Application of Multi Criteria Decision Making (MCDM) and Geographical Information System (GIS) on The Cultivated Land Use Evaluation

(Case Study: The Upper Stream of Ciliwung Watershed, Bogor District, West Java)

Syartinilia[1], Hadi Susilo Arifin[2], Lilik Budi Prasetyo[3], Satoshi Tsuyuki[4]

[1] *Research Student of Laboratory of Global Forest Environmental Sciences, The University of Tokyo, Japan*
[2] *Laboratory of Landscape Architecture, Bogor Agricultural University (IPB), Indonesia.*
[3] *Laboratory of Environmental Analysis and Spatial Modeling, Bogor Agricultural University (IPB), Indonesia.*
[4] *Laboratory of Global Forest Environmental Sciences, The University of Tokyo, Japan.*

Contact address: syartinilia@yahoo.com

Abstract

Regarding land use planning of Bogor-Puncak-Cianjur (BOPUNJUR) region, Presidential Decree (KEPPRES No. 114/1999) explains the area is defined to have 2 main functions i.e. protected area and cultivated area. Land use evaluation should be done to assess land resources potential for every utilization. The cultivated area comprise with paddy field, dry land, tea plantation and settlement. MCDM and GIS is a powerful combination tools to analyze the land use evaluation in spatial decision-making process, effectively and efficiently. The study site is a part of Bogor-Puncak-Cianjur (BOPUNJUR) region. The study site is located in the upper stream of Ciliwung watershed, Bogor District of West Java comprising Ciawi, Megamendung and Cisarua sub-districts. The objectives of this study are: (1). To develop land suitability models for paddy field and dry land based on different distance parameter, (2) To determine the optimal model of land suitability for paddy field and dry land. Several physical factors (elevation, slope, drainage, land use) were used as evaluation criteria in this study. A combination of Compromise Programming (CP) of MCDM techniques and GIS was implemented as the main methodology to evaluate land suitability for cultivated area. By using Pairwise Comparison of Analytic Hierarchy Process (AHP) techniques, value and weight assessment of physical factors was determined. The CP analysis for the three strategic values of p = 1, 2 and ∞ (e.g. p=10) was used to derived land suitability models of paddy field and dry land. The models were compared with the existing land use, and the optimal models were grasped. The optimal models of paddy field and dry land were obtained for distance parameter p = 1 because it had the biggest area of existing land use that suitable with land use evaluation results. The existing land use of the optimal models comprise with suitable area for paddy field (58%) and for dry land (56%). Reccomended strategies can be applied through Land Rehabilitation by Incentive System and re-evaluation land use policies. Unsuitable area in cultivated area should be conducted by advanced analysis in order to determine the other cultivation activities.

Key words: *Analytic Hierarchy Process (AHP), Compromise Programming, Cultivated Area, GIS and Remote Sensing, Land Use Evaluation.*

INTRODUCTION

Ciliwung watershed that empties it self into Jakarta Bay extends as long as 117 km and covers an area of about 347 km^2. Twenty years ago natural damage started occur from the upper stream to the lower of Ciliwung watershed. In the upper stream of Ciliwung watershed especially in Ciawi and Cisarua sub-districts, which are conservation areas, land ownership of 2,200 ha had changed within 10 years (1985 – 1995) (Harijono, 2002).

Furthermore, a changing land use in the BOPUNJUR region happened within a decade (1983-1993) converting greenery open space into built areas constituting

5,310 hectares of dry land, 3,754 hectares of plantation state, 1,748 hectares of paddy field and 740 hectares of forest. Uncontrollably rapid changes in the land use, from open space into built areas, had brought about big floods in Jakarta in early February 2002 (Arifin, 2002).

In human culture, population growth and economic growth are dominant factors in land use and land cover changes (LUCC) in the entire world (Weng, 2001). Urbanization also contributes to LUCC that has caused deforestation and agriculture farmland degradation. The area once functioned as catchment area had changed into settlement area with impermeable characteristic.

