# The Agroecological Zone using Fuzzy Logic for Land Suitability and Regional Sustainable Food Insecurity in Boyolali, Central of Java Indonesia

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**Abstract**

This study is aimed to develop agroecological zone model (AEZ) integrated with the evaluation of land suitability in order to attain the food tenacity in Boyolali County, Central Java, Indonesia. This model is established through five steps. First, it is stocktaking and identifying biophysical land characteristic. The second step is compiling map of suitability of land commodities. The third is compiling the indicator of food vulnerability. The fourth step is classifying variable with fuzzy logic and the last is generating map based on the selected variable. Fuzzy method was chosen because most research data contain uncertainty value. *Fuzzy Inference Systems* (FIS) concept enables to stipulate the suitability of land to be used by a particular type of plant, inhibiting factor and managerial advice that can be applied to overcome the presence of inhibiting factor, and also the appropriate location for a particular plant species.

The findings of this study show some benefits that can be used for 1) compiling the indicator and detail map (1:50.000) of agroecological zone integrated with the suitability of commodities and the character of land (soil and climate) for agricultural cultivation, 2) compiling the appropriate sustainable land management, 3) compiling the indicator and detail map (1:50.000) of food vulnerability at the district level by a certain periodicity.

***Keywords:*** *Agroecological Zone, Land Suitability, Fuzzy Logic, Land Management, Food Insecurity*

## 1. Backgrounds

In Indonesia, agricultural development to improve food tenacity of an area has not been integrated among AEZ, classification of land suitability and capability, regional agricultural commodity and planning for sustainable land management. Due to this reason, a research was conducted to build the integrated system of AEZ, land suitability evaluation, regional commodity, determination of indicators and food vulnerability map in a sustainable manner for the strong agricultural development.

Food tenacity is the attempt to attain food availability for all households which is adequate, good in quality and nutrition, safe to eat, equitable and affordable for every individual. One of the main pillars of regional food tenacity is the variety of food, where the development of food variety will be determined by the biophysical condition of land, land management, and ideal agricultural system used.

The food vulnerability in one area will happen when regional food resource depends only on one type of food commodity. The area which is lack of food commodity, food distribution, and affordable price will tend to have a risk of food vulnerability. The regional food availability constitutes the function of food production and distribution capability. Food production capability itself is determined by various factors comprising climate, soil attributes, rainfall, irrigation, agricultural production component used, and even incentives for the farmers in order to produce food grain. The food commodity development in one area has not been conducted integratedly among AEZ, classification of land suitability and capability, regional food commodity and planning for sustainable land management. In line with this situation, integrated AEZ development and suitability of spatio-temporal based land was conducted. AEZ system used Fuzzy method to classify region based on the similar biophysical characteristic of land (slope, depth, and elevation), climate (rainfall, humidity, and temperature), growing plants requirements, so that plants can grow and produce optimally. The aim of the classification process is to define areas of crops and potential commodities, which are economic scaled and well-conceived in order to attain the sustainable farming system.

## 2. Theoretical Backgrounds

The Land constitutes a significant means of production in farming system because it provides nutrient, water resource, and air circulation. The land is also the site of a broad range of farm management activities. Moreover, the land is the part of a landscape, encompassing physical environment of climate, topography, soil, hydrology, and natural vegetation, affecting the use of land [1][2]. By its role, it is multi functions (the function of production, biotic environment, climate regulatory, hydrology, raw material and mineral resources, waste and pollution control, living space, and spatial link). Functioning as the site of farming production, there were six groups of the most important land resources for farming. They were (i) climate, (ii) geological relief and formation, (iii) soil, (iv) water, (v) vegetation, and (vi) artificial elements. At some points, those six factors affect the land potential and capability for agricultural uses[3].

The development of agricultural commodities should be in line with supporting capacity of land in order to be optimal according to its capability and to be able to be sustainable used. The problem appears in an inefficiency of land use, caused by lack of information about suitability of land use and management actions needed for every land area. Information about the suitability of land use will consider various factors, both physical and socioeconomic environment. Related to the physical factor, land evaluation is necessary in giving various suitable alternative use of land.

