# Geographic Information System of Critical Level of Land Degradation (Critical Land) Based on Agro-ecological Zone (AEZ) in Agricultural Areas with Recombination Method of Fuzzy Logic and Scoring

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**Abstract**

This study aims to develop inventory, monitoring and evaluation system of land degradation critical level based on the Agro-ecological Zone (AEZ) data of agriculture (cultivation) area using geographic information system (GIS) technology. The study was conducted through 4 stages, comprising (1) inventory and collecting data to compose Agro-ecological Zone (AEZ), (2) developing analysis method by using fuzzy logic as stated in Regulation of Dirjen 4/V-SET/2013 about Technical Guidance of Conducting Spatial Data of Critical Land of The Ministry of Forestry Republic of Indonesia, (3) establishing prototype by using PHP and MapServer tool, and (4) disseminating system. The results of this study showed that applying GIS technology based on Fuzzy Logic Recombination and Scoring Method can be conducted the analysis of temporal data changes, spatial characteristic identification, graphical output production and visualization, model or simulation production to generate new spatial data of land degradation (critical land). GIS technology enables feature provider for modelling, simulating and manipulating data through fuzzy logic recombination and scoring method as well as the other techniques to determine the land degradation (critical land).

Keywords : GIS, agro-ecological zone, fuzzy logic, scoring

## 1. Introduction

Agricultural area has high potential value to experience the land quality decline or land degradation. Land degradation leads to the reduction of crop yields, in which the land degradation has a correlation to the land use, especially in the case of a conventional farming practice through the conversion of forest land to agriculture land and the shifting cultivation practices without land and water conservation efforts. In Indonesia, degraded land up to certain level is called Critical Land. Critical land is defined as a land which experienced the function decline (degradation) up to the given and supposed level due to the land damage. The function intended in that definition is production and water system function. Production function relates to land function as nutrients source for plants. Water system function relates to land function as the root base and ground water storing.

The data of Land and Agro-climate Research Center, The Department of Agricultural Research and Development RI 2013 shows that the total area of the critical land in Indonesia reaches 52,5 million hectares, comprising 7,1 million hectares for Java and Bali, 4,8 million hectares for Sumatera, 7,4 million hectares for Kalimantan, 5,1 million hectares for Sulawesi, 6,2 million hectares for Maluku and Nusa Tenggara, and 11,8 million hectares for Papua. Based on the inventory result of critical land area as stated in Central Java Provincial Forestry Statistics in 2009, critical land is classified into four categories, i.e. potential critical (839.665 ha), somewhat critical (551.864 ha), critical (136.366 ha), and very critical (8.567 ha). Besides those four categories of critical land, there is a land category which is not critical (1.822.475 ha) [1].

Based on the data of The Department of Watershed Management of Pemali Jratun 2009, Boyolali regency in Central Java has the largest critical land based on the area proportion, that is 39,49% of 109.491 Ha of total area. The data of The Department of Watershed Management of Solo Ditjen of The Watershed Management and Social Forestry portrays that Boyolali belongs to the category of the area with the largest critical land, that is 165,35 Ha other than Klaten which is 432,17 Ha. The critical land in Boyolali, Central Java Indonesia is caused by human activities, such as illegal logging and land management with inappropriate cultivation of annual crops.

The weakness of some regencies in Indonesia found that the land exploitation for agricultural activities pays less attention in following the appropriate land use planning. For agricultural activities, especially, the proper land use planning can be only conducted by having evaluation and land suitability, in which the approach applied in evaluation and land suitability activity, is by determining Agro-ecological Zone (AEZ). The base and foundation of AEZ includes the use of identification, evaluation and land zone determination method based on the equation of biophysical features of land. AEZ determination would generate information of the weakness and the strength of land for specific commodity use. The main components of agro-ecology are climate, physiographic or physical patterns of area and land [2].

All this time, the inventory, monitoring, evaluating and identifying of land suitability did not run well, hence the development of land use function towards productive aspects could not be conducted yet along with the subject needs [2][3][4].

GIS according to Taupier and Willis (1994) is a set of tools and methods to collect, store, manage, convert, analyze, summarize and display spatial data in order to comprehend and look for the solution of the real world problems. Generally, GIS is applied for several purposes: (1) analyzing temporary data changes, (2) identifying physical and biological spatial characteristics, (3) determining spatial characteristics, such as proximity, contiguity, patch size and form, (4) analyzing the direction and magnitude of energy, organism or material fluxes, (5) generating graphical output, and (6) generating visualization, model or simulation to generate new spatial data [5]. Anselin (1993a) and Anselin (1993b) develop GIS in four stages, i.e. (1) modelling the data, (2) organizing the storage, (3) analyzing method and system, and (4) representing geographic information [6][7][8][9][10][11][12][13][14].

