Visualization of agroecological suitability of peatland to pineapple productivity in Kampar District with Fuzzy approach

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Abstract. Pineapple is one of the peat-friendly plants in fire prevention and peatland restoration. The nature and characteristics of the soil are the basis for developing sustainable agroecology. This study aims to create a visualization module of pineapple agro-ecological suitability in peatland. This study uses a Fuzzy inference system to determine the suitability of pineapple land. It visualizes the results in the study area of Kampar District, Riau Province, Indonesia using ArcGIS online. This study resulted in peatlands' agro-ecological suitability with three limiting factors, particularly climate, soil, and peat characteristics. Based on the climate factors, Kampar District is moderately suitable (S2) and marginally suitable (S3) for cultivating pineapple. Based on the soil factors, Kampar District is an unsuitable class (N), moderately suitable (S2), and marginally suitable (S3) for cultivating pineapple. Based on peat characteristics, Kampar District is an unsuitable class (N), moderately suitable (S2), and marginally suitable (S3) for cultivating pineapple based on peat characteristics. Analysis of the agro-ecological suitability of peatlands and pineapple productivity in Kampar District concluded that the land suitability was moderately suitable (S2) and marginally suitable (S3) categories. This study's results are expected to be used as decision support in increasing the productivity of pineapple in peatlands in the Kampar District.

1. Introduction
Pineapple (Ananas comosus (L.) Merr.) is one of Indonesia's horticultural subsectors' superior commodities. Pineapple production has increased. However, it was not too high in the last five years, as has the harvest area. If in 1980 Indonesia’s pineapple production reached 180.64 thousand tons, then in 2015 it reached 1.73 million tons. Based on Riau Central Statistics Agency data, pineapple production in Riau Province in 2015 amounted to 74,388 tons, down from 96,173 tons in 2013, and Kampar District production in 2015 was 8,482 tons, down from 20046 tons in 2013; this was not a maximal number, considering the area in Kampar District was still considerably wide for pineapple cultivation. One of the efforts to increase pineapple production in the Kampar District is to evaluate land for peatland suitability [1].

Studies on land suitability with Fuzzy approaches have previously been conducted, including research, which examines knowledge-based systems to achieve physical land suitability for 45 plant cultivation following Fuzzy inference [2]. The study on pineapple and peatland suitability which examines land suitability for pineapple plants in South Kualuh Sub-district, North Labuhanbatu District with survey method on the land map unit has been conducted by [3]. Other studies had also analyzed the suitability of liberica coffee-type land for peat-friendly commodity development in Ogan Komering Ilir District.
using matching methods using land slope variables, drainage, rainfall, soil texture, acidity, and land use using geographic information systems [4]. [5] have conducted the study on the evaluation of land suitability with a spatial approach. This study evaluating the suitability of oil palm land in Bogor District using spatial decision tree algorithms by producing three models where the best models are obtained based on the results of accuracy optimization (98.18%) with land Suitability mapping obtained a percentage of S2 (29.94 %), S3 (53.16 %), N (16.57 %), and body of water (0.33 %)[5]. Furthermore, [5] research the suitability of soybean land in Bogor District using spatial decision tree algorithms that produce 26 decision trees with 92.73% accuracy [6].

The aim of the research was to create a visualization module of the agro-ecological Suitability of pineapple plants built using the weighted Fuzzy mandani inference system. This research also produces a comparative analysis of pineapple production with land suitability.

ArcGIS Online makes it easier for users to manage and analyze peatland agro-ecological Suitability data in Kampar to help users make decisions.

2. Methods

This research was conducted in Kampar Regency, Riau Province with an area of approximately 1,128,928 ha, located between 00'40 "North Latitude to 0 27'00" South Latitude and 28'30 "to 14 '30" East Longitude, with a potential peatland area of 191,363 ha [7]. This research was conducted using the following hardware and software:

- Intel CORE i7th Gen
- 8GB RAM, 128GB Harddisk SSD, and 1TB internal hard drive
- Python version 3 as a programming language
- Google Collaboratory as coding python language environment with notebook format. Notebook.
- ArcMap version 10.3 as a library for processing and visualizing spatial data
- Microsoft Excel 2019, as a non-spatial data processing supporter.
- ArcGIS Web to visualize agro-ecological Suitability maps online.

