

SPATIAL MULTI-CRITERIA DECISION MAKING FOR DELINEATING AGRICULTURAL LAND IN JAKARTA METROPOLITAN AREA'S HINTERLAND: CASE STUDY OF BOGOR REGENCY, WEST JAVA

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ABSTRACT

The hinterland of Jakarta has experienced high pressure in its land utilization due to Jakarta's rapid development. The objective of this research was to analyse the suitable land available for agriculture. The research was conducted in Bogor, a hinterland regency of Jakarta. The methodology used includes two steps of analysis, which are land suitability and land availability analysis. Land suitability for agriculture was analysed using multi-criteria decision making method. Seven (7) criteria were included, which consist of soil class, land capability class, slope, elevation, slope aspect, land use/land cover and distance to roads. The criteria were weighted using the Analytical Hierarchy Process. Combining criteria weights and sub-criteria scores, an overlay model in Geographic Information System was applied. The result from land suitability analysis was used as a feed for determining land availability, considering the forest area status and land allocation in the official spatial land use plan. The results indicate that an area amounting to 87.5% of Bogor Regency is suitable for agriculture. Land which is suitable and available for agriculture is 16.7% of the regency's area. Considering available land which is currently in use, the area that can be allocated for the expansion of agriculture is 3.3%.

Keywords: land availability; land capability; land suitability; land use planning; soil order

INTRODUCTION

The state capital of Indonesia, Jakarta, has been developing very rapidly to become the second largest metropolitan area in the world after Tokyo (Fukami *et al.*, 2014; Pravitasari *et al.*, 2015). Data on the period from 1972 until 2010,

for example, indicated that the urban area of Jakarta and its surroundings, namely the Jakarta-Bogor-Depok-Tangerang-Bekasi (Jabodetabek) region had increased by more than 2,096 km², as a result of urbanization process (Rustiadi *et al.*, 2013; Pravitasari *et al.*, 2015). The pace of development of Jakarta has induced rapid land use changes in the surrounding area. The surrounding region, which was an agricultural region with regencies such as Tangerang, Bekasi and Bogor forming the agricultural hinterland, has experienced the pressure of Jakarta's development through the development of urban areas that are often random sprawl (Hidajat *et al.*, 2013). One of the implications is the increase of the industrial, residential and built area as well as the decrease in agricultural land. Statistical data shows that despite the extent of paddy field in Bogor which was relatively constant at around 47,500 ha, dry land agriculture has been reduced from 142,764 ha in 2002 (Statistics West Java, 2003) to 127,369 ha in 2013 (Statistics West Java, 2014, data processed). In the same period, yards, buildings and built area in Bogor Regency has increased from 37,020 ha (Statistics West Java, 2003) to 92,294 ha (Statistics West Java, 2014, data processed).

Such situation indicates the high pressure on land utilization in Bogor Regency, including on agricultural land. Similar phenomena seem also to have occurred in the hinterland of other metropolitan cities on the island of Java, an island which makes up only 7% of the land area of Indonesia (Statistics Indonesia, 2014a), but is inhabited by more than 50% of Indonesia's population (Statistics Indonesia, 2014a). In fact, in current conditions and at least for the next few years, Indonesian agriculture will still be highly dependent on the availability of land in Java Island, given that agricultural development outside of

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Java Island is relatively slow (Widiatmaka *et al.*, 2015a).

Addressing the increasing pressure on agricultural land, one of the measures that can be taken - other than finding alternative agricultural land outside the island of Java - is using agricultural land available on Java Island in a more efficient way. This is unavoidable, given that the actual base of food production, and this is true both in the immediate short to medium term and in the future, will remain on Java Island. To illustrate the situation, in 2013, 52% of the domestic paddy yield as well as 53% of corn, 65% of soybean and 70% of green bean came from Java Island (Statistics Indonesia, 2014b, data processed). One of the questions which can be raised is therefore, how much area can actually still be used for agriculture? Which areas of land should be used in a more efficient way? This research was conducted in Bogor Regency and analysed the situation in its local conditions.