This study aims to develop the inventory, monitoring and evaluation system of critical level of land in agricultural (cultivation) field as significant component in the identification of land suitability based on AEZ [15]. The model development method is divided into two categories, i.e. fuzzy logic and scoring of critical level of agricultural (cultivation) field based on standard as defined in Regulation of Dirjen 4/V-SET/2013 about Technical Guidance of Conducting Spatial Data of Critical Land of The Ministry of Forestry Republic of Indonesia.

## 1. Related Works

The previous study conducted the development of land suitability identification system with AEZ based in association with the local top-quality commodities and food tenacity using GIS and fuzzy logic method [15]. The applied indicator comprises land slope, altitude and rainfall. Fuzzy logic is a procedure of grouping the analyzed indicator asserted in form of membership function. Membership function is a curve showing the mapping of data input points into the membership value. This study employs linear and triangular curve representation in establishing the membership function as shown in Equation (1) and Equation (2).

$$\mu(x) = \begin{cases} 0; x \leq a \\ \frac{x-a}{b-a}; a \leq x \leq b \\ 1; x \geq b \end{cases} \quad 1$$

$$\mu(x) = \begin{cases} 0; x \leq a \; atau \; x \geq c \\ \frac{x-a}{b-a}; a \leq x \leq b \\ (c-x)/(c-b); b \leq x \leq c \end{cases} \quad 2$$

Fuzzy logic in developing GIS has been conducted many times in the previous studies. The combination of GIS with fuzzy grouping and deterministic model theory is called as GIS Fuzzy Model (GISFM). GISFM is adopted to support the sustainable land use planning in Saint-Petersburg. The criteria applied in modelling comprise technology, economic, ecologic and social [16].

Food tenacity identification based on AEZ uses fuzzy logic and Mapserver. Recombination of local wisdom and agro-meteorology in the prediction of local planting pattern uses fuzzy logic [17].

## 2. Experiments

Research procedures and stages were conducted according to the diagram depicted in Figure 1. The research was conducted through 4 stages: (1) Inventory and collecting data (primary and secondary of the land and climate biophysical) with field survey method, laboratory analysis of the land and climate features, and focus group discussion. All the research data was stored in MySQL database. The required data comprises contour map, soil map, rainfall map, administrative map, Landsat satellite imagery, land use map, social, economic and demography data, and crops pattern system. The map scale used is the scale of 1 : 50.000. (2) Developing analysis method using fuzzy logic equation to form AEZ of area and determine the critical land based on the assembled AEZ as well as the scoring standard of critical level of land as stated in The Regulation of Dirjen 4/V-SET/2013 about Technical Guidance of Conducting Spatial Data of Critical Land of The Ministry of Forestry Republic of Indonesia. (3) Developing application of inventory, monitoring and evaluation of critical level of land based on AEZ using geographic information system technology. The application was established by using PHP and MapServer tool. The architectural application of GIS can be seen in Figure 2. (4) Disseminating system on *stakeholders* was conducted in two forms, i.e. seminar and application use training. The final stage of the whole experiments is composing policy recommendations to the Department of Agriculture and Forestry Boyolali.

