

Forest and Land Fire Vulnerability Mapping Based on Land Physical Parameters in Sumatera and Kalimantan Region of Indonesia

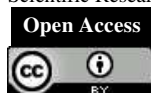
Ardila Yananto¹, M. Bayu Risky Prayoga², Budi Harsoyo³

^{1,2,3}National Laboratory for Weather Modification Technology - BPPT, Jakarta, Indonesia

*Corresponding author e-mail: ardi.geo@gmail.com

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Abstract

Indonesia is a country that has vulnerability to land and forest fires danger. This is not out of the existencies of peatland in Indonesia which are quite wide and mostly located in Sumatera and Kalimantan. The nature of peatlands are capable to store water in large quantities, but the surface dries quickly and become flammable during the dry season. This research aims to perform mapping area that vulnerable to land and forest fires danger based on the physical parameters. The results of this research can be used as the basis for developing an early warning system for land and forest fires in Indonesia. This research uses GIS (Geographic Information System) for processing mapping of physical parameters which consist of Land Use Map, Topography Map and Soil Map in Sumatra and Kalimantan to get the forest and land fires danger map. The results of the mapping areas that vulnerable to forest and land fire based on the physical parameters have indicates uniform patterns with the distribution and density of hotspots in the Sumatra and Kalimantan over the last 10 years (2006-2015). It is confirm with the accuracy test where the number of hotspots during the last 10 years both in Sumatera and Kalimantan area is exactly vulnerable up to very vulnerable to land and forest fires danger by 74%.

Keywords: Forest and Land Fire Vulnerability Mapping, Land Physical Parameters, Sumatera and Kalimantan Region

1. Introduction

1.1. Background

The Sumatra and Kalimantan islands are areas in Indonesia that have large peatlands. The peatlands are scattered along the east coast of Sumatra and also in the South and West of Borneo Island. The character of peatlands is able to store water in large quantities but the surface rapidly drying out and easily burning during the dry season. Land clearing, both for agriculture and for plantation and also the canalization in peatland areas, are the main factor of Indonesia's peatlands fires almost every year.

Based on peatland area by Wetlands International 2014/2015 with a map scale of 1: 250.000, it is known that the peatland area in Sumatera is 6.436.649 ha, where most of the peat land is found in Riau, Jambi and South Sumatra provinces. In Kalimantan, there are 4.778.004 hectares of peatland in Central Kalimantan, West

Kalimantan, East Kalimantan and South Kalimantan.

One of the activities undertaken in the prevention of forest and land fires by mapping vulnerable areas. Information on forest and land fire vulnerable areas are very important and necessary for fire manager to control activities in forest and land fire (Rianawati, 2016).

Spatial presentation of forest and land fires vulnerable areas will be more helpful to provide a clear and accurate picture of the location, distance and accessibility between the location of fire vulnerable areas with existing power outages in the field. Therefore, the creation of a vulnerable area map of forest and land fires is necessary because it plays an important role in assisting decision making and can be used as early warning information to prevent and control forest and land fires (Solichin, 2007).

The development of mapping methods of forest and land fires vulnerable areas has been

undertaken by the Provincial Forestry Office of South Sumatra in cooperation with the German Government in 2015 through the GIZ Bioclimate Project, with study areas in South Sumatra Province. The accuracy test of this mapping method uses hotspots data and the history area burned land where the mapping of forest and land fires vulnerable area produced has a high level of accuracy.

There is no previous research has been done in Sumatera and Kalimantan islands, and this research aims to mapping forest and land fires vulnerable areas in the island of Sumatra and Kalimantan by using GIZ Bioclimate methods Based on the results obtained can be used as the basis for develop forest and land fires early warning system in Indonesia.

1.2. Basic Theory

1.2.1. Forest and Land Fires

The forest fire according to Brown and David in Tarigan (2015) is a process of rapid reaction of oxygen with other elements characterized by the presence of heat, light and illumination spread freely and consumes natural forest fuel. The phenomenon of forest fires is the greatest threat and has an important role to the destruction of nature, especially to plants in nature. In forest and land fires, humans are dominantly encouraging forest and land fires supported by high temperature conditions, vegetation composition, lack of rainfall, and low levels of soil water.

