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Fuzzy Inference System for Suitability of Corn Crop Land in Bogor Regency

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A B S T R A C T

Corn is one of the crucial food crop commodities in Indonesia. The Ministry of Agriculture has stated that the national corn production has shown a rapid increase in the last three years, with an average growth reaching 24,037,581 tons. This upward trend in corn production over the past three years indicates the government's commitment to making corn a primary food crop commodity that requires attention. One of the efforts to sustain corn production is by enhancing productivity, including evaluating land suitability based on corn planting characteristics. This research aims to develop a fuzzy inference system for corn land suitability. The fuzzy inference system comprises nine parameters to determine land suitability, consisting of seven numeric parameters: temperature, rainfall, slope, base saturation, cation exchange capacity (CEC), soil acidity, soil depth, and two categorical parameters: drainage and soil texture. In this research, land suitability evaluation was employed to classify land suitability into categories: Highly Suitable (S1), Moderately Suitable (S2), Marginally Suitable (S3), and Not Suitable (N). The research successfully developed a fuzzy inference system for corn land suitability assessment. Experimental results utilizing several corn growth condition data obtained from expert knowledge revealed that in Bogor Regency, the land classified as Highly Suitable (S1) covers an area of 151089.90 Ha, Moderately Suitable (S2) covers 59701.35 Ha, Marginally Suitable (S3) covers 53737.34 Ha, and Not Suitable (N) covers 23118.16 Ha.

1. Introduction

Corn, as one of the food crop commodities in Indonesia, has experienced rapid growth in its production over the past few years compared to other food crop commodities such as mung beans, peanuts, soybeans, upland rice, sweet potatoes, and cassava [1]. According to the Ministry of Agriculture, the national corn production in the last three years, namely 2015, 2016, and 2017, has shown a rapid increase, averaging 24,037,581 tons. This three-year escalation in corn production signifies the government's serious consideration of making corn a primary food crop commodity that demands attention. The escalating global demand for corn as a livestock feed ingredient, replacing other grains, stands as one of the factors contributing to the rise in corn production [2]. In meeting the continuously increasing food demands, future challenges extend beyond simply augmenting production efforts. They must also consider sustainability concerning environmental preservation. Agricultural land is diminishing due to the needs of industrial activities, subsequently converting land use for industrial purposes, followed by significant-scale residential sector activities. This challenge can be addressed by enhancing the quality of untapped land for agricultural purposes.

Improving the quality and quantity of food crops can be achieved, among other methods, by conducting land evaluations to select suitable food crop types based on the soil's characteristics that will be utilized [3]. The land to be utilized should be assessed based on its inherent qualities or land qualities for the intended purpose. Through land evaluation, the land's potential or land suitability classes for specific types of crop land use can be determined. According to FAO (1976), the objective of land evaluation is to ascertain the value of a particular land for specific purposes [4].

Several studies related to land suitability for various agricultural commodities have been conducted. Research has explored knowledge-based systems for the physical evaluation of land suitability for 45 cultivation crops based on fuzzy inference[5]. Other land suitability research was carried out by [6] Presenting data and information on the evaluation of land suitability for corn cultivation using a spatial analysis model. Human Research [7] Studying expert systems based on software computation for evaluating land suitability of cereal commodities.

This research evaluates the land suitability for planting corn. The research applied Fuzzy Inference Systems (FIS) using the Mamdani method. Fuzzy sets were employed to determine ratings, limitations, and land suitability classes. The evaluation outcomes for the land were then presented through visual maps, providing information on the suitability of corn cultivation areas in Bogor Regency.

Previous research conducted by Arief Munajat [8] The research titled “Analysis of Student Satisfaction and Perception at IPB University and the Evaluation of Teaching and Learning Processes” conducts an analysis of student satisfaction regarding the teaching and practical activities. This analysis involves testing chi-square independence, importance-performance analysis (IPA), and biplot analysis. The conclusion drawn from this research is that there are several attributes deemed important but exhibit low satisfaction levels, indicating the need for improvements.

This research evaluates the suitability of land for corn cultivation. The research employs Fuzzy Inference Systems (FIS) using the Mamdani method. Fuzzy sets are utilized to determine ratings, constraints, and classes of land suitability. The evaluation results of the land are then presented in the form of visual maps, providing information on the suitability of land for corn cultivation in Bogor Regency.