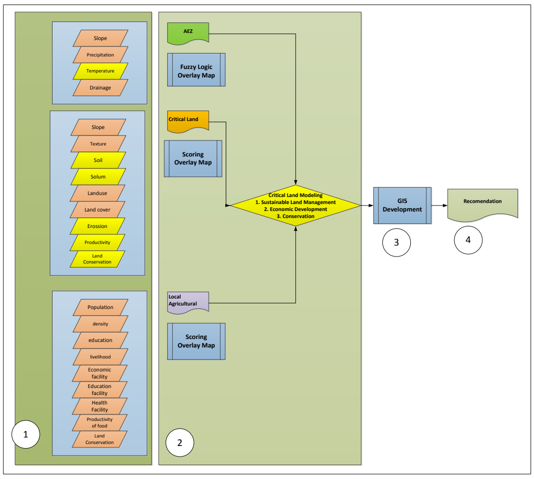


**Figure 1.** Experiment stages

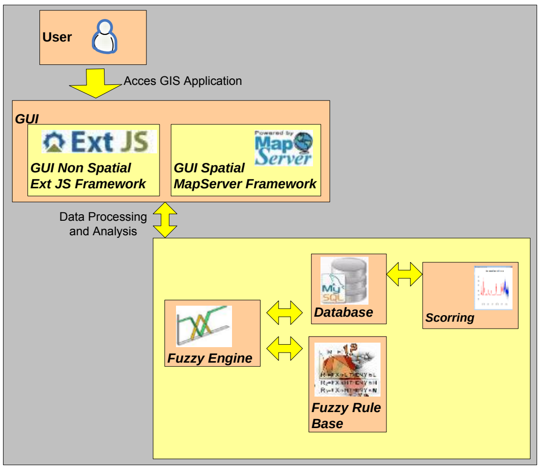


**Figure 2.** Architectural application of GIS

## 3. Result and Discussion

Data analysis and processing of AEZ system was conducted by using fuzzy logic on indicators: (1) slope, (2) rainfall, (3) temperature and (4) drainage. Slope land value for determining the physiographic type of an area, comprises: zone I : < 8%, with flat to slightly flat physiographic, zone II : 8-15%, with wavy and slightly steep slope physiographic, zone III : 15-40%, with hilly and steep physiographic, and zone IV : > 40%, with mountainous and vastly steep slope physiographic. GIS visualization can be seen in Figure 3.

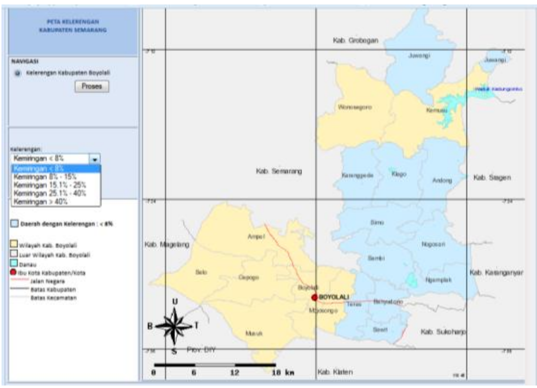

**Figure 3.** Steepness fuzzy analysis and visualization with GIS

The rainfall value of an area is used to determine the humidity in the area, comprising: (1) dry, if the annual rainfall is <1500 mm or with dry months indicator > 7 months in a year, (2) moist, if the annual rainfall is 3000 – 1500 mm or with dry months indicator 4 – 7 months in a year, and (3) wet, if the annual rainfall is >3000 mm or with dry months indicator < 3 months in a year. Fuzzy analysis of rainfall and visualization with GIS can be seen in Figure 4.

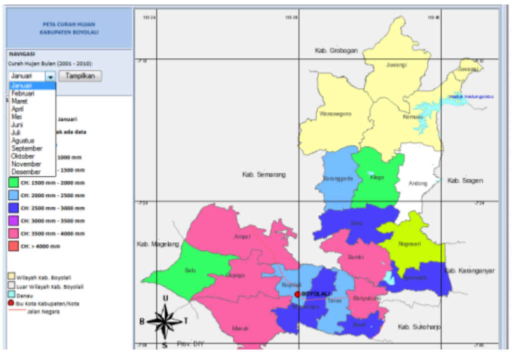

**Figure 4.** Fuzzy analysis of rainfall and visualization with GIS

Referring to the Regulation of Dirjen 4/V-SET/2013 about Technical Guidance of Conducting Spatial Data of Critical Land of The Ministry of Forestry Republic of Indonesia, the critical land is the land which has been damaged, hence losing or reducing the function up to the defined or intended level. Therefore, the assessment of critical land in an area is adjusted with the area function. The value of critical level of land is acquired from multiplication of weights and scores value. Related to AEZ, the determined critical land is the critical land in agricultural areas. The agricultural areas are attempted with the purpose of sustainable production. The main function of these areas is principally as the production areas, hence the assessment of critical land in the areas related to the influencing factors of the production level and sustainability as well as the vegetation, land and water resources sustainability. Thus, the parameter of plant canopy closure of land area and plant productivity value will determine the critical level of the agricultural land.

The critical land is classified based on the total score of protected forest area, agricultural cultivation area, protected area outside the forest area, critical level of land according to the Regulation of Dirjen 4/V-SET/2013.