There are 3 (three) types of fire based on the place of occurrence, that is ground fire which burns humus and peat in, surface fire which propagates on the forest floor like bush / shrubs and canopy fires propagate in higher plants between dry canopy. In peat forest ecology this event can occur in all three types of fires (Tarigan, 2015).

1.2.2. Factors Causing of Fires

In general there are 2 (two) main factors causing of fires, that is the trigger factor of fire and supporting conditions. Fire triggering factors are the factors that directly affect the occurrence of ignition. The triggering factor of this fire is mainly caused by human activity, either intentional or negligence factor. While the trigger of land fires caused by natural factors such as lightning or dry twig friction is very rare. The large-scale fires triggered by human activities include several things: land preparation, hunting, land conflicts, and human negligence. While the supporting conditions causes of forest and land fires include climatic conditions, physical conditions of the land, and socioeconomic conditions (Solichin, et al., 2007).

The results of Rucker's study (2006) that calculated the magnitude of fire-ignition risk based on hotspots in some land cover mentioned some flammable ecosystems, that is open areas with scrubland cover, litter and twigs both on land and in peat swamps, plantations mainly in peat swamps, cultivation/ agriculture especially in peat swamps, and secondary forests both on land and in peat swamps.

1.2.3. Forest and Land Fires Vulnerable Mapping Areas

The forest and land fires vulnerable areas is an area where the elements and factors that cause the fires are available in sufficient quantities. Furthermore, the characteristic of forest and land fires vulnerable areas is to have sufficient quantity of potential fuel, high human mobility, human activities often use fire, and have serious drought during the dry season. Meanwhile, based on the characteristics of landscape that often occurs forest and land fires is on bumpy land, low-moderate land, land with rare tree cover, have accessibility but the quality of access is not good and generally occur in area with sparse population (Mapilata, 2013).

Mapping of forest and land fires vulnerable areas is a spatial model used to represent the conditions in the field related to the dangers of forest and land fires. Mapping of forest and land fires vulnerable areas can be short and long, depending on data resolution used either spatially or temporally. Mapping of multi-time / long-range forest and land fires vulnerable areas is very useful in understanding the patterns of forest and land fires that occur so as to facilitate the prevention management of forest and land fires (Mapilata, 2013).

The development of mapping of forest and land fires vulnerable areas can be done with the remote sensing technology and Geographic Information System based on factors affecting forest and land fires, like fuel conditions, climatological conditions and fire behavior. Critical parameters associated with forest and land fires vulnerable areas in long-term mapping, like human activity, vegetation type, topography, and climate with consideration of these factors have not changed drastically and tend to be stable during a fire. Along with its development, the mapping of forest and land fires vulnerable areas uses density / type of vegetation, humidity (climate and topography), distance from road, and distance from settlement. (Sowmya and Somashekar, 2010). As for the importance of spatial planning, the key parameters in this case as the recommended geoinicator for mapping forest and land fires vulnerable areas are rainfall, soil type, land cover and landform (Barus, et al., 2010).

2. Materials and Methods

The study area in this research are Sumatra and Kalimantan Islands, where the two regions are identical with forest and land fires events for each year. Data used in this study are Indonesia Land Use Map of 2015 taken from the Kepohutan-Greenpeace site, Soil Map and Topographic Map of Indonesia obtained from Center for Agricultural Land Resources, Ministry of Agriculture. The processing of Forest and Land Fire Vulnerability Map in Sumatera and Kalimantan Islands using spatial analysis method. Where input maps include Land Use Map, Land Map, and Topographic Map are weighted first for each class / type. The parameter using weighting tiered weighting type which gives the value (score) on each parameter and gives weights on each parameter of magnitude corresponding to the effect on the vulnerability forest and land fires. The weighting basis of each variable in the input map is represented in Table 1.

