Spatial Modeling for People Forest by Using Remote Sensing-GIS and AHP to Support Rural Municipal Sustainable Development for the SDGs

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Abstract

This research conduct to model people forest in the study area. Although there are many levels of importance to land-use, land-use of people forest must also be prioritized. Prioritizing the people forest land-use by using spatial modeling is play an important role in rural municipal sustainable development. People forest or non-state forest in rural municipality able to act as lungs that can provide coolness and ensure the sustainability of the surrounding ecosystem. Modeling is one of decision support tools for the success of people forest in rural municipal area. Therefore, spatial modeling of people forest plays an important role for fostering rural municipal sustainable development agenda. The methodology used is remote sensing -Geographic Information System (GIS) and Analytic Hierarchy Process (AHP). Remote sensing combined with GIS is done for spatial and attribute data processing which is used as input data. AHP is used to analyze the level of importance of space to find the most potential models based on the pairwise comparison technique. Pairwise comparison in AHP able to help to minimize land-use conflicts of interest by managing the level of importance every criterion. All pairwise comparisons produced are consistent to gain consistent models for multi-criteria decision making. Three potential models are gaining in this research i.e., model $1 = \pm 559,14$ ha, model $2 = \pm$ 547,55 ha, and model $2 = \pm$ 543,69 ha. Model 1 is selected as potential model for people forest in the study area. The selected model can be used as an alternative model for the spatial planning of people forest area to support rural municipal sustainable development for the SDGs.

Keywords: Modeling, People Forest, Rural Municipality, Remote Sensing, GIS, AHP, SDGs

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I. Introduction

There are increasing concerns on forest and land deforestation which reducing forest and land cover in certain areas caused by both natural and human factors (Luna et al. 2020). Deforestation caused by natural factors such as flooding, strong winds, and tidal waves (Li et al. 2017) and caused by human factor such as mining activities, clearing of plantation areas, felling trees, and fires. Based on monitoring of Forest Hansen satellite imagery from 2000-2012, many forests and lands in Indonesia have experienced deforestation. Indonesia experiences the largest deforestation among other countries in the world, amounting to 1,021 km2 / year (Hansen et al. 2013) and many rural municipalities in Indonesia undergo deforestation. The study shows that one of rural municipalities in Belitung Island experience deforestation from 2000 to 2019 i.e., rural municipality of Gantung, East Belitung Regency of Bangka Belitung Islands Province of Indonesia. The term rural municipality in this study refers to a city in subdistrict. The area of interest (AOI) of land ecosystem of rural municipality of Gantung is \pm 16,001 ha. The existing forest consists of \pm 8,915.50 ha forest cover and \pm 203.22 ha of forest gain. In contrast, the area of forest lost is about \pm 2,568.76 ha in that interval time. The percentage of deforestation, by dividing forest loss with existing forest, is 2.568.76 / (8.915.50 + 203.22) = 28.17%. It means for ten years (2000 – 2019) rural municipality of Gantung experience deforestation about 28,17%. This phenomenon if allowed to continue will result in massive deforestation in rural municipality of Gantung. Therefore, the deforestation phenomena must be intervened with appropriate programs (Velasco et al., 2020). One way proposed to address this difficult situation is people forest (Bray et al. 2008).

People forest or called as private forest in Indonesia is defined as forest in land with ownership rights which located in outside the state forest (Safe'i and Sukmara 2019). Site selection for people forest is based on suitable location for the tree planting in that area because the right site for tree planting is one of main factor for good greening with people forest based (Novotny et al. 2021). New studies show that people are willing to pay for good greening (Sass, Lodder, and Lee 2019). Trees are an important part of life (Nyelele, Kroll, and Nowak 2019). Trees can produce oxygen, cool air, provide shade in summer, prevent soil erosion and water pollution, and also tackle climate change (Helen, Jarzebski, and Gasparatos 2019). Trees in terrestrial ecosystems will provide health benefits for the environment (Berg et al. 2015) and the animal species that live around it (Pretzsch et al. 2015). In addition, trees are a transactional place for circular or sustainable economic activities in the community (Husgafvel et al. 2018). Although money does not grow directly from trees, these trees can revive community economic activities (Tate et al. 2019). So, study for site selection of people forest based spatial modeling is play an important role.