2. Method

Fuzzy Inference System (FIS) also known as fuzzy control is one of the most important applications of fuzzy logic and has the largest application field in fuzzy logic [9]. By highlighting that fuzzy logic operates through linguistic terms rather than equations, it underscores that inference is the act of deriving conclusions from specific data and predefined rules [10].

The Fuzzy Mamdani Method is one part of the Fuzzy Inference System which is useful for drawing conclusions or the best decision in uncertain problems [11]. The Fuzzy Mamdani Method was introduced by Ebrahim Mamdani in 1975. The Fuzzy Mamdani method in the process uses linguistic principles and has a fuzzy algorithm that can be analyzed mathematically, making it easier to understand [12].

3. Results and Discussion

The data acquisition process involves gathering expert knowledge regarding land use prerequisites or land characteristic data. The data concerning land characteristics utilized in this study encompass rainfall (mm), temperature (tc), average temperature (°C), drainage, soil depth (cm), slope (%), base saturation (%), cation exchange capacity (cmol), soil texture, acidity or pH, and soil depth (cm). These land characteristic data are categorized into two groups: nominal and numeric datasets. The nominal dataset comprises drainage and soil texture, while the numeric dataset includes rainfall (mm), temperature (tc), average temperature (°C), soil depth (cm), slope (%), base saturation (%), cation exchange capacity (cmol), acidity or pH, and soil depth (cm). Subsequently, these land characteristic data are further classified into classes, namely S1 ("highly suitable"). The determination of the trapezoidal membership functions is established based on expert experiences regarding the tendencies observed in the existing data patterns.

The selection of fuzzy sets and domains for each set is determined based on the parameters contained in the Technical Guidelines for Land Evaluation for Agricultural Commodities [13] and interviews with experts. These nine parameters have their respective advantages. Temperature significantly influences the development of soil profiles and serves as a determining factor for both the chemical and physical properties of the soil. Higher average temperatures tend to accelerate weathering and the formation of clay. Increased rainfall also accelerates weathering and clay formation while influencing soil reactions. Regarding plant growth, rainfall acts as a supplier of water in accordance with the plant's needs. Drainage is essential for plants that require good drainage, particularly corn. Soil texture is closely related to the type of soil. The most suitable soil texture for corn plants is fine texture or clay soil. Cation exchange capacity (CEC) indicates the soil's ability to retain cations. The soil's pH value holds significant importance.

To determine whether or not nutrients are easily absorbed by plants [14]. Requirements for growing corn, land suitability class criteria according to expert knowledge referring to the technical book for land suitability evaluation and land use planning can be seen in Table 1.

Table 1. Corn Growing Requirements

Land Characteristics	Land Suitability Class			
	S1	S2	S3	N
Temperature (tc)	20-26	-	16 – 20	< 16
Average temperature (°C)	-	26 - 30	30 – 32	> 32
Rainfall (mm)	900-1200	1200-1600 500-900	>1600 300-500	< 300
Drainage	Good enough	Rather Fast A bit hampered	Hampered	Very Hampered, Fast
Slope (%)	< 3	3 - 8	8 – 15	> 15
Base Saturation (%)	> 50	35 - 50	< 35	-
Cation Exchange Capacity (cmol)	> 16	5-16	<5	-
Soil Texture	h,ah,s	h,ah,s	Ak	K
Soil Acidity pH	5.8 – 7.8	5.5 – 5.8 7.8 – 8.2	< 5.5 > 8.2	-
Soil Depth (cm)	> 60	40 - 60	25 – 40	< 25

Information: h (smooth), ag (quite smooth), ak (quite rough), k (rough)

Fuzzy rule base. In this research, the rule base section in “if” indicates land conditions which consist of several parameters determining land suitability, while the “then” section indicates land suitability which consists of very suitable (S1), quite suitable (S2), marginally suitable (S3). and Not suitable (N).