Table 1. Weighting Input in Forest and Land Fire Hazard Map

Parameter	Weight	Class	Factor		
Land Cover	40%	Spread	4		
		Swampland	5		
		Primary Mangrove Forest	1		
		Secondary Mangrove Forest	3		
		Primary Forest	1		
		Primary Swamp Forest	5		
		Secondary Swamp Forest	5		
		Secondary Forest	3		
		Peatland Forest	5		
		Dry Plantation	3		
		Settlement	1		
		Plantation	2		
		Rubber Plantation	2		
		Oil Palm Plantation	3		
		Cane Plantation	3		
		Mixed Farming	2		
		Dryland Farming	3		
		Swamp	5		
		Rice Fields	2		
		Swamp Bush	5		
		Pond	0		
		Mine	1		
		Water	0		
		Open Land	4		
		Transmigration	2		
		Land Topography	30%	≤ 8 degrees	5
				9 – 25 degrees	3
≥ 26 degrees	1				
Soil Type	30%	Peat	5		
		Not Peat	1		

Source : Forestry Departement of South Sumatera Province with Modification

After the weighting are then processed to make Forest and Land Fire Vulnerable Map on Sumatera and Kalimantan Islands. The third processing of the input map uses the following algorithm :

$$\text{Fire Hazard Map} = ([0.4 * \text{Land use Map}] + [0.3 * \text{Soil Map}] + [0.3 * \text{Topographic Map}])$$

After the results are obtained, the next process is reclassification. Where this reclassification is done to classify / explain the value of vulnerability classes from not vulnerable, somewhat vulnerable, enough to very vulnerable. As for each class of vulnerability with the range of values used in this study is represented in Table 2.

Table 2. Weighting of forest and land fire vulnerable map

No	Vulnerable Class	Class
1	Not Vulnerable	≤ 190
2	Rather Vulnerable	191 - 290
3	Enough Vulnerable	291 - 425
4	Very Vulnerable	426 - 500

Source : Forestry Departement of South Sumatera Province with Modification

To test the accuracy of mapping results of fire and land vulnerable area, used the hotspot data identified by MODIS (Terra & Aqua) satellites with a

confidence level of ≥ 80% during the last 10 years (2006-2015) in the Sumatera and Kalimantan islands. This accuracy test is done by calculating the number /percentage of hotspots in each class vulnerability of forest and land fire vulnerable map in the Sumatera and Kalimantan islands. With this accuracy test will be able to know how accurate mapping results of fire and land vulnerable area in the region of Sumatera and Kalimantan is produced in this study.

After completion of processing fire and land vulnerable area map then analyzed the distribution and extent of fire and land vulnerable area in Sumatera and Kalimantan islands.

3. Results and Discussion

3.1. Data Input Preparation

There are at least three data input that need to be prepared to be able to mapping the forest and land fire vulnerable area, that are Land Use Map, Soil Map and Topography Map. In this study Land Use data in Sumatera and Kalimantan Islands is obtained from Greenpeace's Kepo Hutan site, while the physical data like soil and slope / topography is obtained from Agricultural Resources Research and Development Center, Ministry of Agriculture of Indonesia.

Soil Map Sumatera and Kalimantan Islands as one of the input data in mapping of forest and land vulnerable areas is represented in Figure 1. Based on Soil Map. it can be known that the peatland distribution on Sumatera Island is the most dominant in Riau Province, South Sumatera, and Jambi. While on Kalimantan island, the most dominant peatland distribution is in the provinces of Central Kalimantan and West Kalimantan.