Based on PP No. 47/1997 concerning regional land use planning, Bogor-Puncak-Cianjur (BOPUNJUR) region is categorized into a specific area that needs special management and land use planning. In addition, KEPPRES No. 114/1999 regarding BOPUNJUR explains the area is defined to have 2 main functions: protected area and cultivated area.

Land suitability analysis is an evaluation/decision problem of the kind economist, engineers/planner and decision theorists address with *Multiple Criteria Decision Making* (MCDM) methodologies (Pereira and Duckstein, 1993). MCDM and GIS is a powerful combination tools to analyze the land use evaluation in spatial decision-making process, effectively and efficiently (Joerin et. al., 2001: Malczweski, 1999). The objectives of this study are (1). To develop land suitability models for cultivated area based on different distance parameter, (2) To determine the optimal model of land suitability for cultivated area comprising paddy field and dry land.

MATERIALS AND METHOD

The study area covers 3 sub-districts (Ciawi, Megamendung and Cisarua) in the upper stream of Ciliwung watershed, Bogor district, West Java (Fig.1). This area is located in BOPUNJUR region (latitude of S6°37'10"- S6°46'15" and longitude of E106°49'48"-E107°0'25") and covers about 18,681.75 hectares. Its average annual temperature is about 16.9° C with 65.5% relative humidity and precipitation of 3,925 mm/year. The population of the study area in 2000 was estimated to be about 224,406 with a density of 1,919 inhabitant/km^2 (BPS, 2000). In this area, a big tea plantation of PTPN VIII, Gunung Mas already exists. In addition, there are many agriculture lands as well consisting of paddy fields and dry land.

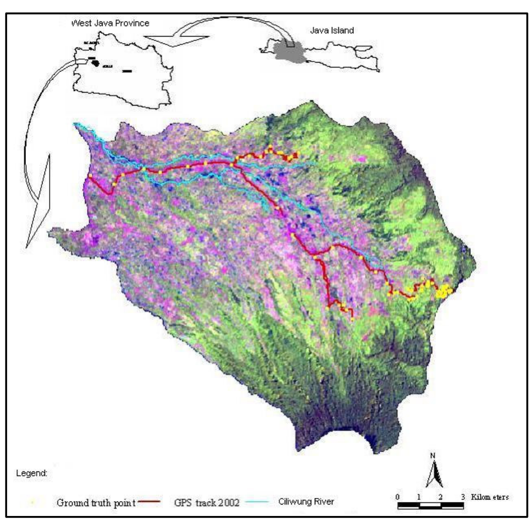


Figure 1. Study area.

Physical factors were used as criteria of land use evaluation i.e.: 1) Slope, 2) Elevation, 3) Drainage, 4) Existing land use (Table 1). All criteria were used raster data with pixel size 30*30 m.

Table 1. Criteria of land use evaluation for cultivated area

Land use	Criteria			
	Slope (%)	Elevation (m)	Drainage	Existing Land use
Paddy field	**< 3**	**300-700**	**Poor**	Forest
	3-8	700-1000	Moderate-good	Tea Plantation
	9-15	1000-1500	Fast	Shrub
	16-25	1500-2000		Dry land
	>25	>2000		**Paddy field**
				Settlement
Dry land	**< 3**	**300-700**	**Good-moderate**	Forest
	3-8	700-1000	Fast	Tea Plantation
	9-15	1000-1500	Poor	Shrub
	16-25	1500-2000		**Dry land**
	>25	>2000		Paddy field
				Settlement

Note: The **bold-faced** is ideal point was determined from result of AHP questioner
Source: - Research Centre of Soil and Agroclimate - Bogor, 1994

Topographic maps

Five sheets of topographic maps (1:25 000, 1209-141, 1209-142, 1209-144, 1209-231) were digitized, and contour vector data were created using GIS. Digital Elevation Model (DEM) was generated from the contour data by TIN (Triangulated Irregular Network) creation. Slope and aspect were generated from DEM. The whole process was conducted using GIS software, MicroImages TNT Mips Version 6.8

Satellite remotely sensed data

Landsat ETM+ 2001/12/22 was used in this study. In pre-processing, satellite image was georeferenced to Lat/Lon projection using more than 40 GCPs (Ground Control Points) selected from the topographic maps. Maximum error of geometric correction was less than 0.5 pixel size. After geometric correction, resample image was conducted to 30m*30m. Land use/cover map was created using Maximum Likelihood Method (MLM). Land use/cover classifications were categorized into 7 classes: 1). Forest, 2). Tea plantation, 3). Shrub, 4). Dry field, 5). Paddy field, 6). Built up, 7). Water.