One approach utilized in establishing the regulatory foundation for land suitability classes involves the barrier method. This method determines land classes by assessing the quantity and severity of barriers, as outlined in Table 2. The table illustrates the correlation between land suitability classes and the degree of barriers present, serving as a guideline for classification [15]. So, based on Table 2, the limiting levels related to temperature and rainfall are respectively heavy, medium and light. The barrier method suggests evaluating climate-related constraints first

Table 2. Relationship between Land Suitability Class and Limit Level

Land suitability class	Limiting Level
S1: Very suitable	0:none
	1:light
S2: Quite Suitable	2:medium
S3: Marginally suitable	3: heavy
N: Not suitable	4:very heavy

Climate limiting rate rule base:

IF The temperature is quite cold AND the rainfall is quite high THEN The limiting level of climate is Severe.

IF Cool temperature AND high rainfall THEN The climate limiting level is Moderate

IF Temperature is cool AND rainfall is quite high THEN the climate limiting level is Mild

S1: Very suitable

S2: Quite Suitable

S3: Marginally Suitable

N: Not suitable

Fuzzification. The fuzzy sets' membership functions and their respective domains are established by clustering the patterns of values for each parameter. A graphical representation of the membership function for corn plant temperature is presented in Figure 1.

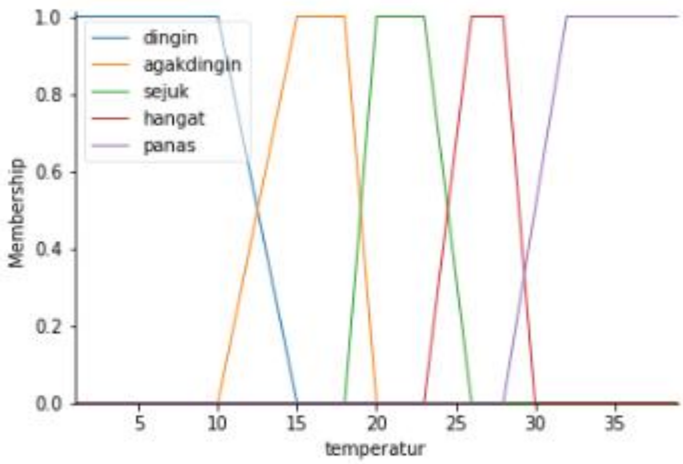

Figure 1. Temperature Membership Function (°C)

Categorizing temperature and other characteristics allows us to perceive them as variables with linguistic values like cold, somewhat cold, cool, warm, and hot. Furthermore, Table 3 outlines the domain for the temperature fuzzy sets.

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Table 3. Fuzzy Temperature Set (°C)

Linguistic value	Domain
Cold	[1, 1, 10, 13.5]
A bit cold	[10, 13.5, 17.5, 20.5]
Cool	[17.5, 20.5, 23.5, 26.5]
Warm	[23.5, 26.5, 28.5, 30.5]
Hot	[28.5, 32.5, 40, 40]

Rainfall is characterized by linguistic values, including very low, low, somewhat high, high, and very high. Rainfall measurements typically fall within the range of 320 mm to 1600 mm. Table 3 outlines the specific fuzzy sets related to rainfall. Additionally, Figure 2 displays the membership function representing rainfall in millimeters.

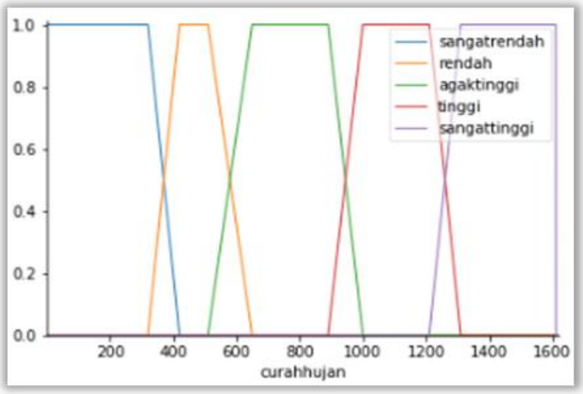

Figure 2. Rainfall Membership Function (mm)

Within the fuzzy set denoting the boundary level for climate, linguistic values include light (S1), moderate (S2), heavy (S3), and very heavy (N). This set operates within a domain spanning from 0 to 100 for the climate boundary level. As depicted in Table 4 and Table 5, the fuzzy set specifically representing the boundary level for corn plants is detailed. Furthermore, Figure 3 visually presents the membership function for this boundary level.