One of the approaches used in land evaluation is conducting AEZ determination based on the method of the evaluation of land suitability for agricultural uses. The concept of regional agriculture or AEZ mapping is the simplification and grouping of diverse agroecosystems into a more applicable form of classification. Conducting the evaluation of land use for farming through AEZ determination, according to Amien (1994), has the integrated approach from various factors, where determinants of agricultural production (soil, hydrology, and climate) get a balanced consideration[4].

In addition, AEZ constitutes one way in managing the use of land through the zone classification based on the similar nature and condition of the area [5][6]. The classification itself was aimed to determine cropping area and potential commodities, which are economic-scaled, well-orchestrated in order to attain the sustainable farming system. In AEZ, lands were sorted out based on its nature of land and climate conditions in order to determine the alternative land use. Each of land has different particular nature and farming system. Consequently, it calls for vary management and technology. Regarding this concept, by applying AEZ in each use of land for farming, the firm and sustainable farming system can be attained. In Indonesia, AEZ determination was only conducted on the scale of 1:230.000 and the classification of land suitability produced can only be used for planning on the level of province and county. Meanwhile, for the regional farming plan, the existing AEZ has not been able to be used to the applicable scale in fields. Hence, to support specific development programs in the area and in order to construct regional food tenacity model, characterization of the potential of land resources to the level of semi detail (scale of 1:50.000) for the entire villages was conducted.

Moreover, AEZ can be used for optimizing the utilization of land resources targetedly and efficiently through 1) compiling the alternative land use or appropriate farming system, 2) determining the planting area and developing commodities (eminent) according to its environmental supporting capacity, which is economic-scaled and well-orchestrated. The development of crops in accordance with AEZ will deliver a sustainable farming venture and finally, the increase of communities' revenue will occur.

The food vulnerability in one area is related to the farming system development, whether it is suitable or not with AEZ. In their research in Semarang, Simanjuntak and Marina (2009) asserted that the sequence of the top five indicators that potentially provoke the food vulnerability are (1) the percentage of the number of unemployed inhabitants; (2) potentially natural disaster area (drought, poor drainage – stagnated water, avalanche – erosion );( 3) the ratio of inhabitants per number of inhabitants in the scale of the health care; 4) the percentage of the number of inhabitants that do not have access to clean water; and 5) the normative consumption per capita. Based on that research, land factor constitutes the significant factor leading to food vulnerability of a region. Accordingly, the right land use system will be able to contribute in the increase of regional food tenacity[7][8].

This paper is organized as follows. Section 2 describes some related AEZ researches used as the reference and theoretical concept for model development. The section 3 is the research methods, the concept of *fuzzy inference system* method. The section 4 is the finding research, describes architectural model proposed in this research. The section 5 is conclusion and future work.

## 3. Methods

Stages of the research conducted are shown in Fig. 1. Inventory of primary and secondary data was conducted on the biophysical land variables such as the existing air temperature, rainfall, soil texture, slope, solum depth, drainage, and local knowledge. The existing pranatamangsa pattern conducted by the society, agricultural production, and farming system were the examples[9]. The analysis and generation of food vulnerability map and agro-ecological zone map in one area, in detail, used the preparation of regional food tenacity model based on the results analysis and the generation of map of AEZ, food vulnerability and the evaluation of land suitability.

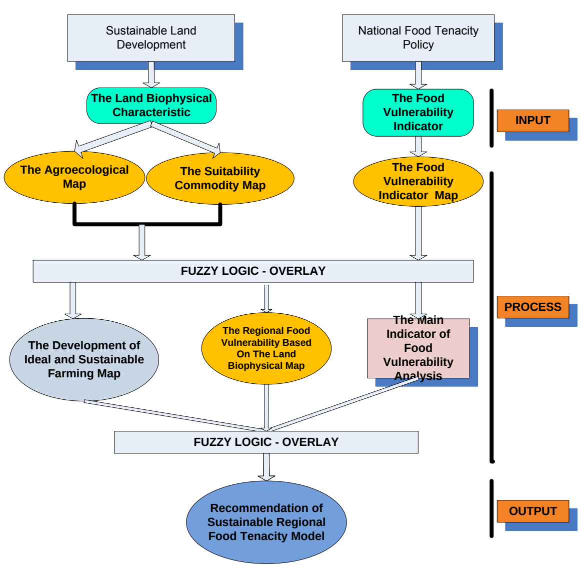



Fig.1. The Stages of the Research Procedure

Fuzzy logic concept constitutes the classification based on the variable revealed in the form of the membership function. It is a curve that shows the mapping of points of data input into the value of membership. Representation of Linear and Triangle curve in membership function preparation as in Equation (1) and Equation (2) was used in this research[10][11].