Ground-truth data

Field investigations were conducted in September 2002 and April 2004 to identify land use/land cover of the area. 90 points of landmark data (latitude/longitude) were recorded using the GPS receiver (Garmin).

Land use evaluation method for cultivated area

Application of Multiple Criteria Decision Making (MCDM) and Geographical Information System (GIS) was selected as land use evaluation method for cultivated area. Compromise Programming (CP) was selected for MCDM method because this could be neglegted scale difference problem in land use evaluation. CP method is used to identify solutions that are closest to the ideal solution as determined by some measure of distance. The solutions identified to be closest to the ideal solution are called compromise solutions and comprise the compromise set. To measure distance between every alternative and ideal point, CP use family of distance metrics (dp) expressed as:

$$d_p = \left[\sum_{i=1}^{I} \beta_i^p \left(x_i^* - x_i^k \right)^p \right]^{1/p}$$

d_p = family of distance metrics

β_i = Weights assigned to the criteria indicating decision maker preferences

where β_i >0, $\sum \beta_i = 1$

x^* = ideal point

p = distance parameter, ranges from 1 to ∞

CP is usually applied with sensitivity analysis for the three strategic values p = 1, 2 and a nominal (e.g. p>10). When p = 1, total compensation between criteria is assumed, meaning that a decrease of one unit of criterion can be totally compensated by an equivalent increase on any other criterion. For p = 2, there is only partial compensation and p = ∞ represents totally non-compensatory situation (Zeleny, 1982).

Value and Weighting Assessment

A weight can be defined as a value assigned to an evaluation criterion that indicate its relative importance to other criteria under consideration. Value and weighting assessment by using Pairwise Comparison from Analytical Hierarchy Process method (AHP) through asking questionaires to all respondent who are experts in cultivated field (agronomist, horticulturist, etc.).

Beforehand, to conduct value and weigthing assessment, the evaluation criteria were compiled in the form of AHP structure (Figure 2). The top level is the ultimate goal of the MCDM analysis process to be achieved, i.e., land suitability for paddy field. The intermediate level lists the relevant evaluation criteria that were compared pairwise to asses their relative weights. These criteria refer to categorical data and branch off to a bottom level representing the actual evaluation objects. Pairwise Comparison also estimated their values. Meanwhile, ideal point (bold-faced) representing highest score obtained from result of AHP questionaires to expert respondent. The whole process was conducted using software EXPERT CHOICE 9.5. Value functions were normalized to a [0,1] by Maximum Standardization method, where highest score becoming ideal point is given by value 1.