Table 4. Fuzzy Set Rainfall (mm)

Linguistic value	Domain
Very low	[1, 1, 320, 420]
Low	[320, 420, 510, 650]
A bit high	[510, 650, 890, 1000]
High	[890, 1000, 1210, 1310]
Very high	[1210, 1310, 1610, 1610]

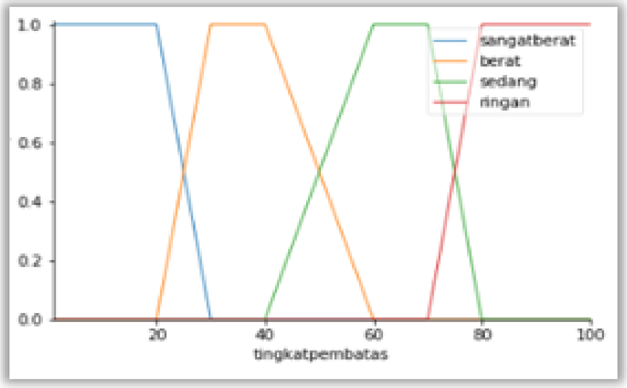

Figure 3. Limiting Level

Table 5. Fuzzy Set Rainfall (mm)

Linguistic value	Domain
Light (S1)	[70, 80, 90, 100]
Medium(S2)	[40, 60, 70, 80]
Heavy (S3)	[20, 30, 40, 60]
Very heavy (N)	[1, 1, 20, 30]

Results of inference. In the inference process, the boundary level is deduced from the input values of land characteristics. Land characteristics expressed as linguistic variables encompass aspects related to climate, topography, physical soil attributes (excluding texture), soil fertility, salinity and alkalinity, and land preparation. The boundary level is obtained through fuzzy inference. The inference process to determine these boundary levels relies on input data with crisp numerical values.

Defuzzification results. In describing the fuzzification process, an example of input data on land characteristics related to the level of climate constraints is given: (1) Temperature: 29.75 °C; (2) Rainfall: 970 mm; (3) Slope: 12%; (4) Base saturation: 50 %; (5) CEC: 33 cmol; (6) Soil acidity: 11 pH H2O; and (7) Soil depth: 23 cm. These results are shown in Figure 4.

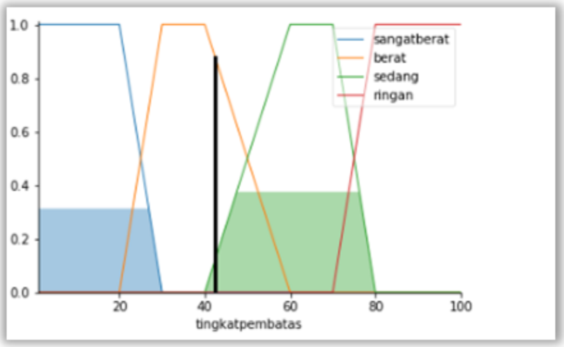

Figure 4. Defuzzification Results

It has been established that the calculated climate boundary level is 42.25, achieved by inputting temperature at 29.75 and rainfall at 970 into a fuzzy inference system utilizing the Mamdani method. This suggests that the climate boundary level falls into the heavy category, while the land suitability class resides in the moderately suitable category (S3), indicating land with substantial limitations for sustainable use.

Land suitability visualization results. The illustration of land suitability involves layering processes. The outcome of this layering process produces spatial information presented as a map indicating land suitability in the research area within Bogor Regency. This study encompasses four categories: climate, soil fertility, physical attributes, and topography. The quantitative values derived from the Fuzzy Inference System (FIS) are assessed using a scoring technique to depict the level of closeness, correlation, or impact intensity on a particular phenomenon in spatial terms.

The results of the visualization can be seen in Figure 5, Figure 6, Figure 7, Figure 8, Figure 9, Figure 10, Figure 11, Figure 12, and Figure 13.