$$\mu(x) = \begin{cases} 0; & x \le a \\ (x-a)/(b-a); & a \le x \le b \\ 1; & x \ge b \end{cases} \qquad (1)$$

$$\mu(x) = \begin{cases} & u\, x \ge c \\ (x-a)/(b-a); & a \le x \le b \\ (c-x)/(c-b); & b \le x \le c \end{cases} \qquad (2)$$

Defuzzification method used the composition of Mamdani bisector rule. It is taking value of the fuzzy domain that has membership value (half of the total numbers of membership on the fuzzy area). The equation of bisector method is shown on the equation (3)

$$\int_{\alpha}^{zBOA} \mu(z)dz = \int_{zBOA}^{\beta} \mu(z)dz \qquad (3)$$

$$\alpha = \min\{z \mid z \in Z\}$$
$$\beta = \max\{z \mid z \in Z\}$$

That concept representation was conducted by applying in the form of application using programming language (PHP), MySQL database, MapServer framework for maps, and XTJS for graphics. The classification process in the system was done by *Fuzzy Engine* and Fuzzy Rule Base. The system architecture is shown in Fig. 2.

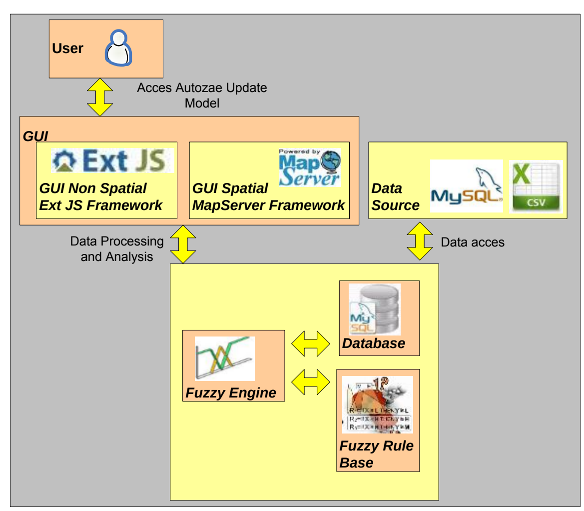



Fig. 2. The Architecture of conceptual system

# 4. Findings

F*uzzy logic* was used for determining agroecological zone from one village area in one county. Indicators used are the slope, elevation, and rainfall. The magnitude of the slope of the land was used to determine the type of physiography of a region[12].
The physiography are:

- Zone I : The slope < 8%, with flat to slightly flat physiography.
- Zone II : The slope is 8-15%, with choppy physiography and slightly steep slope .
- Zone III : The slope is 15-40%, with rolling/hilly physiography and steep slope.
- Zone IV : The slope > 40%, with mountainous physiography and very steep slope

The regional altitude/elevation value was used for determining the air temperature in one area. Those air temperatures are:

- Hot (A) the height of 500 msl or the average of yearly air temperature > 26°C.
- Cool (B) the height of 500 – 1000 msl or the average of yearly air temperature is 26°C – 23°C.
- Cold (C) the height of >1000 msl or the average of yearly air temperature < 23°C.

The regional rainfall value was used for determining the humidity in one area. The humidities are:

- Dry (X), when the dry month > 7 months in a year or yearly rainfall <1500 mm.
- Humid (Y) when the dry month is between 4 - 7 months in a year or the yearly rainfall is between 3000 – 1500 mm.
- Wet (Z) when the dry month < 3 months in a year or the yearly rainfall >3000 mm.