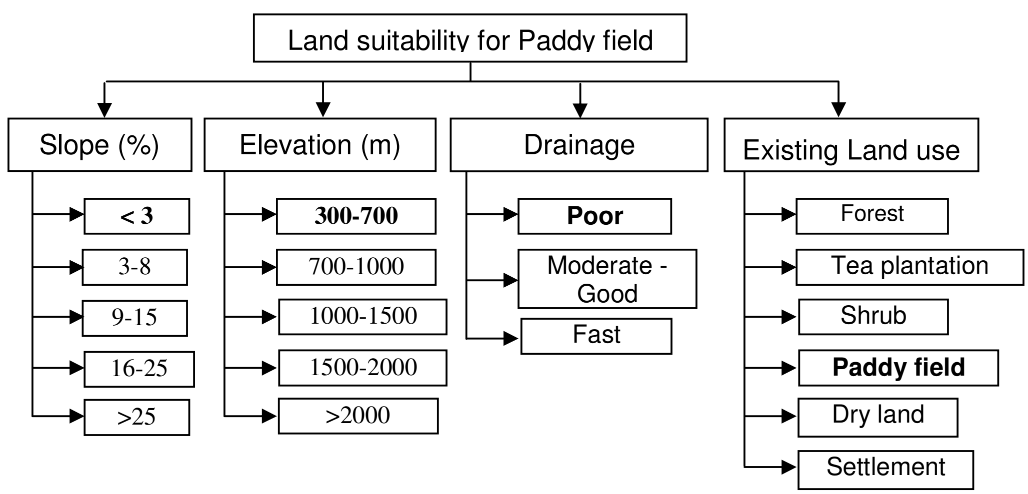


Figure 2. Structure of Analytical Hierarchy Process (AHP).

Implementation of MCDM in a GIS framework

Step of implementation of MCDM in GIS framework comprise with:

1. Input the value which have standardized and weight obtained from Pairwise Comparison
2. Develop a model of land suitability in order to produce Family of Distance metrics from distance parameter p = 1, p = 2 and p = 10
3. Classify Family of Distance metrics of land suitability model to become 10 classes where value 0 showing as ideal (best) and 9 on the contrary (worst)
4. Conducting thresholding, to make 10 classes to become 2 classes that is suitable and not suitable class (dichotomous land suitability model). Class 5 as middle value is determined as threshold value
5. A models is optimized through overlay between dichotomous land suitability model and existing land use. The optimal model is a model with the suitable area has the bigest area that located in the existing land use.

The whole process was conducted using *model maker* from ERDAS IMAGINE 8.5.

RESULT AND DISCUSSION

Value resulted from Pairwise Comparison was standardized by using Maximum Standardization Method where score value obtained was divided with highest score for the criterion. For example, values for slope types of paddy field were:

Tabel 2. Standardized values of slope types for land suitability of paddy field

Slope type	Score value	Standardized value
<3 %	**0.460**	1.000
3-8 %	0.307	0.667
9-15 %	0.131	0.285
16-25 %	0.069	0.150
>25 %	0.034	0.074
Inconsistency ratio	0.05	

Note: The **bold-faced** is highest score was resulted from Pairwise Comparison technique

Expert derived values and weigths for the land suitability models of paddy field and dry land can be seen as follow:

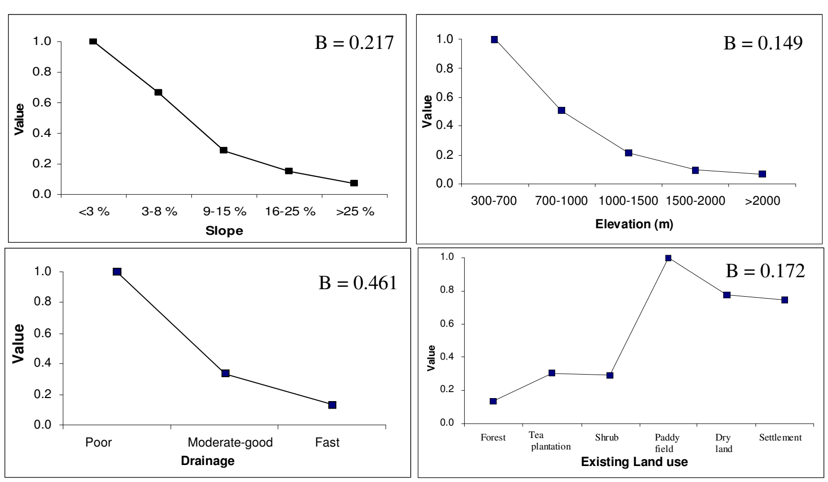


Figure 3. Standardized values and weights for land suitability models of paddy field.