Stages of the creation of pineapple agro-ecological Suitability visualization modules include: 1) data acquisition, 2) data analysis, 3) knowledge acquisition, 4) knowledge representation, 5) fuzzification, 6) inference process, 7) defuzzification, 8) visualization. Here is an explanation of each stage:

2.1. Data Acquisition

The data collected in this study is a semi-detailed land map from Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian [8], peatland map from Ministry of Agriculture [9], district and sub-district administration boundary map from Badan Pusat Statistik [10], data on the number of pineapple crops produced by sub-district and pineapple production data from BPS, temperature data [11] and rainfall per sub-district during 2014 to 2017 Kampar District based on sub-districts that have peatlands [1, 11-13].

2.2. Data analysis

The data analysis approach in this study is an overlay technique against the data/map that has been collected in order to obtain data characteristics of peatland, particularly drainage, soil texture, pH H2O, alkaline saturation (%), soil cation exchange capacity (cmol), peat thickness (cm), peat maturity and slope (%). The device used was ArcMap version 10.3, which has been frequently used in data processing in .shp format.

2.3. Knowledge acquisition

The acquisition of knowledge in this study is to conduct interviews with experts, organize data from textbooks, and then model the knowledge of peatland’s suitability with pineapple plants. Following obtaining knowledge from various sources, a knowledge base was subsequently created.
2.4. Knowledge representation
At this stage, all the land suitability parameters obtained from the knowledge acquisition process are represented in rules. The general form of the rule used in the basic rules is: IF THEN (if then), with the cloaking operator used, i.e., AND [14]. In this study, the section "if" shows the land's condition consisting of several variables determining its suitability. In contrast, the section "then" indicates the suitability of pineapple plant land consisting of S1 (very suitable), S2 (moderately suitable), S3 (marginally suitable), and N (not appropriate).

2.5. Fuzzification
At this stage, the Fuzzy system’s input system (crisp) is transferred into a Fuzzy set for use in calculating the true value of the premise of each rule in the knowledge base.

2.6. Inference
The stage of concluding rules or logic that has been built. In this study, the inference process was accomplished using Fuzzy logic. Each parameter is arranged in the form of a Fuzzy set to represent and manipulate obscure (unclear) information in concluding.

2.6.1. Phase I Inference. In the Mamdani-type Fuzzy Inference System, each rule in the Fuzzy knowledge base will be associated with Fuzzy. Rules on the basis of rules are made based on expert opinion. The number of rules in a basic rule in this study is as many as 95 rules based on a group of variables. In this study, there are seven numerical variables categorized into four groups, particularly climate (temperature and precipitation), nutrient retention (ktk, base saturation, and H2O pH), peat (maturity and peat thickness), and topography (slopes). The suitability of peatlands in relation to climate, nutrient retention, peat, and the topography is given input data as follows:

Characteristics of climate-related land:
- Average temperature (temp): 29.75 C
- Rainfall (ch) : 1990 mm

Land characteristics related to nutrient retention:
- KTK: 20 cmol
- Base saturation: 13 %
- H₂O pH: 4.5

Characteristics of peat-related land:
- Peat thickness: 250 cm

Characteristics of land related to topography:
- Slopes: 2 %

While the variable category of non-Fuzzy drainage, soil texture, and peat maturity, the land Suitability output are based on land suitability class rules; for example, if the peat maturity is saprik then it is classified as S1, if the drainage is good then it is classified as S1, and if the soil texture is smooth then it is classified as S3.

[R1 peat maturity] IF Peat maturity is saprik THEN the Land Suitability Class is S1
[R4 drainage] IF Drainage is good THEN the Land Suitability Class is S1
[R2 soil texture] IF soil texture is Smooth THEN the Land Suitability is S3

2.6.2. Phase II Inference. The next stage is to form an inference machine between Fuzzy output and non-Fuzzy variables for each variable into 3 limiting factor groups, particularly Climate identification (temperature and precipitation), Soil identification (nutrient retention (ktk, alkaline saturation, and H2O pH), topography (slope), soil texture and drainage), Peat identification (maturity and peat thickness) using if-THEN rule then it can be concluded:
IF the nutrient retention group class is moderately suitable OR drainage is moderately suitable OR soil texture, THEN land suitability class land identification group is S2.
IF peat thickness group class is (S2) OR peat maturity THEN land suitability class peat identification group is S2.