One way to improve land utilization efficiency in agriculture is by using land with high suitability for agriculture. More detailed analysis for specific commodities can then be carried out afterwards. Land evaluation is the first step towards land use planning (Kabanda, 2015; Widiatmaka *et al.*, 2014a, b), with the aim of delineating land at various levels of suitability.

Since the introduction of the FAO's land evaluation concept in 1976's that considers physical, social and economic aspects of land resources (Akinci *et al.*, 2013; Widiatmaka *et al.*, 2015b), this concept has been developed rapidly. Various tools have been developed for analysis (Mendas and Delali, 2012; Elsheikh *et al.*, 2013; Akinci *et al.*, 2013). Recently, land evaluation has been integrated with soft system methodology for decision making, known as multi criteria decision making (MCDM). Tools for decision-making, among others the Analytical Hierarchy Process (AHP) (Saaty, 2008) and the Analytical Network Process (ANP) (Saaty and Vargas, 2013; Aragonés-Beltrán *et al.*, 2014; Zabihi *et al.*, 2015) can be integrated with land suitability evaluation.

This development is supported by the rapid development in remote sensing and geographic information systems (Malczewski, 2006). This has allowed the land evaluation method to be achieved through the decision-making concept

utilizing several criteria which can be done spatially. The concept is not only useful for agriculture (Baja *et al.*, 2007; Bandhyopadhyay *et al.*, 2009), but also used for other sectors including forestry (Segura *et al.*, 2014), industry (Rikalovic *et al.*, 2014), tourism (Rozman *et al.*, 2009), landfill site (Guiqin *et al.*, 2009; Effat and Hegazy, 2012), parking site (Zucca *et al.*, 2008) and environment (Comino *et al.*, 2014).

Apart from carrying out analysis to select suitable land, land availability also needs to be analysed in view of the need for land by other sectors. In the Indonesian context, the forest area has been formally defined in the Forest Area Status (FAS) map, where the use of land for farming can only be undertaken in land outside the forest area, defined as "area for other utilization" (AOU) (Ministry of Forestry, 2009). This regulation was intended to maintain the sustainability of forest cover for ecosystem sustainability (Kusmana, 2011). Land allocation was also formally arranged through formal allocation by the Official Spatial Land Use Plan (OSLUP) (Government of Indonesia, 2007), where land was allocated for many sectors. Consideration of such regulations can be achieved through the integrated analysis of land suitability and land availability (Widiatmaka *et al.*, 2015b). In such a manner, land use planning for agriculture can be achieved in the context of land utilization for other sectors. Selection of land through the integration of land suitability and land availability will also be useful in keeping land utilization sustainable. The objective of this research was, therefore, to delineate land suitability for agriculture and then to delineate such suitable land which was also available for agriculture.

MATERIALS AND METHODS

Study Area

The study was conducted during 2015 in Bogor Regency; the study area was chosen in this research as a case study of land with high pressure land utilization considering its proximity to the capital urban area (Figure 1). This regency has an area of 2,301.95 km², or approximately 5.19% of the area of West Java Province (Statistics Bogor Regency, 2014). The research area lies in the geographical position of 6°19'-6°47' South and 106°1'-107°103' East.