Table 1. The classification of critical land based on the total score.

| Protected forest Area | Agricultural Land Area | Buffer Forest Area | Critical Land Grades |
|---|---|---|---|
| 120-180 | 115-200 | 110-200 | very critical land |
| 181-270 | 201-275 | 201-275 | critical land |
| 271-360 | 276-350 | 276-350 | rather critical land |
| 361-450 | 351-425 | 351-425 | potential critical land |
| 451-500 | 426-500 | 426-500 | not critical land |

The parameter of land coverage is assessed based on the percentage of plant canopy closure to the extent of each land. The parameter is classified into five classes: (1) canopy closure of > 80 %; very good; 5 score, (2) canopy closure of 61 - 80 %; good; 4 score, (3) canopy closure of 41 - 61 %; moderate; 3 score, (4) canopy closure of 21 - 40 %; poor; 2 score; and (5) canopy closure of < 20 %; very poor; 1 score. The analysis of land closure scoring and visualization with GIS can be seen in Figure 5.

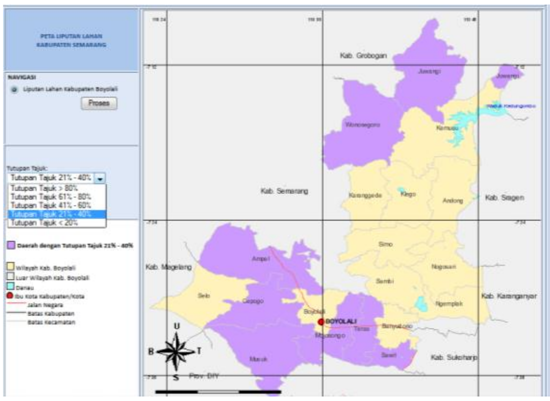

**Figure 5.** Analysis of land closure scoring and visualization with GIS

Productivity data is a criterion for assessing land critical level in the agricultural cultivation areas based on the ratio of management commodity production which has been conducted by the society. The productivity data is also influenced by the specific geomorphologic features, hence having a farming pattern and specific land condition as well. The productivity and scoring classification for determining critical land consists of: (1) productivity ratio of > 80%; very high; 5 score, (2) productivity ratio of 61 –80%; high; 4 score, (3) productivity ratio of 41 –60%; moderate; 3 score, (4) productivity ratio of 21–40%; low; 2 score, and (5) productivity ratio of < 20%. The analysis of productivity scoring and visualization with GIS can be seen in Figure 6.

**Figure 6.** Analysis of productivity scoring and visualization with GIS

Based on the combination of AEZ indicator and critical level of agricultural land, the final result of the analysis is represented in form of critical land category for all indicators in rural area unit as depicted in Figure 7.

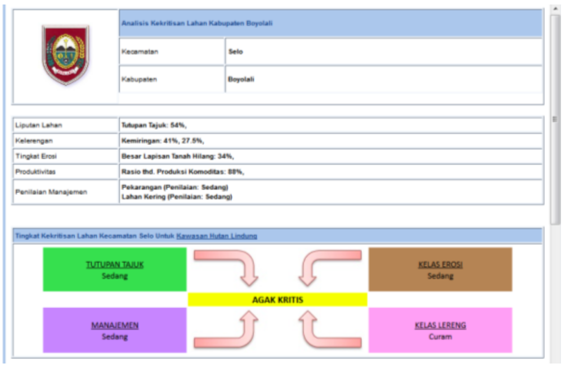

**Figure 7.** Representation of critical level category for all indicators in agricultural land unit

Regarding to the combination of AEZ indicator and critical level of agricultural land, land management is required in order to generate the sustainability and productivity of land.

The critical level of land would be determined by land closure of plant canopy, land slope, erosion hazard level, crops productivity and land management conducted by society. The parameter of land closure of plant canopy in determining the critical land weighted 50%, as land closure of plant canopy value vastly determines the land damage process. Besides, the land slope positively correlates to land erosion and damage level. Therefore, the parameter of land closure of plant canopy and land slope vastly determines the critical level of land. The high slope land and the low land closure of plant canopy make the land have high potential of the critical land. Thus, according to AEZ parameter of land slope and critical land determination of land closure of plant canopy, it is recommended that the land management is not supposed to be conventional agricultural area anymore, but supposed to be conservation area as protected forest.

## 4. Conclusion

Inventory, monitoring and evaluation system of critical level of land as the significant components in identifying land suitability with AEZ-based can be developed by using GIS technology. GIS technology enables to conduct analysis of temporal data changes, spatial features identification, generating graphical output and visualization, model or simulation to generate new spatial data. GIS technology provides features for modelling and simulation through recombination of fuzzy logic and scoring method according to Regulation of Dirjen 4/V-SET/2013 about Technical Guidance of Conducting Spatial Data of Critical Land of The Ministry of Forestry Republic of Indonesia.

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