The Land Physiography Value:

- Flat physiography (<8%)
- Slightly Steep Physiography (8% - 15%)
- Steep Physiography (15% - 40%)
- Very Steep Physiography (>40%)

The Value of Altitude/elevation:
*Fuzzy* Set Domain:

- Hot Temperature (<500 msl)
- Cool Temperature (500 msl – 1000 msl)
- Cold Temperature (> 1000 msl)

The Humidity Value

- Dry (< 1500 mm)
- Humid (1500 mm – 3000 mm)
- Wet (> 3000 mm)

Basic map information in the system is displaying the studied area data (Boyolali County, Central Java, Indonesia). The map was displayed up to the limit of the scope of the sub district. On the next stage, data analysis and the representation of information will be detailed up to the level of village. Boyolali County can administratively be seen as shown in Fig. 3.

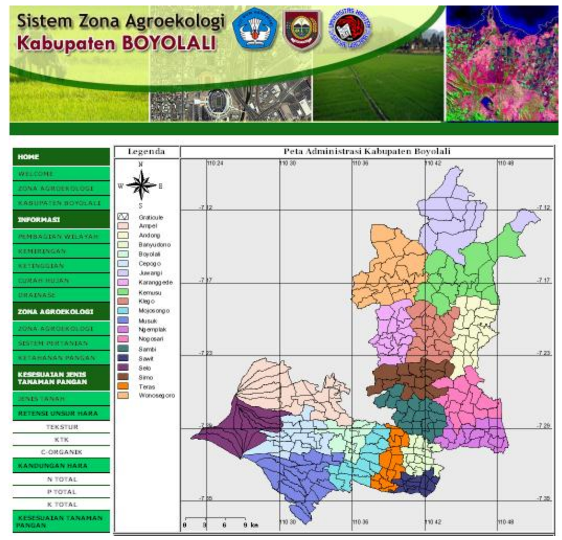



Fig. 3. The Information of Administrative Area of Boyolali County

The commodity suitability classification presents the distribution of agricultural commodities in the 5 year period produced by Boyolali County. On the earlier research, there were rice, corn, tobacco, sengon woods and in a small percentage of wheat commodities. The type of commodities information was presented in the form of polygon colour difference so that the production expansion and capacity of each subdistrict area was unknown. The improvement of this model is to make the village unit become the smallest unit and show the amount of production capacity with data rates in the last 5 years as map AEZ (Fig.4.), AEZ information in Fig.5., recommendation local agriculture system (Fig.6.), and information of food insecurity in Fig.7.

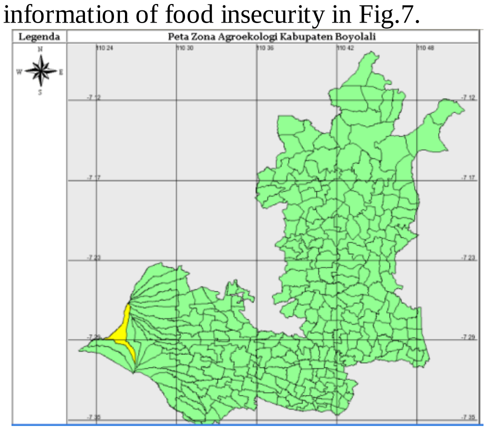



Fig. 4. Representation information in the form of map AEZ area of Boyolali County

**Daerah Terpilih**

| | |
|---|---|
| Nama Kecamatan | Kec. Selo |
| Nama Desa | Jrakah |
| Zona Kemiringan | III |
| Sub Zona Curah Hujan | Z |
| Sub Zona Suhu | C |
| Sub Zona Drainase | 1 |

Fig. 5. Detail zones information in map AEZ local area of Boyolali County

**Daerah Terpilih**

Kecamatan : Kec. Selo
Desa : Jrakah

| | | | | |
|---|---|---|---|---|
| Zona Agroekologi | III | Z | C | 1 |

| | |
|---|---|
| Sistem Pertanian yang disarankan: | Budidaya tanaman tahunan, Perkebunan |