2.6.3. Phase III inference. Based on the previous stage, the results of Mamdani Fuzzy inference will be formed rules with Fuzzy and non-Fuzzy input variables until finally produced the result of the evaluation of the suitability of pineapple plant land.

IF the land suitability class of the Climate Identification Group is Moderately suitable (S2) OR the Soil Identification Group is Moderately suitable (S2), OR Peat Identification Group is unsuitable (N) THEN The Agroecological Land Suitability Class is unsuitable (N).

Based on the final result of the rule representation of land output for Fuzzy output, results show that the non-Fuzzy class of overall land suitability is unsuitable (N). Decision-making is taken from the worst level of land suitability by studying at the most severe damage; therefore, a solution is required for land improvement using the Weighted of Input Variables method to perform weighting on variables with severely limiting factor [15].

2.7. Defuzzification
This stage is the opposite of the fuzzification stage. At this stage, the value of the Fuzzy set obtained from the composition process is converted back into a crisp shape using the Centroid Method can be observed in figure 1.

2.8. Visualization
At this stage, a visualization of the land Suitability map is based on the Mamdani Fuzzy inference system process's crisp results. Peatland compatibility map visualization is performed using ArcGIS Web Online.
3. Results and discussion

3.1. Analysis of peatland agroecological suitability and pineapple productivity

After conducting the Fuzzy inference system process, further analysis was performed between the Fuzzy inference system’s output and the pineapple productivity data in the Kampar District based on the pineapple number plants and their production. The number of pineapple plants produced by the sub-district in the Kampar District can be observed in Table 1.
Table 1. Number of pineapple plants according to the sub-district in Kampar District in 2014-2017.

| Sub-District       | 2014 | 2015  | 2016  | 2017  |
|--------------------|------|-------|-------|-------|
| Kampar Kiri        | 0    | 0     | 0     | 0     |
| Kampar Kiri Hulu   | 1,073| 1,073 | 1,073 | 1,073 |
| Kampar Kiri Hilir  | 3,903| 3,903 | 3,938 | 4,033 |
| Gunung Sahilan     | 4,190| 1,150 | 1,150 | 1,174 |
| Kampar Kiri Tengah | 1,150| 4,100 | 3,975 | 3,855 |
| XIII Koto Kampar   | 5,542| 5,090 | 4,620 | 4,311 |
| Koto Kampar Hulu   | 2,438| 2,254 | 2,034 | 1,996 |
| Kuok               | 485  | 485   | 485   | 485   |
| Salo               | 919  | 919   | 919   | 919   |
| Tapung             | 20,004| 20,004| 20,004| 20,004|
| Tapung Hulu        | 6,710| 6,710 | 6,710 | 6,710 |
| Tapung Hilir       | 490  | 490   | 490   | 490   |
| Bangkinang Kota    | 340  | 340   | 340   | 340   |
| Bangkinang         | 1,851| 1,801 | 1,801 | 801   |
| Kampa              | 151  | 151   | 151   | 164   |
| Kampar Timur       | 0    | 0     | 0     | 0     |
| Rumbio Jaya        | 0    | 0     | 10    | 20    |
| Kampar Utara       | 1,770| 1,607 | 1,650 | 1,642 |
| Tambang            | 7,250,000 | 7,274,000 | 7,274,000 | 13,774,000 |
| Siak Hulu          | 1,393| 1,393 | 1,393 | 1,393 |
| Perhentian Raja    | 9,900| 9,900 | 9,925 | 9,995 |
| Total              | 7,312,309 | 7,335,443 | 7,334,668 | 13,833,405 |

Source: [1,7,12,13]

The mining sub-District is an area with the number of pineapple plants produced from 2014 to 2017 the most is 13,774,000 clumps while Kampar Kiri, Kampar Timur with the number of 0 clumps. According to the sub-district in Kampar District, data on the number of pineapple plants that produce also obtained pineapple production data can be viewed in table 2.