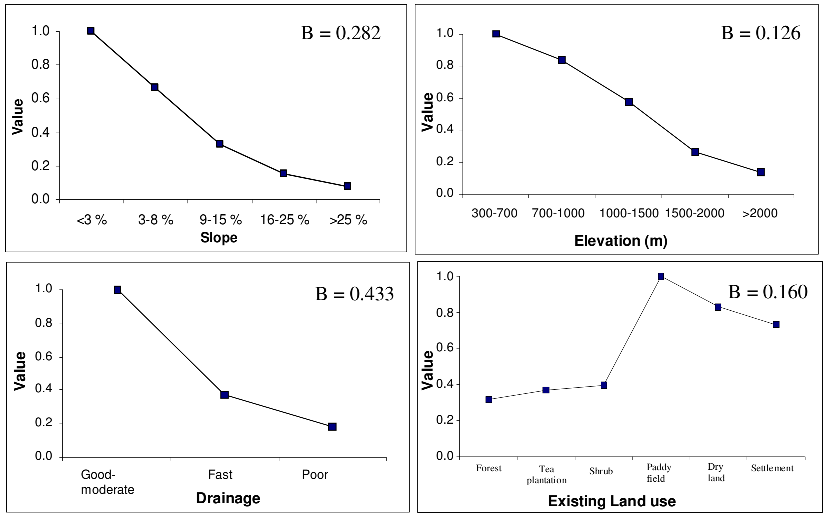


Figure 4. Standardized values and weights for land suitability models of dry land.

Land suitability models were developed by implementation Compromise Programming and GIS are given in figure 5.