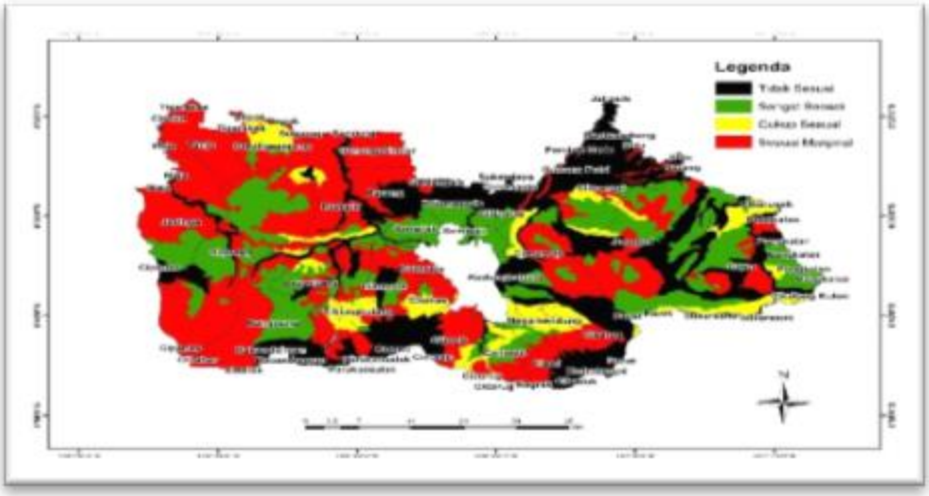

Figure 5. Suitability of Corn Land Based on The Temperature Map

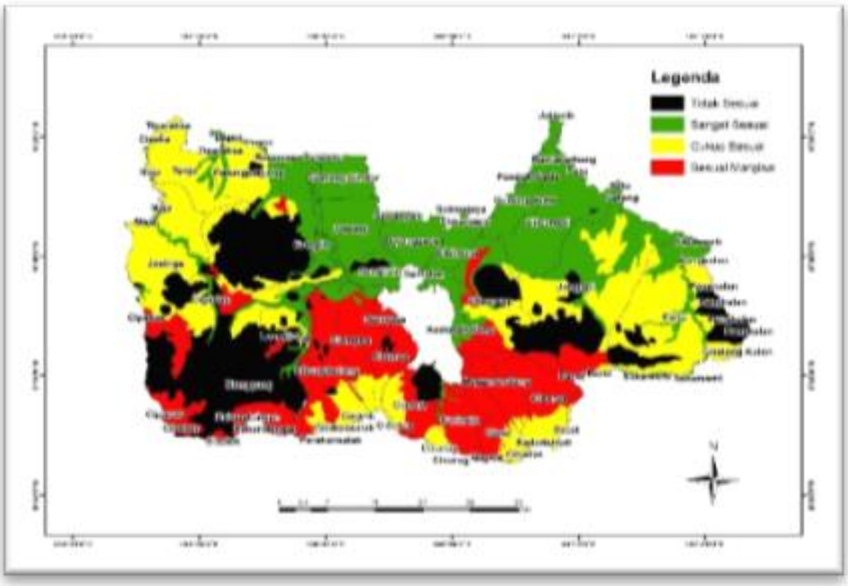

Figure 6 Suitability of Corn Land Based on Rainfall

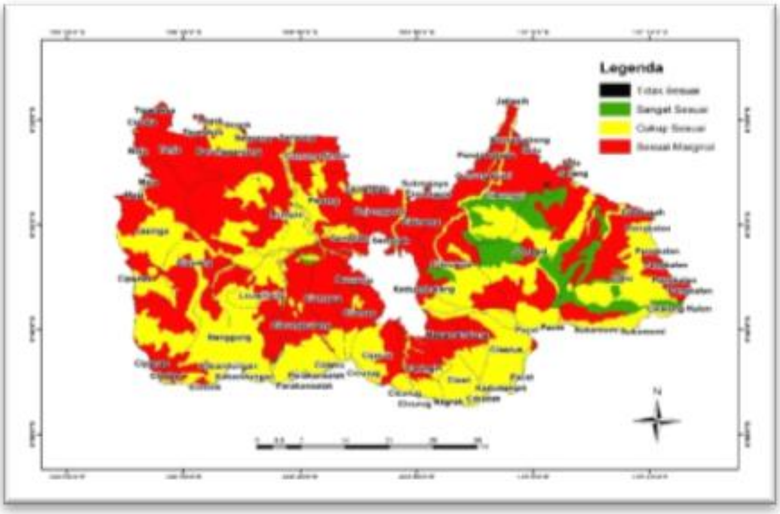

Figure 7 Suitability of Corn Land Based on CEC

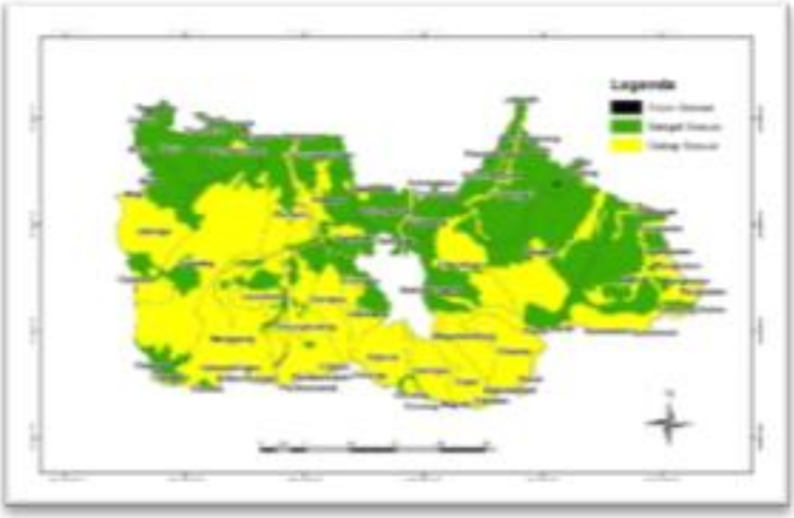

Figure 8 Suitability of Corn Land Based on Soil Acidity

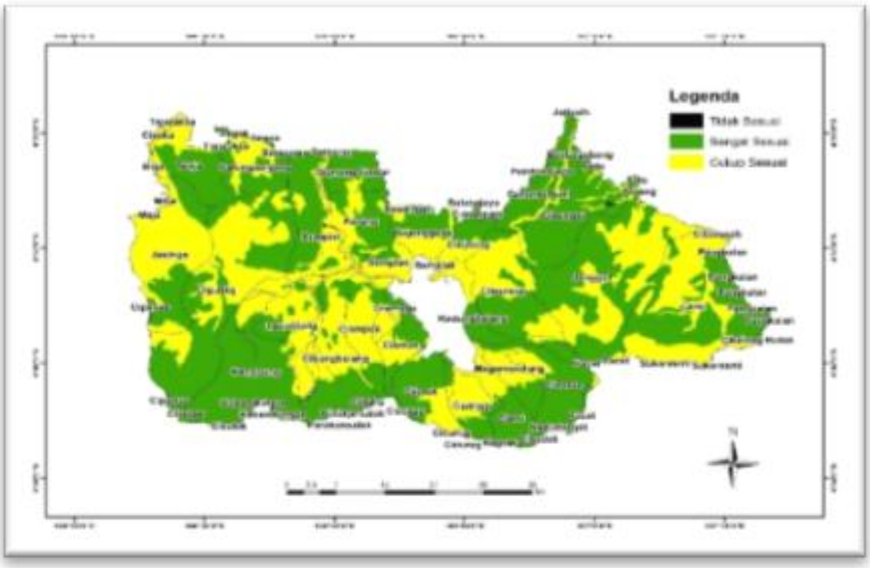

Figure 9 Suitability of Corn Land Based on Drainage

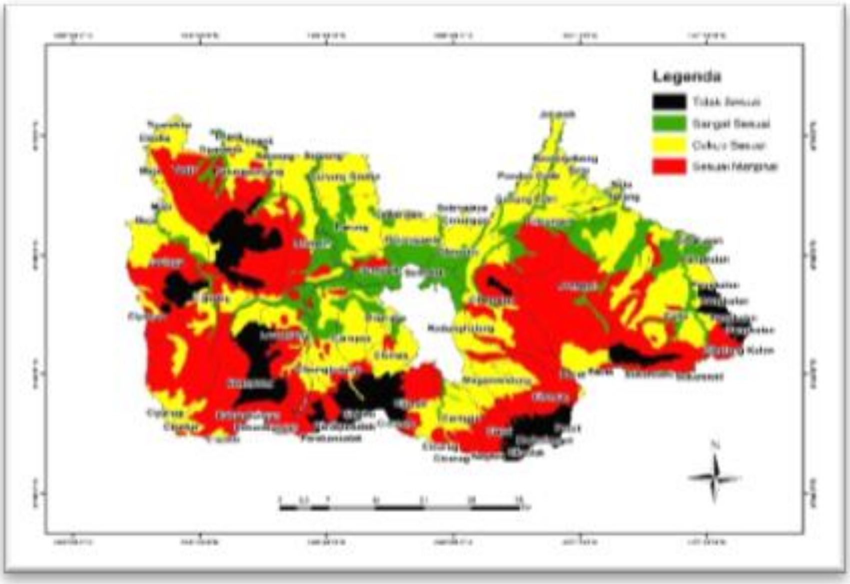

Figure 10. Suitability of Corn Land Based on Base Saturation

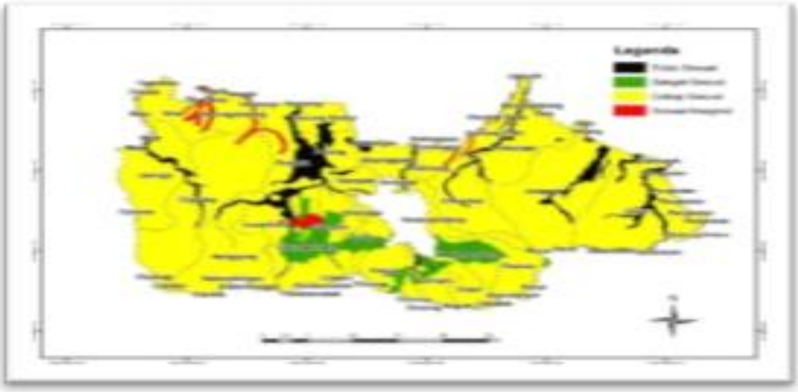

Figure 11. Suitability of Corn Land Based on Slope

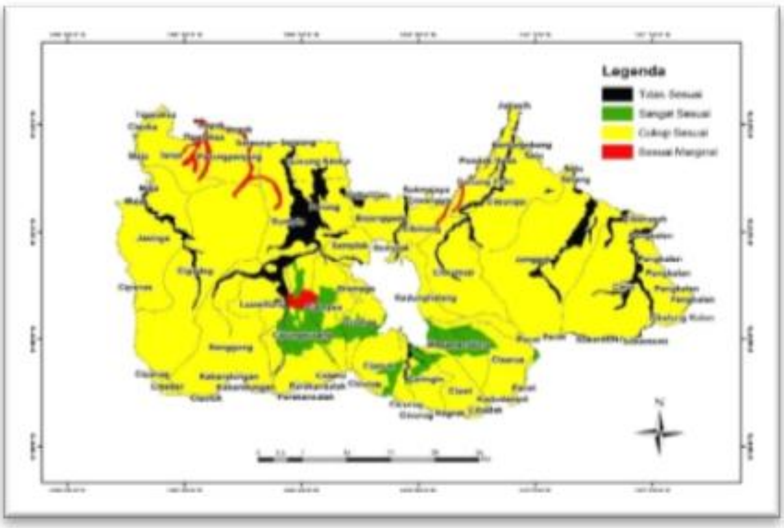

Figure 12. Suitability of Corn Land Based on Texture