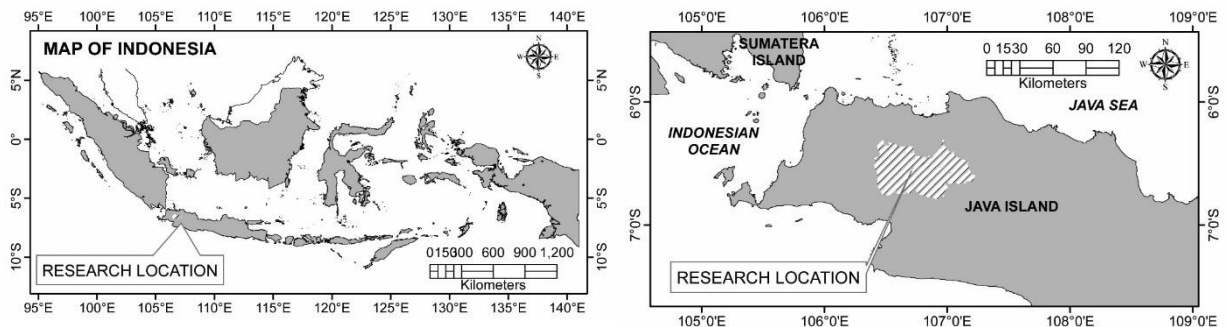


Figure 1. Research area of Bogor Regency, West Java

The average annual rainfall is 3,992.7 mm. The wettest month is January, with an average monthly rainfall of 509.2 mm, while the driest month is June, with an average monthly rainfall of 62.3 mm. The average air temperature in 2013 ranged from 25.1° C to 26.4° C. The hottest air temperature occurred in June, amounting to 34.7° C, while the coldest was in December at 19.0° C. The landforms of the region are diverse, predominantly flat in the north part, while the southern part is dominated by undulating to mountainous landforms (Statistics Bogor Regency, 2014).

Data

The spatial data of soil class are compiled from the results of previous soil survey mapping which include the area of Bogor Regency: soil mapping at the area around Bogor by Soil Research Institute, soil mapping at Jabotabek area by the Center for Soil Research, and soil mapping at Upper Cisadane Watershed by the Center for Soil and Agroclimate Research. They were compiled by Widiatmaka *et al.*, (2015c) as soil map at a scale of 1:50,000. Although on the original map, soil was classified in more detailed classification, in this research soil class was presented in soil order category only (Soil Survey Staff, 2014). Data from these previous studies were also used in this study for the creation of a land capability map according to the criteria of Soil Conservation Service, United States Department of Agriculture (Fenton, 2006; Singer, 2006).

Topographic maps from the Indonesian Geospatial Information Agency at a scale of 1:25,000 were used for the creation of spatial data on elevation, slope and slope aspect using the spatial module of ArcGIS 10.2 (Widiatmaka *et al.*,

2015c). The data on the distance from the road were created by buffering the 1st and 2nd order road on such topographical maps. The actual land utilization was interpreted from Landsat OLI of 2013, interpreted in this research by supervised classification using ERDAS Imagine software (Widiatmaka *et al.*, 2015c). The Indonesian standard imagery classification (SNI, 2010) was used. Field checking was done in August 2015.

Analysis

The analysis of land suitability and land availability for agriculture was carried out sequentially. Land suitability analysis was first performed using the method of MCDM. In this procedure, an AHP was carried out to obtain the weighting of criteria. The criteria consist of several parameters which are considered influential for land suitability. The criteria used can be grouped into 3 (three) parameters: (i) parameters of soil and land, (ii) topographic parameters, and (iii) land management parameters. The parameters of soil and land include soil class and land capability class; the parameters of topography include slope, elevation and slope aspect; while the parameters of land management include distance from the road and the actual land use/land cover. Each criterion consists of sub-criteria. The spatial data for criteria and sub-criteria were presented in Figure 2, while their quantitative distributions were presented in Table 1 (columns d-e). The AHP was conducted, involving 4 (four) experts. In practice, this process used pairwise comparisons of Saaty's AHP concept. Each pair of criteria were assessed for their importance from 1 to 9 (Saaty, 2008) (Table 2). The result of this process is valid if the consistency ratio (CR) is less than 10% (Saaty, 2008).