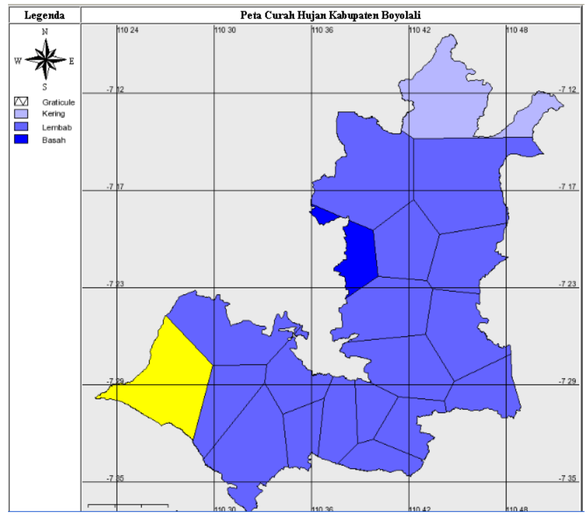
Fig.6. Recommendation local agriculture system area of Boyolali County

The rainfall variable is the significant indicator in agricultural cultivation because it will affect the type of commodities and cropping practices to be appied in one area. The rainfall map was orchestrated based on the data obtained from daily data for 10 years from the station of National Indonesian Air Force (TNI-AU) Indonesia Surakarta. The rainfall information was presented in the form of map (Fig.8.). The presentation of the rainfall information will be refined based on the pattern of rain distribution using *isohyets* map instead of the administrative area.

**Daerah Terpilih**

| | |
|---|---|
| Nama Kecamatan | Kec. Selo |
| Nama Desa | Jrakah |
| IELEC (Indeks Akses terhadap Listrik) | 0.40 |
| IAV (Indeks Rasio Ketersediaan Pangan) | 1.0000 |
| Keterangan IAV | Defisit Rendah |
| IHEALTH | 0 |
| Indeks Ketahanan Pangan Komposit | 0.28 |
| Range IFI | Prioritas 5 |
| Keterangan Ketahanan Pangan Komposit | Ketahanan Pangan Sedang |

Fig.7. Information of food insecurity area of Boyolali County



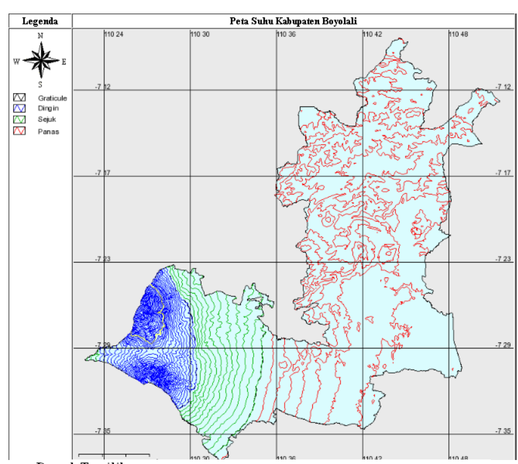

**Daerah Terpilih**

Curah Hujan : 3240 ml/thn
Keterangan: Basah
Sub Zona Curah Hujan : Z

Figure 8. The Information of rainfall according to the sub district in the form isohyets map to Boyolali County Administratives

The division of interval in the rainfall comprises: " kering" as dry, "lembab" as humid and "basah" as wed.

The information of one area elevation was visualized on the map because this variable influences the variable of commodity, humidity, and temperature in one area. Some of Boyolali areas are located in two active volcanoes (Merapi and Merbabu). The interval of area elevation is < 400 msl, 400 msl - 700 msl, 700 msl - 1000 msl, 1000 msl - 1300 msl and > 1300 msl. The map of elevation area can be seen on Fig. 9.




Daerah Terpilih

Ketinggian: 1800 meter
Rejim Suhu : Dingin
Sub Zona Suhu : C

Fig.9. The map of elevation Area of Boyolali County

The other visualized information is the map of soil type. It becomes the important indicator in agricultural commodities determination. The sorts of soil in Boyolali are Litosol, Regosol, Andosol, Mediterranean and Grumosol. The map of soil type can be seen on Fig.8.