The current condition, there is minimum study about site selection modeling of people forest in the developing countries like Indonesia. Selection for people forest generally based on the land suitability for the people forest itself (Bisjoe et al. 2016). much research has been done on modeling but few have addressed modeling of people forests. In Swedia, people forest or private forest is one of important factors in supporting municipal comprehensive planning (Thellbro et al. 2017, 189). By using spatial modeling, any geomatics planner able to desain the study area for green planning like people forest. But the study only just views from forest management

side not the spatial modeling. Researches on GIS and AHP-based modeling usually discuss land suitability for green space. This is adjusted to the problems that occur in each study area. In any rural municipality in Indonesia, it is very important to conduct a community forest modeling study to support its life on land for the SDGs (Jusuf and Darajati 2017). Therefore, new research on spatial modeling needs to be done to support spatial modeling in the area of people forest (Fig. 1).



Figure 1: AHP building for People Forest

The problem is how to model the site selection of people forest in rural municipality with deforested area. Remote sensing and GIS based and AHP spatial modeling is a widely used methodology that can assist in the site selection of potential location using multicriteria decision making (Malczewski 2004). The spatial modeling of forest areas has previously been carried out in the protected forest area of Belitung Island using the AHP pairwise comparison method (Fahrudin, et. al. 2013, 594–601). Determination of land suitability for people forest can also be done using a method above with preferred criteria. People forest modeling can be carried out by integrating biophysical and socioeconomic criteria (Arnaiz-Schmitz et al. 2018). This modeling is useful as a spatial decision support system in determining community forest areas (Thellbro 017). The determination of people forest in a strategic program acts as the development of green facilities in rural municipalities to support SDGs (Ordóñez et al. 2020). Hence, people forest modeling based remote sensing-GIS and AHP is effective to be applied in deforested rural municipality area.

Modeling is one of the approaches used to support decision makers towards the complex SDGs agendas (Allen, Metternicht, and Wiedmann 2016). Spatial modeling is a widely used methodology that can assist in the selection of potential locations for community forest development in rural municipality. This approach able to reduce the gap between theory and practice that is often found in community forest area planning in rural municipality area (Bjärstig et al. 2018). Modeling enable us to evaluate spatial planning of people forest for rural municipality comprehensive planning (MCP) because people forest is one of real models of rural MCP. People forest in rural MCP is detailed regional spatial planning and it is customized with every country because every country has its own spatial regulation (Kanako, Mahesti, and Hiromi 2020). A good spatial regulation like MCP is one of key factors in supporting people forest or community forest (Baynes et al. 2015). Finally, people forest able to support rural municipality development for SDGs.

The current paper will study site selection modeling of people forest based on remote sensing-GIS and AHP for finding the best model. A combination of AHP and GIS was used to describe a site suitability model for people forest area. AHP is a very effective tool used in very complex decision making which was introduced by Thomas Saaty in 1980 (Mu and Pereyra-Rojas 2018). In addition, AHP is a suitable technique for evaluating the consistency of results, thereby reducing bias in the decision making process (Aboulola 2018). GIS is a suitable tool for processing data with attributes to obtain regional indicators of suitable locations for people forest (Dragićević, Dujmović, and Minardi 2018). In addition, GIS also has spatial data operations through robust spatial analysis and geo-statistical functions for spatial analysis of the assessment of the suitability of people forest sites (Palaiologou et al. 2020). Rural municipality of Gantung is selected as area of study because this region undergoes significant deforestation number (Figure 2). Taking all this into account, this technique was used to model the potential people forest site on rural municipality of Gantung for supporting fifteenth SDGs agenda i.e., life on land.



Figure 2: Area of Interest (AOI)

II. Data and Methods

People forest relates to biophysics and socio-economic aspects. So, the input data come from these criteria. Biophysical criteria such as soils, slopes, water bodies, and deforestation. Socio-economics such as settlement and accessibility Table I.

