \]

where:

- \( U_{sf}[x_i] \) is the membership value of the fuzzy solution until achieving the \( i - \text{rule} \)
- \( U_{kl}[x_i] \) is the membership value of the fuzzy consensus until achieving \( i - \text{rule} \).

7. Defuzzification

Defuzzification is converting the fuzzy set output to a strict form. In Sugeno method, defuzzification can be determined by weighted average as follows:

\[ WA = \frac{\sum_{i=1}^{N} a_i z_i}{\sum_{i=1}^{N} a_i} \]
WA is the weighted average value, $\alpha_i$ is $\alpha$-predicate $i$, $z_i$ is consequent $i$.

The Case of the Sugeno Method in Estimating Soil Pollution

Table 5. Land Sample Data in Pangkal Baru Village, Tempunak District, Sintang Regency

| No | Code | Location       | Acidity | Mineral | Nutrient |
|----|------|----------------|---------|---------|----------|
| 1. | YA   | Rubber 0 – 30 cm| 4.72    | 0.6     | 50.24    |
| 2. | YB   | Rubber 30 – 60 cm| 4.90   | 0.33    | 42.65    |
| 3. | YC   | Rice 0 – 20 cm   | 4.72    | 1.91    | 51.03    |
| 4. | YD   | Pulses 0 – 20 cm | 4.50    | 1.49    | 42.42    |
| 5. | YE   | Shrubs 0 – 30 cm | 4.87    | 0.39    | 52.75    |
| 6. | YF   | Shrubs 30 – 60 cm| 4.92    | 0.22    | 47.64    |

Source: Results of Laboratory Analysis by Yulianto et al Faculty of Agriculture, Tanjungpura University (2013)

Based on Table 5, the land data coded YA, for example, refers to the land with rubber trees which depth ranges from 0-30 cm. It has acidity of 4.72, thus it is considered as ‘normal’. The total percentage of carbon (mineral) is 0.6%, so it could be categorised in ‘less’ and the total potassium per 100 gram land (nutrient) is 50.24 mg. Thus, it is considered ‘normal’. All of the data above will be calculated by Sugeno method to predict land condition based on the rules. A sample of calculation using Sugeno method will be selected to predict land contamination on land conditions with YA code.

**Step 1. Determine the Fuzzy Set**

a. For the $pH$ input variables, three fuzzy sets were defined, namely: Acid, Normal and Base (with intervals in equations (1), (2) and (3)). Therefore, the three equations were obtained: $\mu_{\text{acid}} = \frac{4.5 - 4.2}{4.5 - 0} = 0.67, \mu_{\text{normal}} = \mu_{\text{base}} = 0$, which means that the $pH$ can be said to be ‘base’ with a membership degree of 0.67.

b. For input variables Nutrient, three fuzzy sets were defined, namely: Less, Sufficient and Normal (with intervals in equations (7), (8) and (9)). The three equations are obtained: $\mu_{\text{less}} = \frac{1.5 - 0.6}{1.5 - 0} = 0.6, \mu_{\text{normal}} = 0, \mu_{\text{enough}} = 0$, which means that the nutrient content can be said to be ‘sufficient’ with a membership degree of 0.6.

c. For mineral input variables, three fuzzy sets were defined, they are: Less, Sufficient and Normal (with intervals in equations (4), (5) and (6)). The three equations are obtained: $\mu_{\text{less}} = 0, \mu_{\text{enough}} = 0, \mu_{\text{normal}} = 1$, which means that the mineral content can be said to be ‘less’ with a membership degree of 1.

**Step 2. Application of Function Implications**

The implication function used in this process was the $MIN$ (minimum) function, which was performed by selecting the minimum membership level of the input variable as its output.

[R1] If the $pH$ is acid, less nutrients and minerals are ‘less’, the soil is safe for residents. $\alpha$-predicate $\alpha_{\text{acid}} = \mu_{pH_{\text{acid}}} \cap \mu_{\text{nutrient less}} \cap \mu_{\text{mineral less}} = \min(0.67, 0.6, 0) = 0$. According to Table 4, the linguistic variable is Pollution.

[R3] If the $pH$ is acid, less nutrient elements and minerals are ‘normal’, the soil is safe for residents. $\alpha$-predicate $\alpha_{\text{acid}} = \mu_{pH_{\text{acid}}} \cap \mu_{\text{nutrient less}} \cap \mu_{\text{mineral normal}} = \min(0.67, 0.6, 1) = 0.6$. Thus, the linguistic variable is Resident-Safe.