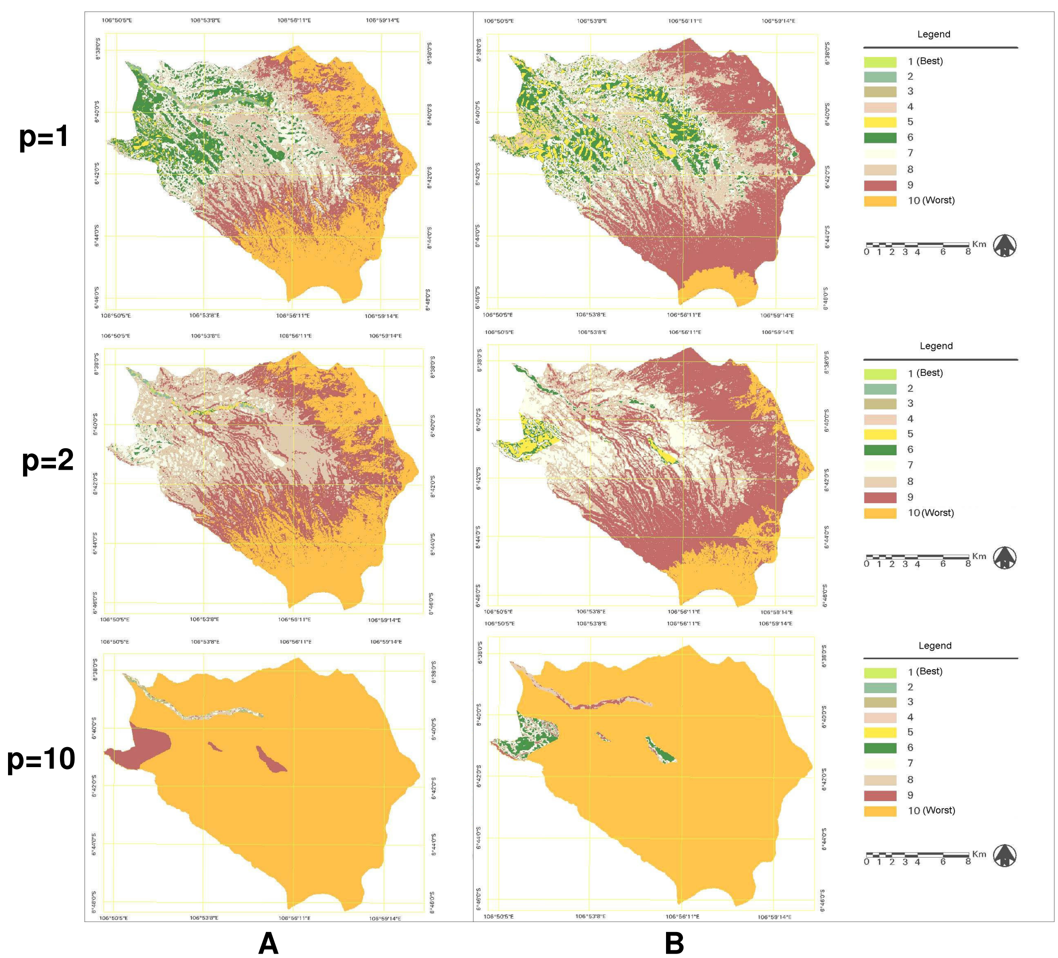
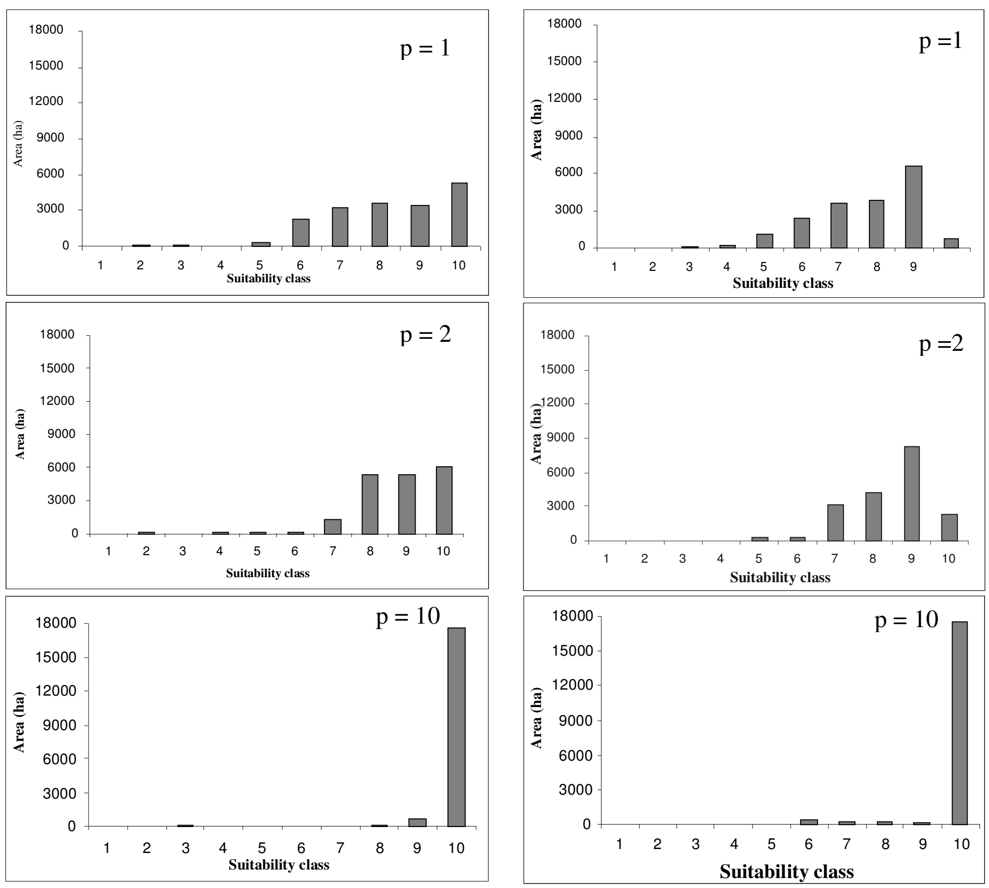


Figure 5. Land suitability models of paddy field (A) and dry land (B), with distance parameter p =1,2 and 10.

Sensitivity analysis for the three strategic values p yield clearly distinct maps, with different ranges of distance to ideal evaluation scores. A simple visual comparison of the suitability patterns revealed by the three maps shows sharpest contrats between p=1 and p=10. The first map (p=1) assigns a larger proportion of the study area to higher suitability classes, resulting from the compensatory of the underlying decision model. If a cell/alternative has a poor rating on a few criteria but good ratings on other criteria, it can still get a reasonably high score. The second map (p=10), based on a totally non-compensatory, rates each cell/alternative based only on the criterion showing the poorest performance. This strategy emphasizes weaknesses and shows a different view of land suitability in the study area, whereby stricter demands are placed on alternatives and high ratings are harder to reach. The model based on partial compensation (p=2) shows intermediate characteristics.