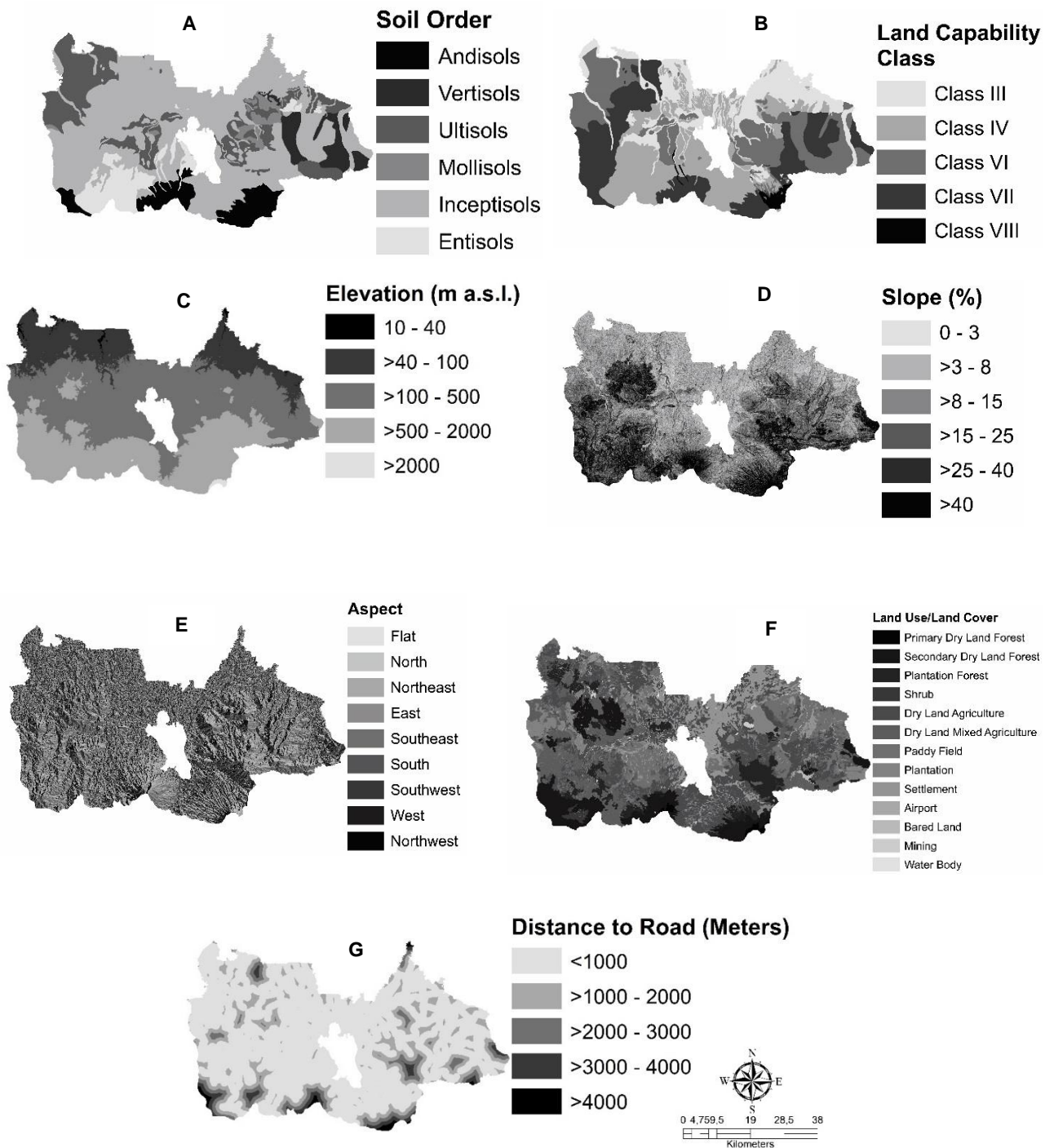


Figure 2. Spatial distribution of: A. soil order¹; B. land capability class¹, C. elevation^{2,3}, D. slope^{2,3}; E. slope aspect^{2,3}, F. land use and land cover^{2,4}, G. distance from road^{2,3}. Data sources and reference: ¹) Compiled and processed by Widiatmaka et al. (2015c) from previous soil survey and mapping which include Bogor Regency; ²) Widiatmaka et al. (2015c); ³) Spatial treatment from Geospatial Information Agency's topographic map of 1:25,000; ⁴) interpreted from Landsat OLI of 2013