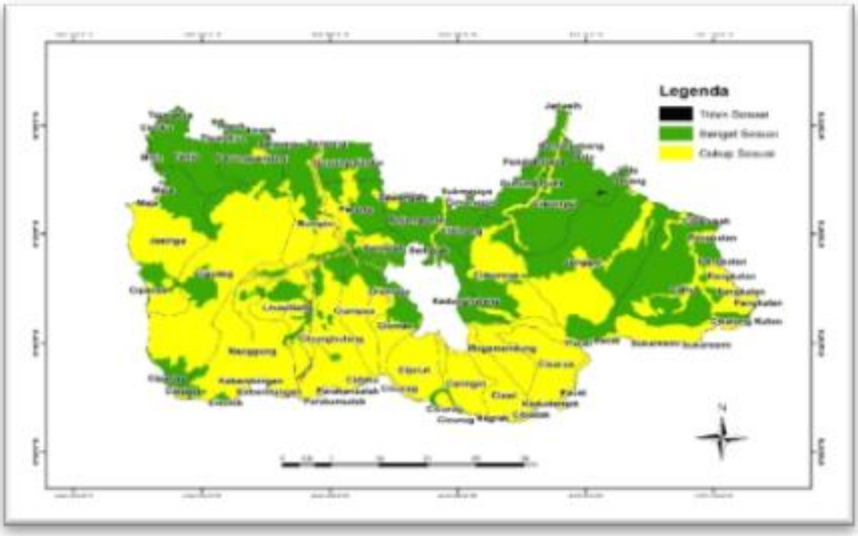

Figure 13. Suitability of Corn Land Based on Soil Depth

The entire map above utilizes raster data, which is then processed and overlaid using the Land Suitability Map for Corn Plants = {(Rainfall Map) + (Temperature Map) + (Texture Map) + (pH Map) + (CEC Map) + (Drainage Map) + (Slope Map) + (Base Saturation Map) + (Soil Depth Map)}. Subsequently, a conversion to nominal form is necessary because the final output consists of decimal numbers. The resulting overlay map from the 9 parameters—temperature map, rainfall map, texture map, CEC map, drainage map, slope map, base saturation map, and soil depth map—can be observed in Figure 14, displaying the Visualized Map of Land Suitability in Bogor Regency.