Histograms comparing the area to each suitability class are given in figure 6. An ideal suitability is represents value of 0 can not found in the study site for all distance parameter.



A **B**

Figure 6. Histograms comparing the area to each sutability class, for paddy field (A) and dry land (B).

Each land suitability model is converted to a series of Boolean maps, through thresholding by class 5 as threshold value. Any cell with values below a given threshold is considered not suitable and any cell with values above it becomes suitable. Boolean land suitability model at class 5 threshold are given in figure 7.

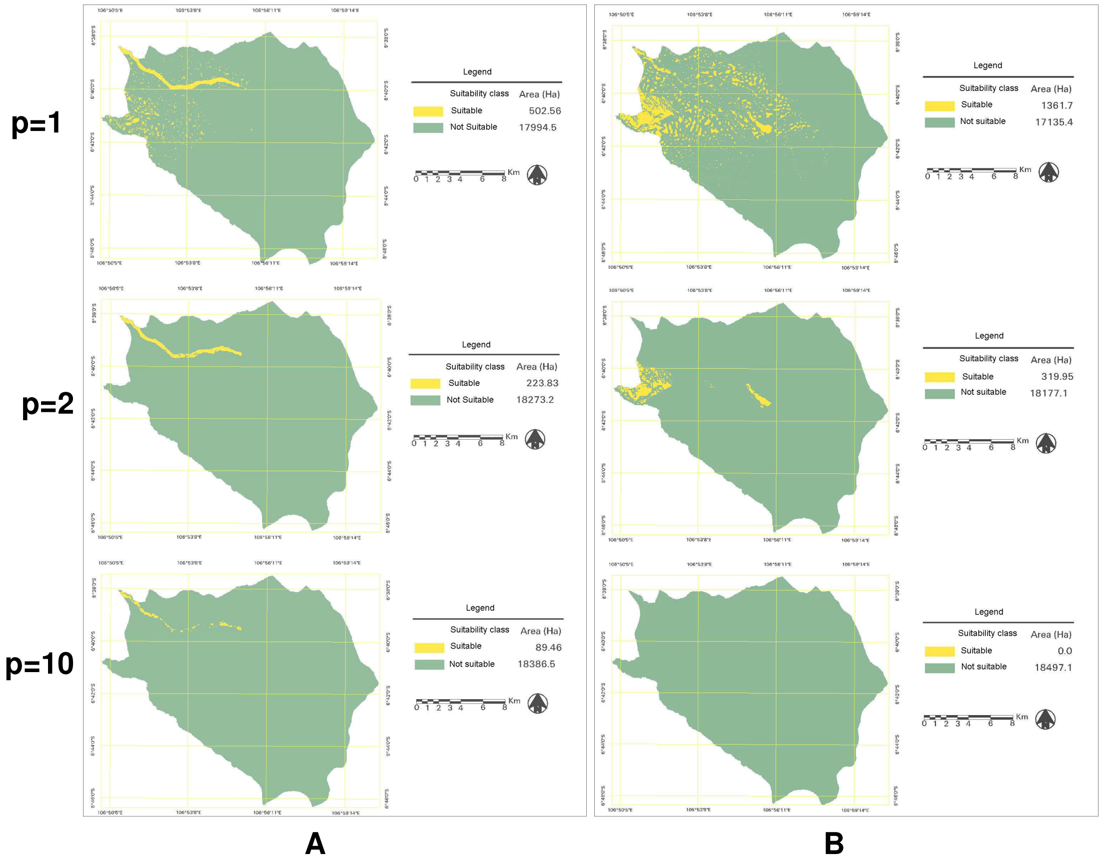


Figure 7 . Boolean model at class 5 threshold fo paddy field (A) and dry land (B), with distance parameter p =1,2 and 10.