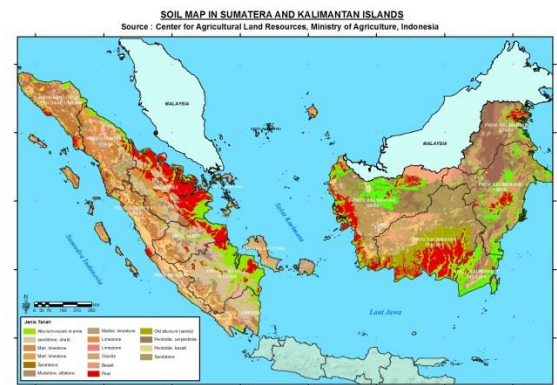


Figure 1. Soil Map on the Sumatera and Kalimantan Islands

Therefore, for several decades provinces in Sumatera and Kalimantan Island that have extensive peatland, especially Riau, Jambi, South Sumatera, Central Kalimantan and West Kalimantan become subscriptions forest and land fire disaster almost every year during the dry season. The existence of land clearing activities both for agriculture or plantation and also the canalization that makes the peatland to dry faster causes the peatlands on Sumatera and Kalimantan Islands is a very vulnerable to burn.

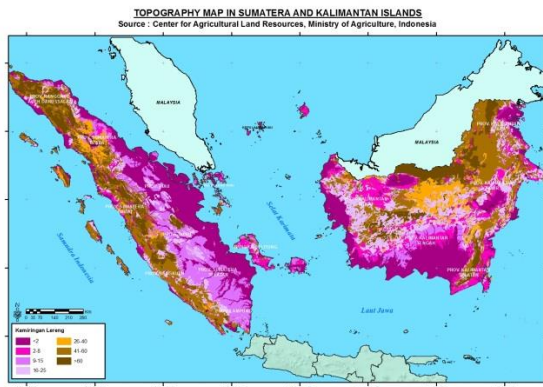


Figure 2. Slope Map of Sumatra and Kalimantan Islands

Topography Map of Sumatra Island and Kalimantan Island is represented in Figure 2. Where peatland areas in Sumatra Island and Kalimantan tend to be in areas with slope $< 2^\circ$ and altitude < 30 msl. This region is dominant in the east coast of Sumatra Island as well as the South and West of Kalimantan Island. The provinces of Central Kalimantan and Riau Province have the highest slope $< 2^\circ$ area, in proportion to the large areas of peatland in both provinces.

The Land Use Map on Sumatra Island and Kalimantan Islands as well as one of the input data in mapping of forest and land vulnerable areas is represented in Figure 3. Based on the Land Use Map, it can be seen that most of the peatland areas in Sumatra island have been changed into Industrial Plantation Forest (HTI), while the area of peatlands in Kalimantan Island, especially in the province of Central Kalimantan has not change. The conversion of these peatlands has resulted in enormous environmental impacts, including the occurrence of forest and land fire, degradation of groundwater reserves and the depletion of carbon stocks in the peatlands into the atmosphere in considerable numbers.

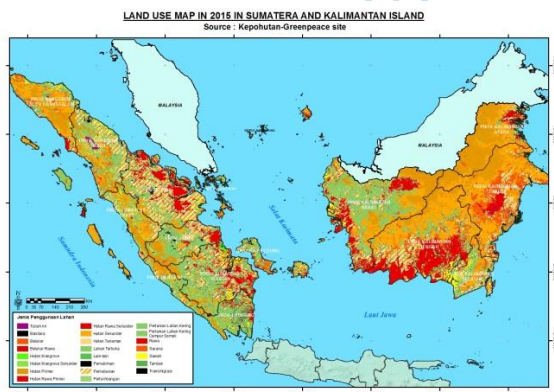


Figure 3. Land Use Map Sumatra and Kalimantan Islands in 2015

3.2. Spatial Mapping Forest and Land Fire Vulnerable Area

Mapping of Forest and Land Fire Vulnerable Area using input data that has been made in the previous stages. The input data includes Soil Map, Topography Map and Land Use Map of Sumatra and Kalimantan Islands. The results of the mapping

Forest and Land Fire Vulnerable Area in Sumatra and Kalimantan islands are represented in Figure 4.