In the preparation of the land suitability map for corn cultivation in Bogor Regency, the soil map of Bogor Regency, obtained at a scale of 1:50,000 from BBSDLP, plays a crucial role as fundamental information. This map offers valuable insights into the soil conditions, which are pivotal in evaluating land suitability for corn cultivation in the Bogor region.

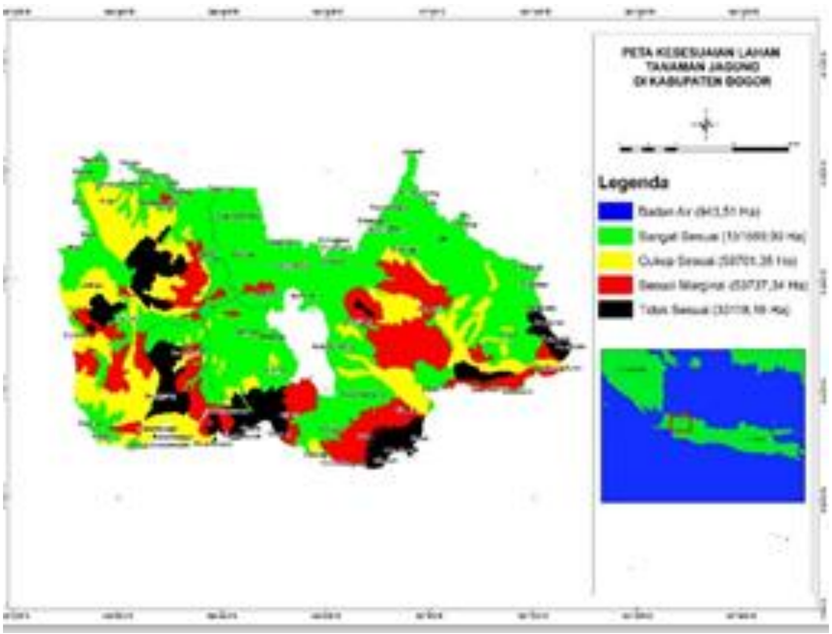

Figure 14 Visualization Results of Corn Land Suitability Map

4. Conclusion

Following the research conducted, a successful development of a Fuzzy Inference System for assessing corn land suitability in Bogor Regency has been achieved. Subsequently, the evaluation map for corn land suitability in Bogor (shown in Figure 14) identified different classes: highly suitable (S1) covering an area of 151,089.90 hectares, moderately suitable (S2) covering 597,01.35 hectares, and marginally suitable (S3) covering 537,37.34 hectares. The study findings highlighted specific districts within Bogor Regency—namely Leuwiliang, Ciampea, and Cibubulang—as unsuitable for corn cultivation, totaling an area classified as Not Suitable (N) covering 231,18.16 hectares.

The research suggests exploring alternative agricultural crops suitable for cultivation, taking into account factors that limit growth, along with their extent and distribution within Bogor Regency. This strategy aims to assist governmental bodies and stakeholders in the agricultural sector in formulating policies directed at achieving food sovereignty.

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