[R11] If pH is acid, nutrient elements are ‘sufficient’ and ‘enough’ minerals are polluted. $\alpha$-predicate $\alpha_{\text{acid}} = \mu_{pH_{\text{acid}}} \cap \mu_{\text{nutrient enough}} \cap \mu_{\text{mineral enough}} = \min(0.67, 0, 0) = 0$. According to Table 4, the linguistic variable is Pollution.

**Step 3. Composition of Rules**

The composition of the rules is the overall conclusion by selecting the maximum membership level of each consequence application function and by combining all the conclusions of each rule, so
as to obtain a fuzzy solution area. The composition of the rules uses the max function as follow $U_{sf}[x_i] = \max(U_{sf}[x_i], U_{kf}[x_i])$. Thus, the composition of the rules of max contaminated land function is obtained as follows:

1. Polluted Land $= \max(0.06) = 0$
2. Safe-Resident Land $= \max(0.445) = 0.6$
3. Arable Land $= \max(0) = 0$

**Step 4. Defuzzification**

Sugeno method has better processing time since the Weighted Average replace the time consuming defuzzification process [14]. The results derive from the Sugeno method were compared using weighted average calculation; 

$\text{Weighted Average} = \frac{\sum_{i=1}^{N} \alpha_i x_i}{\sum_{i=1}^{N} \alpha_i} = \frac{0.33+0.6(0.66)+0(0.99)}{0+0.6+0} = 0.66$. 

Therefore, using Sugeno method, the land coded YA has a defuzzification value of contamination as much as 0.66 with linguistic variables are Safe-Population.

Based on six data above, the following results were obtained:

**Table 6. The results of the Manual count with the Sugeno Method**

| No | City | Location | Land Predict | Defuzzification Score | Prediction |
|----|------|----------|--------------|-----------------------|------------|
| 1. | YA   | Rubber 0 – 30 cm | Arable Land  | 0.66                   | Safe Population |
| 2. | YB   | Rubber 30 – 60 cm | Arable Land  | 0.865                  | Arable Land |
| 3. | YC   | Rice 0 – 20 cm | Arable Land  | 0.99                   | Arable Land |
| 4. | YD   | Pulses 0 – 20 cm | Arable Land  | 0.863                  | Arable Land |
| 5. | YE   | Shrub 0 – 30 cm | Arable Land  | 0.99                   | Arable Land |
| 6. | YF   | Shrub 30 – 60 cm | Arable Land  | 0.77                   | Arable Land |

Based on Table 6, the land coded YA has been predicted from the rules and was projected as Arable Land. However, based on the analysis using Sugeno method, the land has defuzzification value of 0.66, so it lies within the interval 0.33-0.66. The land has been predicted safe for population, so that the result was not matched to WA calculation. The land coded YB has been predicted from the rules and was projected as Arable Land. Furthermore, based on the analysis using Sugeno method, the land has defuzzification value of 0.865 so it lies within the interval 0.66-0.99. The land has been predicted as ‘arable’ land, so that the result matched to WA calculation. The land coded YC has been predicted from rules and was projected as Arable Land. Based on the analysis using Sugeno method, it has defuzzification value of 0.99 so it lies within the interval 0.66-0.99. The land has been predicted ‘arable’ land, so that the result matched to WA calculation. The land coded YE has been projected from rules and was also projected as Arable Land. Based on the analysis with Sugeno method, the land has defuzzification value of 0.863, so it lies within the interval 0.66-0.99. The land has been predicted as ‘arable’ land, so that the result also matched to WA calculation. The land coded YF has been predicted from the rules and was projected as Arable Land. Based on analysis with Sugeno method, the land has defuzzification value of 0.99, so it lies within the interval 0.66-0.99. The land has been predicted as arable land, so that result also matched to WA calculation. The land coded YF has been predicted from the rules and was projected as Arable Land. Furthermore, based on analysis with Sugeno method, the land has defuzzification value of 0.77, so it lies within the interval 0.66-0.99. The land has been predicted as arable land, so that result also matched to WA calculation.

From the explanation above, it shows that the results obtained by the Sugeno method have resulted differently from the actual data. This is because among six data, only five data match to WA calculation and only the land coded YA which was not matched to the calculation. The percentage of possible errors with the Sugeno method is 16%.
8. Conclusion
It can be concluded that Sugeno method could be easily used to predict land pollution, especially in the areas with the sample above since it only has an error rate of 16%. For further research, the authors give several suggestions which include using more training data; adding variables to the study, such as precipitation level that affects the pH; or adding more variables that cause land pollutions; and using other fuzzy inference system methods, such as Tsukamoto method or Mamdani method.

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