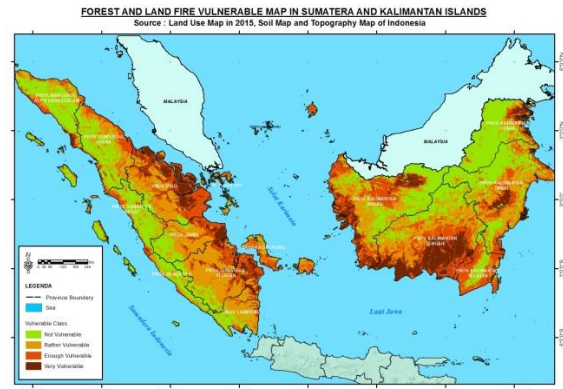


Figure 4. Forest and Land Fires Vulnerable Map in Sumatra and Kalimantan Islands

Forest and land fires vulnerable map is classified into 4 classes, that is areas are not vulnerable, rather vulnerable, enough vulnerable, and the area is very vulnerable to forest and land fire incident. Generally from the map can be seen that the area is very vulnerable to forest and land fire incident in Sumatra Island mostly found in Riau Province, South Sumatra Province, and Jambi Province. While on Kalimantan Island areas that is very vulnerable to the incidence of forest and land fire mostly located in the provinces of Central Kalimantan and West Kalimantan.

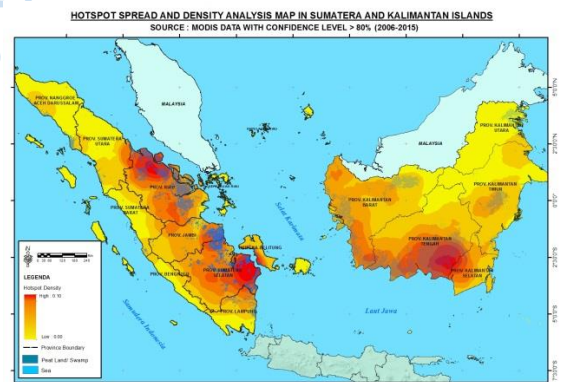


Figure 5. Hotspot Spread and Density Analysis Map in Sumatra and Kalimantan Islands in 2006-2015

Based on Figure 4 that showing the mapping of forest and land fire vulnerable area in Sumatra and Kalimantan islands, it is known that there is uniformity with the pattern of spread and density of hotspot referring to the historical data from MODIS Terra & Aqua data with an accuracy level $\geq 80\%$ in Sumatra and Kalimantan Island for 10 years (2006-2015) which is represented in Figure 5. The darker region on the map (Figure 5) means the more dense the hotspot in the area historically. For Kalimantan Island, areas with high hotspot density are located in the central zone to the south of Central Kalimantan Province and parts of West and South West Kalimantan Province. While the East coast of Riau Province, South Sumatra, and Jambi is a zone with high density hotspot in Sumatra Island. The similarity of the spatial distribution pattern between forest and land fire vulnerable map (Figure 4) and map of spread and density of hotspot

(Figure 5) indicates that the distribution pattern of forest and land fire vulnerable areas is in conformity with the historical patterns of spread and density hotspots in Sumatra and Kalimantan islands.

3.3. Mapping Accuracy Test

The mapping accuracy test was conducted to find out how accurate the forest and land fire vulnerable map in the Sumatra and Kalimantan Islands was generated in this study. The result of accuracy test forest and land fire vulnerable map in Sumatra Island is represented in Table 3. From Table 3, it can be seen that the percentage the number of hotspots found in the not vulnerable areas is 4%, the percentage the number of hotspots in the rather vulnerable is 22% and the percentage the number of hotspots in the area is enough vulnerable to very vulnerable is 74%. Based on the results of this accuracy test can be seen that the forest and land fire vulnerable in Sumatra Island produced in this study has a relatively good level of accuracy and representative with the spread and density of hotspots in Sumatra Island during the last 10 years (2006-2015).