Table 2. Pineapple production by sub-district in Kampar District (ton).2

| Sub-district      | Yields (ton) | Yields (ton) | Yields (ton) | Yields (ton) |
|-------------------|--------------|--------------|--------------|--------------|
|                   | 2014         | 2015         | 2016         | 2017         |
| Kampar Kiri       | 0            | 0            | 0            | 0            |
| Kampar Kiri Hulu  | 0.68         | 0.6          | 0.53         | 37           |
| Kampar Kiri Hilir | 3            | 1.8          | 1.50         | 8.3          |
| Gunung Sahilan    | 1.2          | 0.94         | 1.17         | 5.5          |
| Kampar Kiri Tengah| 0.45         | 1.58         | 1.65         | 5.5          |
| XIII Koto Kampar  | 2.02         | 2.10         | 2.40         | 6.1          |
| Koto Kampar Hulu  | 0.86         | 1.85         | 1.50         | 6.4          |
| Kuok              | 0.30         | 0.32         | 0.32         | 2.7          |
| Salo              | 0.19         | 0.14         | 0.14         | 0.4          |
| Tapung            | 15.60        | 15.60        | 0            | 26.8         |
| Tapung Hulu       | 0            | 2.40         | 5.74         | 19.6         |
| Tapung Hilir      | 0.36         | 0.15         | 0.15         | 1.3          |
| Bangkinang Kota   | 0.15         | 0.08         | 0.20         | 0.4          |
| Bangkinang        | 1.80         | 1.50         | 0.75         | 0            |
| Kampa             | 0.19         | 0.17         | 0.06         | 0.4          |
| Kampar Timur      | 0            | 0            | 0            | 0            |
| Rumbio Jaya       | 0            | 0            | 0            | 0            |
| Kampar Utara      | 1.18         | 1.21         | 0.80         | 2.9          |
| Tambang           | 12,870       | 6,000        | 4,650        | 12,765       |
| Siak Hulu         | 0.56         | 0.74         | 1.02         | 3.7          |
| Perhentian Raja   | 3.75         | 5.70         | 6            | 11.8         |
| Total             | 12,902       | 6,036.87     | 4,673.93     | 12,903.8     |

Source: [1,7,12,13]
There was a decrease in pineapple yields in most sub-districts in Kampar District, then the production increased again from 2016 to 2017. Tambang was an area with pineapple production of 12765 tons in the Tapung sub-District as much as 26.8 tons in 2017. Sub-districts that did not have pineapple production during 2014-2017 were Kampar Kiri, Kampar Timur, and Rumbio Jaya sub-Districts.

3.2. Land suitability analysis of limiting factors for pineapple with productivity

The result of the land suitability of limiting factor in the form of a suitability map is then compared to pineapple productivity data in Kampar District. It is obtained that SPT in each sub-district in Kampar District, from the processing results, shows that the location is in the class of S2 (moderately suitable) and S3 (marginally suitable). Table 3 shows the suitability of pineapple peatland to its productivity level in Kampar District.

Table 3. Peatland suitability to productivity levels in 2017.

| Land Map Unit | Sub-District       | Land Suitability | Productivity | Conclusion |
|---------------|--------------------|------------------|--------------|------------|
| 1             | Gunung Sahilan     | S2               | Increasing   | Suitable   |
| 2             | Gunung Sahilan     | S3               | Increasing   | Suitable   |
| 3             | Tapung Hulu        | S3               | Increasing   | Suitable   |
| 4             | Tapung Hulu        | S3               | Increasing   | Suitable   |
| 5             | Tapung Hulu        | S3               | Increasing   | Suitable   |
| 6             | Kampar Kiri        | S3               | Increasing   | Suitable   |
| 7             | Kampar Timur       | S3               | Increasing   | Suitable   |
| 8             | Sia Hulu           | S2               | Increasing   | Suitable   |
| 9             | Sia Hulu           | S2               | Increasing   | Suitable   |
| 10            | Sia Hulu           | S3               | Increasing   | Suitable   |
| 11            | Tambang            | S3               | Increasing   | Suitable   |
| 12            | Tambang            | S3               | Increasing   | Suitable   |
| 13            | Kampar Kiri Hilir  | S2               | Increasing   | Suitable   |
| 14            | Kampar Kiri Hilir  | S3               | Increasing   | Suitable   |
| 15            | Kampar Kiri Tengah | S3               | Increasing   | Suitable   |
| 16            | Tapung             | S3               | Increasing   | Suitable   |
| 17            | Tapung             | S3               | Increasing   | Suitable   |
| 18            | Tapung             | S3               | Increasing   | Suitable   |
| 19            | Tapung             | S3               | Increasing   | Suitable   |
| 20            | Tapung Hilir       | S2               | Increasing   | Suitable   |
| 21            | Tapung Hilir       | S2               | Increasing   | Suitable   |
| 22            | Tapung Hilir       | S3               | Increasing   | Suitable   |
| 23            | Tapung Hilir       | S3               | Increasing   | Suitable   |
| 24            | Tapung Hilir       | S2               | Increasing   | Suitable   |
| 25            | Tapung Hilir       | S3               | Increasing   | Suitable   |
| 26            | Perhentian Raja    | S3               | Increasing   | Suitable   |
| 27            | Perhentian Raja    | S3               | Increasing   | Suitable   |