Table 1. Distributions of the criteria, and sub-criteria in the study area

Parameter	Criteria	Sub Criteria	Area		Score	
			ha	%		
(a)	(b)	(c)	(d)	(e)	(f)	
Land	Soil Order ¹	Mollisols	7,625.8	2.6	10	
		Inceptisols	171,698.0	57.5	8	
		Andisols	23,655.3	7.9	6	
		Entisols	24,773.2	8.3	6	
		Ultisols	55,071.6	18.4	4	
	Land Capability ¹	III	64,569.0	21.6	6	
		IV	81,515.9	27.3	4	
		VI	72,689.5	24.3	0	
		VII	76,071.4	25.5	0	
		VIII	3,879.6	1.3	0	
Topography	Elevation a.s.l. ²	0-40 m	2,017.6	0.7	10	
		>40-100 m	58,693.7	19.6	6	
		>100 – 500 m	141,511.9	47.4	4	
		>500 – 2000 m	95,819.2	32.1	2	
		>2000 m	795.9	0.3	0	
	Slope ²	0 -3 %	21,137.1	7.1	10	
		3-8 %	67,457.7	22.6	8	
		8-15 %	74,250.7	24.8	6	
		15-25 %	58,628.4	19.6	4	
		25-40 %	42,693.1	14.3	2	
		>40 %	34,671.4	11.6	0	
	Aspect ²	Flat	553.3	0.2	10	
		East	36,193.7	12.1	10	
		Northeast	44,732.1	15.0	8	
		Southeast	30,630.7	10.2	8	
		West	36,364.5	12.2	8	
		Northwest	42,605.4	14.3	6	
		Southwest	30,026.3	10.0	6	
		North	50,575.2	16.9	4	
	Land Manag.	Land Use ¹	Dryland agriculture	83,042.3	27.8	10
Paddy field			58,608.6	19.6	10	
Plantation			14,068.7	4.7	10	
Dryland mixed agriculture			39,649.3	13.3	8	
Primary dryland forest			1,354.4	0.5	8	
Secondary dryland forest			32,347.2	10.8	8	
Plantation forest			24,322.1	8.1	8	
Bared land			745.0	0.2	6	
Shrub			2,375.8	0.8	4	
Settlement			40,726.9	13.6	0	
Airport			69.8	0.0	0	
Mining			666.0	0.2	0	
Water body			862.1	0.3	0	
Distance to Road ²		0-1,000 m	228,183.8	76.4	10	
		>1,000-2,000 m	45,489.1	15.2	8	
		>2,000-3,000 m	16,376.9	5.5	6	
		>3,000-4,000 m	6,593.6	2.2	4	
		>4,000 m	2,194.9	0.7	2	
Total			183,994.6	100.0		

Remarks: Data Source: see Figure 2

Table 2. Rating for pairwise comparison according to Saaty (2008)

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	Very strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very strongly	Extremely
Less important					More important			

Table 3. Weight of parameter resulting from pairwise comparison of criteria

	SO	LCC	EL	SL	SA	LULC	DR	Weight
SO	1	2	5	3	9	4	7	0.362
LCC	1/2	1	4	2	7	3	5	0.238
EL	1/5	1/4	1	1/3	3	1/2	2	0.068
SL	1/3	1/2	3	1	5	2	4	0.156
SA	1/9	1/7	1/3	1/5	1	1/4	1/2	0.029
LULC	1/4	1/3	2	1/2	4	1	3	0.103
DR	1/7	1/5	1/2	1/4	2	1/3	1	0.044