Table 3. Percentage number of hotspots over the last 10 years (2006-2015) at each level of vulnerability of forest and land fire in Sumatra Island

No	Forest an Land Fire Vulnerable Level	Hotspot Count	Percentage (%)
1	Not Vulnerable	3.638	4%
2	Rather Vulnerable	19.066	22%
3	Enough Vulnerable	29.429	34%
4	Very Vulnerable	34.995	40%
Total		87.128	100%

Source : Data Processing

The result of accuracy test forest and land fire vulnerable map in Kalimantan Island is represented in Table 4. From Table 4, it can be seen that the percentage the number of hotspots found in the not vulnerable areas is 6%, the percentage the number of hotspots found in the rather vulnerable areas is 20% and the percentage the number of hotspot in the area is enough vulnerable to very vulnerable is 74%. Based on the results of this accuracy test can be seen that the forest and land fire vulnerable in Kalimantan Island area produced in this study also has a relatively good level of accuracy and representative with the spread and density of hotspots in Kalimantan island during the last 10 years (2006- 2015).

Table 4. Percentage number of hotspots over the last 10 years (2006-2015) at each level of vulnerability of forest and land fire in Kalimantan Island

No	Forest an Land Fire Vulnerable Level	Hotspot Count	Percentage (%)
1	Not Vulnerable	4.204	6%
2	Rather Vulnerable	14.939	20%
3	Enough Vulnerable	25.569	35%

No	Forest an Land Fire Vulnerable Level	Hotspot Count	Percentage (%)
4	Very Vulnerable	29.017	39%
Total		73.729	100%

Source : Data Processing

Based on the results of accuracy tests forest and land fire vulnerable map both in Sumatra and Kalimantan island, can be known both have a good level of mapping accuracy test. So based on this can be seen that mapping methods of forest and land fire vulnerable area in South Sumatra Province developed by the Forest Service of South Sumatra Province in cooperation with the German Government are also quite accurately applied in other provinces in the Sumatra and Kalimantan island. The existence of similarity characteristics of physical condition of land especially in East Coast of Sumatra Island with West Coast and South Kalimantan Island make mapping method of forest and land fire vulnerable area in South Sumatra Province region is also quite accurate applied in Sumatra and Kalimantan island in general.

3.4. Analysis of Forest and Land Fire Vulnerable Map

Based on the results of mapping of forest and land fire vulnerable areas it can be seen that areas is enough vulnerable to very vulnerable to forest and land fire tend to be in the peat soil with slope < 2°, altitude < 30 msl and with the land use is swamp forest, primary swamp forest/ secondary, shrubs and dryland farms mix shrubs.

The tables of wide each vulnerable class of forest and land fire in the Sumatra Island Province that are often disrupted by karhutla disaster are represented in Table 5. From Table 5 can be seen in Sumatra Island which has the most vulnerable from forest and land fire that is Riau Province, followed by South Sumatra Province and Province Jambi. Riau Province has an area that is enough vulnerable from forest and land fire incident 30,692.56 km² and a very vulnerable area 22.598.73 km². Forest and land fire vulnerable area in Riau Province are mostly in Bengkalis, Indragiri Hilir and Pelalawan regency. The province of South Sumatra has an area that is enough vulnerable from forest and land fire incident 18,956.80 km² and a very vulnerable area 12,593.85 km². Forest and land fire vulnerable area in South Sumatra Province are mostly in Ogan Komering Ilir, Banyuasin, and Musibanyuasin regency. While Jambi Province has an area that is enough vulnerable from forest and land fire incident 8,823.75 km² and a very vulnerable area 5,031.61 km². The forest and land fire vulnerable area in Jambi Province are mostly located in East Tanjungjabung, Muarojambi and Tanjungjabung Barat regency.