No	Criteria	Source	Explanation			
1	Biophysics					
	– Soils	Indonesian Ministry	Vector data year 2003 scale			
		of Agriculture	1:25.000			
	– Slopes (derived	Indonesian	Raster data dimension 7,5 m x 7,			
	from DEM Terrasar)	Geospatial Agency	5 m			
		(BIG)				
	– Water bodies	BIG	Vector data year 2014			
			topographic map of Belitung			
			island scale 1:25.000			
	 Deforestations 	Forest Hanson	Raster data Dimension 30 m x 30			
			m			

Table 1	·	Data	for	modeling	peopl	le fo	orest
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2	Socio-economics										
	_	Settlement	_	BIG		_	Vector	data y	ear	2014	
						topog island	raphic r scale 1:2	nap of 25.000	Bel	litung	
			_	– National		_	SPOT-6	5			
			Institute of								
			Aeronautics and								
			Space of Indonesia (LAPAN)								
	_	Accessibility	-	BIG		_	Vector	data y	ear	2014	
						topog	raphic r	nap of	Bel	litung	
						island	scale 1:2	25.000			
			-	LAPAN							
						_	SPOT-6	5			

All data come from different scales and year. Biophysics criteria such as soils, slopes, water bodies, and deforestation. Soils map using in this research come from year 2003. Although it is long time data, many researchers in Indonesia are still using this data. Slope data is gained from national DEM of Indonesia With dimension or resolution 7,5 m x 7,5 m. DEM data is provided by Indonesian Geospatial Agency. By using DEM, slope information in the area of interest (AOI) is gained. Water bodies are derived from topographic maps of Belitung year 2014 scale 1:25.000. Deforestation map is come from Forest Hansen satellite imagery year 2009-2019 with spatial resolution 30 m x 30 m. Accuracy assessment is given to forest Hanson satellite imagery because in Geomatics disciplines it is important to make accuracy assessment for knowing the data accuracy. From the accuracy 99%. It is mean that deforestation data using in this research is accurate based on the forest Hanson satellite imagery.

Socio-economics criteria come from different scales and year too. Settlement is gained from topographic map of Belitung year 2014 scale 1:25.000. Settlement information is limited to year it is mapped. In recent year, there are settlement development in the AOI but it is not too significant. In other mean, there is small chance in the settlement growth. Settlement is validated with SPOT 6, year 2019. Same as the settlement, accessibility map is extracted from topographic map of Belitung year 2014 scale 1:25.000. Accessibility maps or transportation utilities are sets of road maps in the AOI which is consist of collector, local, footpath, and other streets. Besides these data, Satellite imagery orthorectified with spatial resolution 0,5 m x 0,5 m is used for positional accuracy provided by BIG Indonesia.

Method using in this research are the combination of remote sensing-GIS and AHP as one of decision-making tools for multicriteria decision analysis. This is common method in the area of site selection modeling. But, in this research there are something different with previous research. The differences are come from local characteristics of the study area and come from the pairwise comparison weighting in the AHP methodology. Although different, but the concept of people forest is same as regulation of people forest in Indonesia. The main research methodology is shown in the figure 2.



Figure 3: Methodology of spatial modeling for people forest

Step per step in this research is based on the reference from super decision literature written by Mu and Pereyra-Rojas 2018. This is only approach for modeling people forest. Other researchers are free using or not using this approach. The approaches are:

- 1. developing a model
- 2. deriving priorities (weights) for the criteria
- 3. deriving local priorities (preferences) for the alternatives
- 4. deriving overall priorities (model synthesis)
- 5. sensitivity analysis
- 6. making a final decision, and
- 7. final model (conclusion)

III. Results and Discussion

Hierarchy model of people forest which is used in this research as shown in figure 1. The model consists of goal, criteria, and alternatives (Fig. 2). Criteria in this research derived from the definition and function of people forest itself. Criteria is also gained by using google form quiz and literatur study. Google form quiz is used for making assessment from the expert both academic and experience expert. Literature study is used for supporting selected criteria for the people forest.



Figure 4: AHP Design for Modeling People Forest

Every criterion has different level of importance. It is the reason for the second step i.e., weighting for the criteria. Assessment for the criteria weight Is based on the level of importance from Saaty (Fig. 3).



Figure 5: Level of importance from Saaty

Next, rescaling the spatial data and the attribute data of all criteria. It is important step in spatial modeling based AHP. Rescaling need careful assessment because rescaling result will be used as input data in modeling. So, rescaling as part of weight need to be done carefully (Table 1).