According to overlay result between Boolean model and existing land use, hence model with distance parameter p=1 was determined as an optimal land suitability model for paddy field and dry land. Because it has the bigest suitable area that located in the existing land use (Figure 8). The existing land use of the optimal models (p=1) comprise with suitable area for paddy field (58%) and for dry land (56%).

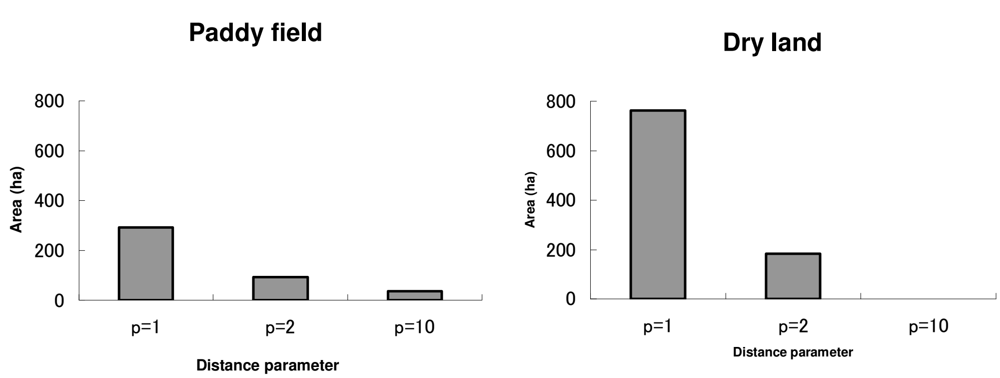


Figure 8. Overlay result between Boolean model and existing land use.

Reccomended strategies can be applied through Land Rehabilitation by Incentive System and re-evaluation land use policies. Unsuitable area in cultivated area should be conducted by advanced analysis in order to determine the other cultivation activities.

CONCLUSION

Application of MCDM and GIS/Remote sensing to evaluate land suitability represents a new way of decision making-process because experts concerning the problem are able to involve in the evaluation process more effectively. Compromise Programming (CP) of Multi Criteria Decision Making (MCDM) method makes it possible to investigate alternative strategies for data aggregation and their consequences

Distance parameter was used based on different approach that is: Compensatory Approach for p=1, Partial Compensation approach for p=2 and Non-Compensatory Approach for p=10 to produce a simple visual comparison of the suitability patterns.

The land suitability evaluation model with distance parameter p=1 was determined as optimal for paddy field and dry land, because it has the largest suitable area in the existing land use. Paddy field of 290.7 ha and dry land of 762.6 ha which covers 58% and 56% of the existing land use respectively, were evaluated as suitable land uses

These results suggest potential usefulness of GIS-based MCDM application for other problems of land suitability analysis, such as urban and rural land use planning, facility location and environmental impact assessment

REFERENCES

Arifin, H. S. 2002. Ecological planning of a sustainable rural landscape in Indonesia. Bulletin of The Hyogo Prefectural Awaji Landscape Planning and Horticulture Academy. 2(2). 202-206.

BPS. 2000. Kabupaten Bogor dalam angka. Bogor. 259p.

Harijono,T. 2002. Banjir dan kerusakan DAS Ciliwung. http://www.lingkungan.nusaspace.com. [21April 2002].

Joerin, F., M. Theriault & A. Musy. 2001. Using GIS and outranking multicriteria analysis for land-use suitability assessment. International Journal of Geographical Information Science. 15(2). 153-174.

Pereira, J. M. C., and L. Duckstein, 1993. A multiple criteria decision-making approach to GIS-base land suitability evaluation. International Journal of Geographical Information Systems. 7 (5). 407-424.

Weng, Q. 2001. A remote sensing-GIS evaluation of urban expansion and its impact on surface temperature in the Zhujing Delta-China. Inter- national Journal of Remote Sensing 22 (10).1999-2014.

Zeleny, M. 1982. Multi Criteria Decision Making. McGraw-Hill. New York.