Remarks: SO = soil order; LCC = land capability class; EL= elevation; SL= slope; SA= slope aspect; LULC= land use and land cover; DR= distance from road; Max eigenvalue (λ_{max}) = 7.203730872; n = 7; Consistency index (Ci) = $(\lambda_{max} - n)/(n - 1) = 0.033955145$; Random index (Ri) = 1.32; Consistency ratio (Cr) = $Ci/Ri = 0.025723595$

The sub-criteria were scored in accordance with the degree of contribution of each sub-criterion to land suitability for agriculture; such scoring was done with consideration of the experts judgements. The scores given for each sub-criterion were presented in Table 1 (column f). For the criteria of soil order, the weight given is 10 for the sub-criterion of Mollisols, 8 for Inceptisols, 6 for Andisols, Vertisols and Entisols, while for Ultisols, the score of 4 was given. The highest score was given to Mollisols because they have good chemical properties. To Inceptisols, sufficiently high scores were given because this soil was considered suitable for agriculture; it was a relatively young soil but having high natural fertility (Soil Survey Staff, 2014). To the Andisols, Vertisols and Entisols the same score of 6 were given. The Ultisols are considered to have the lowest suitability for agriculture due to several barriers such as high exchangeable Aluminium (Ward *et al.*, 2010) and an argillic horizon (Soil Survey Staff, 2014) that constitutes a chemical and physical barrier for root penetration.

For land capability class, the sub-criterion of land capability class V or lower was scored 0 because land with such classes cannot be used for agriculture (Arsyad, 2010), while land with land capability classes I to IV were scored sequentially as 10, 8, 6 and 4. For altitude, land at low altitude is considered more suitable for more crops. Land at an altitude of more than 2,000 m is not permitted

for agricultural use (Government of Indonesia, 2007), so it was given a score of 0. For criteria of slope, a slope of more than 40% was scored 0 because it was not permitted for agricultural use (Government of Indonesia, 2007), while other slopes were scored in a sequence of 10, 8, 6, 4 and 2 parting from flat land.

In the case of slope aspect, flat land and land with a slope facing to east were given the highest score of 10 as an optimal surface to the sun, considered optimal for physiological activities (Akinci *et al.*, 2013). The other slope aspects were scored successively according to their direction towards the sun.

In terms of land use and land cover, land utilization which was not possible for agriculture such as settlements and the airport were scored at 0, while higher scores were given to existing agricultural land. In terms of distance to roads, land that lies closer to the road was considered more suitable for reasons of market access.

Spatial Treatment

The land suitability map was created by multiplying the weight of criteria and score of sub-criteria. The suitability was then divided into four classes: highly suitable, suitable, marginally suitable and not suitable by dividing into equal quartiles, according to the equation below (Rahman and Saha, 2008; Cengiz and Akbulak, 2009; Widiatmaka, 2016):

$$S = \sum_{i=1}^n w_i x_i$$

where: S = land suitability; w_i = weight of land suitability criteria; x_i = score of sub-criteria i ; n = number of land suitability criteria

RESULTS AND DISCUSSION

The results of pairwise comparisons are summarized in Table 3. Such result is considered to be valid as indicated by a value of CR less than the threshold of 0.1. This value indicates that the decision was not given by chance (Saaty, 2008).

The results of the weighting of the criteria show that soil class has the highest role in determining land suitability, followed by land capability class, while the slope aspect has the lowest weight. This fact shows that in terms of suitability for agriculture, soil constitutes the most important factor. For this land and soil parameters, soil class has a more important role than land capability class. The soil class represents more major aspects of land including soil fertility, soil physical properties, chemical and biological aspect of soil as well as ease of management in a wider sense. In the case of topographical factors, slope is the most important criterion. For land utilization for agricultural purposes, flat land is more desirable because of the safety factor against erosion. Meanwhile, for the factor of management, land use and land cover constitute more important criteria than distance from road.