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L	1	Extreme	ly strong		9		2	Very strongly			7	
L	2	Strongly	more important		5		3 Strongly more important			5		
L	3	Equal Im	portant		1		5	Equal Impor	tant		1	
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	VALUE		AHP 1	distance	Saaty		VALUE	Percentage		Name	AHP 1	Saaty
L	1	Equal		200	1		1	0 - 5%	Flat		Equal Important	1
L	2	Moderate		300	3	- H	2 5% - 15% Sloping		bing	Extremely strong	9	
H	3	Strongly m	ore important	400	5	- H	3 15% - 25% Slightly steep		Very strongly	7		
H	4	Very stror	igly	500	7		4	25% - 45%	Stee	ep	Strongly more important	5
L	5	Extremely	strong	600	9		5 :	> 45%	Ver	y steep	Moderate	3
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	Value	Count	AHP		Saaty		VALU	distan	ce		AHP 1	Saaty
	1	19417	Equal		1			1	500	Equal		1
	2	16637	Extremely strong		9			2	750	Moderate		3
	3	12739	Very strongly		7			3 1	000	Strongly m	ore important	5
	4	8350	Strongly more important		5	L H		4 1	250	Very strongly		7
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Tabel 1. Rescaling AHP with the level of importance

After rescaling, spatial data or geospatial information of all criteria have special value.

The value of all criteria is different to each other. Although the spatial data is different, but the level of importance of the criteria is same. Map pattern of the criteria must different but the value of level of importance have same number based on quiz and literature study.

Biophysical Criteria



Figure 6: Spatial data of people forest after deriving priorities

All weighted criteria have met the minimum consistency ratio (CR) since numeric value derived from subjunctive preference. The minimum CR accepted is 0.1. CR in AHP modeling compare the consistency index (CI) of the matrix in question versus the consistency index of a random-like matrix (RI) or in other form CR= CI/RI. Local priorities are derived by using pairwise comparison approach. All criteria are compared each other for gaining the best model which CI < 0,1. Model 2 is the highest result model. It means that model 2 is the best model relative to the other ones.

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Table 7.	Pairwice	comparison	of the	models
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1. Choose	2. Node comparisons with respect to 1.Street	t _ 3. Results
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	2. Model1 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Mode	Model3 0.07692
Choose Cluster	3. Model2 >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Model	le
3alternatives 🗕		

Final decision is made by assessing three potential models, model 1, model 2, and model 3. All models are processed by using ArcGIS software. In ArcGIS module AHP modeling able to assess by using weight sum module. Weight sum is selected for process AHP modeling in ArcGIS because it provides decimal number. It is free of using AHP software based on the skills. Weight sum is different from weighted overlay which can only accommodate the integers. All final models provide the

potential area for people forest which have same area and different level of importance.

Model 2 have highest value, 0.69231. It means this is the best alternative model. But, it can not identificate in the model map which one is model 2. To know that model map is model 2, computing the total suitable area of level of important is taken. Every model has same total area with different level of importance. Saaty values for selecting model in this research are 5, 7, and 9. So based on these value, total model 1 is \pm 559.14, model 2 \pm 543.69, and model 3 \pm 547.55. Model 2 as the best one in Table 2 is model 1 after computing the saaty value (Figure 7).



People forest model percentage per total land ecosystem of AOI is 5 %. This value is gained by comparing total area of people forest versus total AOI, total water bodies, and total land area. Total area of people forest is same for all models i.e., \pm 743,71 ha, total AOI \pm 16,000 ha, total water bodies 1,894.14 ha, and total land area \pm 14,105.96 ha. In Indonesia, value 5 % is accepted for fostering people forest which is at least 0,25%. It makes sense for rural municipality of Gantung allocating people forest location only 5% from total land ecosystem of AOI for supporting SDGs.

IV. Conclusion

AHP succeeds in modeling people forest: model 3.1; model 3.2; and model 3.3. Model 3.1 is the best one. Rural municipality sustainable development can be supported by spatial modeling. Spatial modeling using remote sensing-GIS and AHP success to be done. Many potential models are yielded based on AHP assessment. It depends on the decision makers in selecting the best model. The selected model can be used for the spatial planning of people forest area to support rural municipal sustainable development for the SDGs. Modeling people forest outside case study need to be adapted with the local characteristic area. A key factor for success of people or community forest in rural municipality of Gantung for the SDGs is supporting from the local government. Local government can accommodate people forest in the preferred regulation and give financial support for people forest in rural municipality for the SDGs life on land.

People forest is one way of land rehabilitation for sustainable development. Next research needs modeling land-use of forest cover like afforestation. Afforestation is important in the area which meet deforestation and land degradation. Afforestation able to enhance the proportion of tree in land ecosystem.

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