Table 5. The wide each vulnerable class of forest and land fire in the Sumatra Island Province that often occurs karhutla disaster

Province	Vulnerability Class	Area (Km ²)
RIAU	Not Vulnerable	8.102,63

Province	Vulnerability Class	Area (Km ²)
	Rather Vulnerable	28.367,81
	Enough Vulnerable	30.692,56
	Very Vulnerable	22.598,73
SUMSEL	Not Vulnerable	12.608,77
	Rather Vulnerable	42.168,16
	Enough Vulnerable	18.956,80
	Very Vulnerable	12.593,85
JAMBI	Not Vulnerable	12.851,47
	Rather Vulnerable	22.472,01
	Enough Vulnerable	8.823,75
	Very Vulnerable	5.031,61

Source : Data Processing

Table 6. The wide each vulnerable class of forest and land fire in the Kalimantan Island Province that often occurs karhutla disaster

Province	Vulnerability Class	Area (Km ²)
KALTENG	Not Vulnerable	31.214,16
	Rather Vulnerable	47.825,18
	Enough Vulnerable	36.438,04
	Very Vulnerable	41.609,57
KALBAR	Not Vulnerable	50.833,06
	Rather Vulnerable	38.657,99
	Enough Vulnerable	39.268,85
	Very Vulnerable	19.507,77
KALSEL	Not Vulnerable	9.239,80
	Rather Vulnerable	6.383,94
	Enough Vulnerable	20.547,70
	Very Vulnerable	1.850,31

Source : Data Processing

The tables of wide each vulnerable class of forest and land fire in the Kalimantan Island Province that are often disrupted by karhutla disaster are represented in in Table 6. From Table 6 can be seen in Kalimantan Island which has the most vulnerable from forest and land fire that is Central Kalimantan Province, followed by West Kalimantan Province and Province South Kalimantan. The province of Central Kalimantan has an area that is enough vulnerable 36,438.04 km² and a very vulnerable area 41,609.57 km². Forest and land fire vulnerable area in Central Kalimantan Province are mostly located in Katingan, Pulangpisau and Kapuas regency. West Kalimantan province has an area that is enough vulnerable from forest and land fire incident 39,268.85 km² and a very vulnerable area 19,507.77 km². Forest and land fire vulnerable area in the Province of West Kalimantan are mostly in Ketapang, Kapuas Hulu and Kuburaya regency. While South Kalimantan Province which is also often happened forest and land fire disaster has area which is enough

vulnerable 20,547,70 km² and area which is very vulnerable 1,850,31 km². Forest and land fire vulnerable area in South Kalimantan Province are mostly in Kotabaru, Tanahbumbu and Tanahlaut regency.

4. Conclusion

The result mapping of forest and land fire vulnerable based on physical parameters in Sumatera and Kalimantan island resulting from this research has pattern uniformity with spread and density of hotspots in Sumatera and Kalimantan Islands for the last 10 years (2006-2015). This is reinforced by the results of the accuracy test, where the percentage of the number of hotspots during the last 10 years in Sumatra and Kalimantan island in the area is enough vulnerable to very vulnerable to forest and land fire of 74%.

Based on the results of forest and land fire vulnerable mapping can be seen that areas that have enough to very vulnerability to forest and land fire tend to be in the peat soil with slope < 2°, altitude < 30 msl and with the land use of swamp forest, swamp forest primary /secondary, shrubs and dryland farms mix shrubs.

Based on the results of forest and land fire vulnerable mapping in general can be seen that areas that are very vulnerable to forest and land fire in Sumatra island are mostly found in Riau Province (Bengkalis, Indragiri Hilir and Pelalawan Regency), South Sumatera (Ogan Komering Ilir, Banyuasin and Musibanyuasin Regency) and Jambi (East Tanjungjabung, Muarojambi and Tanjungjabung Barat Regency). While in Kalimantan island, the areas that are very vulnerable to forest and land fire are mostly located in Central Kalimantan Province (Katingan, Pulangpisau and Kapuas Regency) and West Kalimantan (Ketapang, Kapuas Hulu and Kuburaya Regency).

The results of this research can be used as the basis for making early warning system of forest and land fire on a national scale in provinces in Indonesia that are vulnerable to forest and land fire. The early warning system can be used as a reference policy making by Ministries /Institutions, private sector and parties involved in the handling of forest and land fire disaster and peatland management in Indonesia.

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