Results from the agricultural land suitability map are presented in Figure 3 and Table 4 (columns

b and c). It is shown that 87.5% of the land of Bogor Regency is suitable for agriculture, with the large part (43.2%) is moderately suitable (S2).

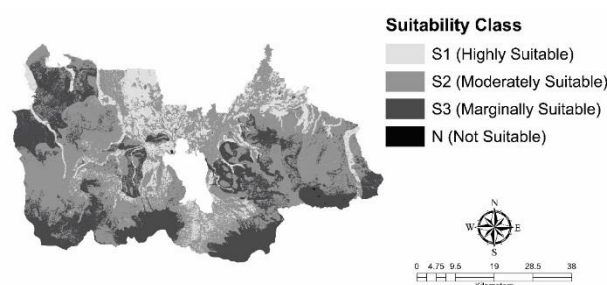


Figure 3. Map of land suitability for agriculture

In terms of land availability, the forest area status map (Ministry of Forestry, 2009) and the OSLUP map (Government of Bogor Regency, 2008) are presented in Figure 4. Based on the FAS map, land can only be used for farming in the area with the status of AOU. Meanwhile, based on the OSLUP of Bogor Regency, land can only be used for agriculture in areas allocated as annual cropping, plantation, dry land and wetlands. Taking into account both maps, a map of suitable land available for agriculture according to both regulations is presented in Figure 5 (a) and Table 4 (columns d and e). This table shows that the land suitable for agriculture in Bogor Regency amounts to 49.812 ha (16.7%). This consists of various levels of land suitability; most of the land is moderately suitable (S2).

Table 4. Summary of suitable and available land for agriculture in Bogor Regency

Suitability/ Availability	Suitability		Suitable and available, taking into account FAS and OSLUP		Suitable and available, taking into account FAS, OSLUP and Actual Use	
	ha (b)	% (c)	ha (d)	% (e)	ha (f)	% (g)
Suitability:						
Highly Suitable (S1)	48,762.8	16.3	14,737.3	4.9	204.9	0.1
Suitable (S2)	129,097.7	43.2	17,554.4	5.9	5,938.9	2.0
Marginally suitable (S3)	83,623.0	28.0	17,520.7	5.9	3,607.6	1.2
Not suitable (N)	37,354.8	12.5	37,354.8	12.5	37,354.8	12.5
Availability						
Not available	-	-	211,671.2	70.8	251,732.0	84.2
Total	298,838.3	100.0	298,838.3	100.0	298,838.3	100

If then the results of this analysis are overlaid with the actual land that has been used for agriculture (for example existing paddy fields, plantations and built area), the land which still allows for the expansion of agriculture is an area of 9,751.4 ha or 3.3% of the area of Bogor Regency (Table 4, columns f and g; Figure 5b). This indicates that the available land for agriculture is not significant, compared with the future requirement for agricultural commodities that need to be increased with population growth. Subsequent analysis can still be done, for example by modelling the needs for land associated with population growth; however it is beyond the scope of this research.

This analysis shows that there is not much more suitable and available agricultural land in the hinterland of Jakarta. The solution to increase the efficiency use of existing agricultural land is to tightly comply with the official spatial land use plan.

It should be noted also the validity of this analysis, related to the use of input map. This analysis use input maps at different scales, depending on the spatial data availability. For

example, topographic maps used to derive slope, altitude, slope aspect and distance from the road is at scale of 1: 25,000. The soil class and land capability class were derived from soil map at scale of 1: 50,000. The data of forest areas statuses use map at scale of 1: 250,000 because the availability of data in all Indonesian territory is only available at such scale. With advances in GIS technology, overlay maps at various scales is possible. However, globally the detail of such analysis remains at scale of 1: 250,000 which is the most un-detail map, although in the region that is not a forest, it can be said of detail analysis of 1: 50,000. Analysis using a variety of map scale was also discussed in the previous analysis using different methods of land suitability analysis (Widiatmaka *et al.*, 2015b). Although this research used maps of various scales because of the input map availability, but basically the methodology used remain valid for application at a more detailed scale in case of the maps for such purpose were available. Certainly for this more detail planning; it would necessary additional costs for the procurement of more detailed input maps.