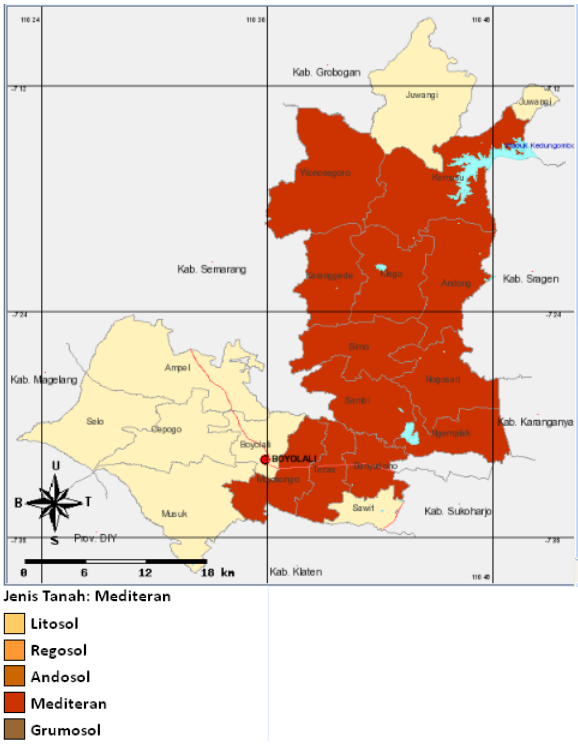
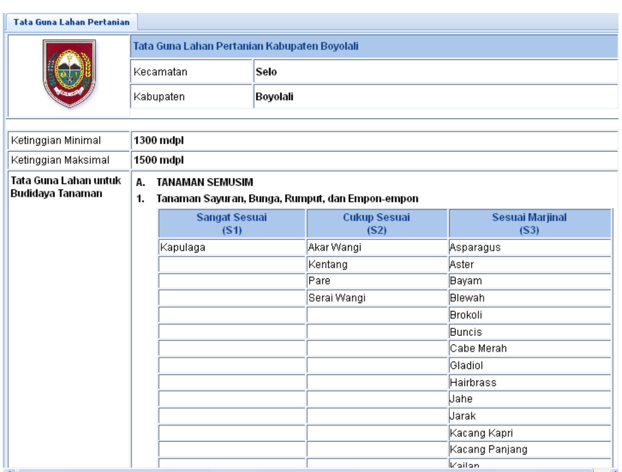



Fig. 8. The Map of Soil Type in Boyolali County

Fuzzy logic conducted the classification of the entire data on the variable for creating commodity suitability. It can be seen in Fig.9. The Suitability category comprises S1 (extremely suitable), S2 (quite suitable) and S3 (marginal suitable).



Tata Guna Lahan Pertanian

Tata Guna Lahan Pertanian Kabupaten Boyolali

| | |
|---|---|
| Kecamatan | Selo |
| Kabupaten | Boyolali |
| Ketinggian Minimal | 1300 mdpl |
| Ketinggian Maksimal | 1500 mdpl |
| Tata Guna Lahan untuk Budidaya Tanaman | A. TANAMAN SEMUSIM<br>1. Tanaman Sayuran, Bunga, Rumput, dan Empon-empon |

| Sangat Sesuai (S1) | Cukup Sesuai (S2) | Sesuai Marjinal (S3) |
|---|---|---|
| Kapulaga | Akar Wangi | Asparagus |
| | Kentang | Aster |
| | Pare | Bayam |
| | Serai Wangi | Blewah |
| | | Brokoli |
| | | Buncis |
| | | Cabe Merah |
| | | Gladiol |
| | | Hairbrass |
| | | Jahe |
| | | Jarak |
| | | Kacang Kapri |
| | | Kacang Panjang |
| | | Kailan |

Fig. 9. Visualization of Commodity Suitability

## 5. Conclusion

Fuzzy Logic method can be applied for classifying data according to its attribute and providing the information of the proper land use suitability. The fuzzy logic method precisely worked by the merger between physiographic characteristic of land (slope, drainage, altitude) and climate (rainfall and temperature). The characteristic of physiograpic land data was acquired from the processing of contour map, elevation map, and the rainfall data becoming the digital map of slope, humidity, temperature regime, and drainage.

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