Source: [1,7,12,13]

From table 3, it can be concluded that Kampar District is suitable for planting pineapple plants because the area has been overgrown with pineapple before and produced despite the increase and decrease in productivity so that the land can be used again to be planted according to the results of the previous analysis by making improvements to some variables categorized quite appropriately and according to marginal.

3.3. Visualization of peatland agroecological suitability

After obtaining the value of pineapple peatland’s suitability on each unit of a land map (SPT), then the results of the evaluation of peatland agro-ecological Suitability for each group of limiting levels as well as overall suitability are visualized using ArcGIS Online. In the agro-ecological Suitability map for pineapples, the land suitability Class is very suitable (S1) expressed with dark green color, light green color for moderately suitable (S2) Class, orange color for marginally suitable class (S3), and red color for unsuitable (N) class.
There are six layers uploaded into the database in ArcGIS Online, particularly climate suitability layer, soil suitability, peat suitability, agro-ecological Suitability of limiting factors, sub-district boundaries, and district boundaries. The base map used in ArcGIS Online is an imaginary hybrid base map. Land suitability based on climate can be examined in figure 2, land-based suitability can be examined in figure 3, land suitability based on peat can be examined in figure 4. The visualization of peatland agro-ecological Suitability based on limiting factors can be examined in figure 5.

![Figure 2.2 Visualization of agro-ecological Suitability based on climate factors.](image)

From the visualization in figure 2, it can be stated that agro-ecological Suitability based on climate factors land peat in Kampar belongs to the class of moderately suitable (S2) and marginally suitable (S3).

![Figure 3. Visualization of agro-ecological Suitability based on soil factors.](image)

From the visualization in figure 3, it can be stated that agro-ecological Suitability based on soil factors in peatland in Kampar belongs to the moderately suitable (S2), marginally suitable (S3), and Unsuitable class (N).
From the visualization in figure 4, it can be stated that agro-ecological Suitability based on peat factors in peatland in Kampar belongs to the class moderately suitable (S2), marginally suitable (S3) and unsuitable class (N).

From the visualization in figure 5, obtained information that for agro-ecological Suitability class based on limiting factors in the category marginally suitable (S3) has an area of 52,531.36 ha slightly wider than in the category Moderately suitable (S2) has an area of 49,674.15 ha. For the suitability of land limiting factor class marginally suitable (S3), the most widespread sub-district is the Tapung sub-district (18,078.96 ha), and the smallest is the sub-district of Gunung Sahilan (1.33 ha). Then Kampar Kiri Hilir sub-district has a wide Suitability area of 17,775.49 ha with a sufficient limiting factor according to (S2).

4. Conclusion
This research results in land agroecology's suitability with three groups, particularly climate, soil, and peat groups. Based on climate factors, peatland in Kampar Riau District includes moderately suitable (S2) and marginally suitable (S3) to be planted with pineapple. Based on soil factors, peatland in Kampar
Riau District includes moderately suitable (S2) and marginally suitable (S3) to be planted with pineapple. Based on peat factors, peatland in Kampar Riau District includes moderately suitable (S2) and marginally suitable (S3) to be planted with pineapple. Based on the analysis of pineapple productivity level with limiting factors, it is concluded that pineapple land's suitability to productivity in Kampar District is in the category moderately suitable (S2) and marginally suitable (S3).

Visualizations, in the form of Geographic Information Systems (GIS), have been created using ArcGIS Online. This system can manage, analyze, and present pineapple agro-ecological Suitability data in Kampar Riau peatland. This research is expected to make a positive contribution in efforts to increase pineapple productivity on peatland in the Kampar area.

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