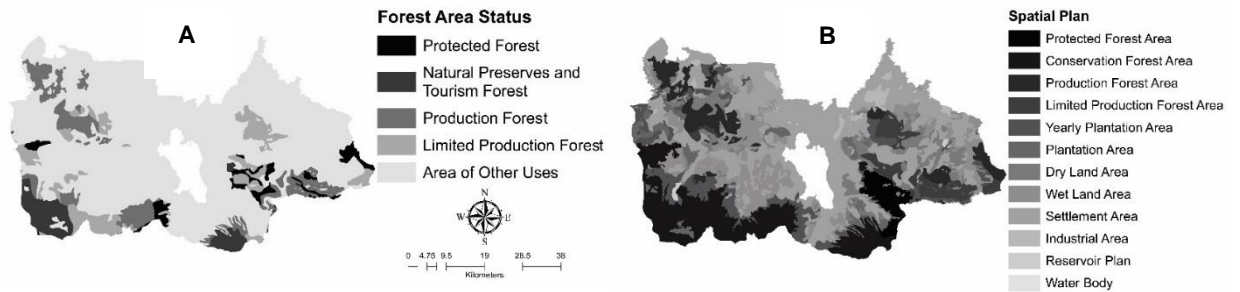


Figure 4. Map of: A. Forest area status (Ministry of Forestry, 2009); and B. allocation in official spatial land use planning (Government of Bogor Regency, 2008)

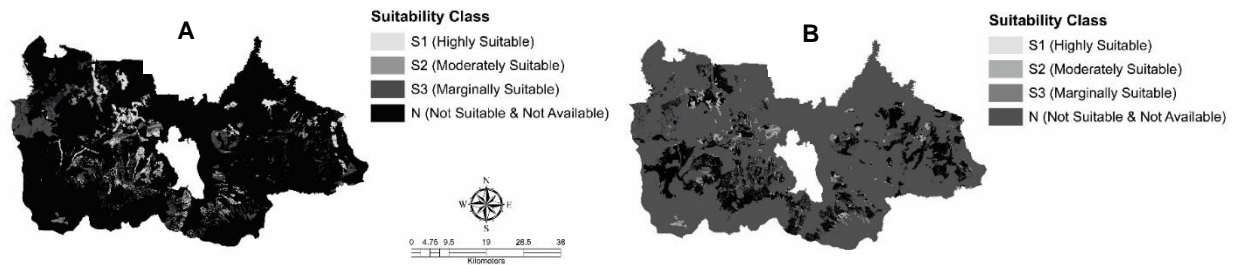


Figure 5. Map of suitable and available land for agriculture: A. taking into account FAS and OSLUP, B. taking into account FAS, OSLUP and actual land utilization

CONCLUSION AND SUGGESTION

Land suitability analysis was performed in this research by using multi-criteria decision making methods that integrated many land parameters used as criteria. The parameters used include soil order, land capability class, elevation, slope and slope aspect, land use/land cover and distance to road. Results of the analysis indicate that Bogor Regency has 87.5% of suitable area for agriculture at various levels of suitability. Considering the regulation on forest area status and the official spatial land use plan, the suitable and available land for agriculture is 16.7%. Of such suitable and available land, much has already been taken for various uses. Considering this actual utilization, the area that can be used as new agricultural land is 9,751.4 ha or 3.3% of the area. The overall analysis shows that there are not many lands could be used for the expansion of agricultural land to keep pace with population growth. This result implies that in the future, land utilization should be planned more strictly, considering the strict application of existing official spatial land use plan allocation and a more efficient use of land for agriculture.

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