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Forest Fire Vulnerability Mapping in Way Kambas National Park

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Abstract

In tropical area, especially in Sumatra Island, shifting cultivation is dominant agricultural system. The farmer used to use fire during land preparation as a strategy to overcome labor shortage. Forest fire has been given special attention due to its impact to the environment. It sources of greenhouse gases emission, ecosystem degradation, and wildlife extinction. Once forest fire occur especially on sensitive area, it is very difficult to be stop. Under such situation, conducting preventive action would be more effective. Mitigation and action through forest fire early warning systems were required in Way Kambas National Park (WKNP). To support it, geographic information system and remote sensing can be applied to develop a fire vulnerability map. The object of the research was to develop fire vulnerability map, based on bio- physical and human disturbance factors. The map was based on the local bio-physical condition, namely land cover, vegetation index, moisture index, and land surface temperature. Human disturbance was determined based on distance, namely center of community activities, and distance from accessibilities. After the variables were scored and weighted, the overlaid map presents the locations with high, medium, and low vulnerability classes. The validation of the model was done using the forest fire occurrence point data.

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Keywords: forest fire; geographical information system; remote sensing; vulnerability; Way Kambas National Park

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1. Introduction

Way Kambas National Park is the largest representative of lowland forest in Sumatra [1, 2]. Five of conservation priority wildlife species live in WKNP, namely Sumatran Tiger, Sumatran Rhino, Sumatran Elephant, Tapir, and Malayan Sunbear. There are also many other important wildlife, such as White-winged Duck, Pheasants, Great Argus, Siamang, Sumatran Leaf-monkey, while examples of flora are Gaharu, Mahang, Nepenthes, etc.

In addition to having excellent existing potentials, based on SWOT analysis approach conducted by the park manager, WKNP also are facing various threats. One of the threats that are faced by the park is related to bio-physical condition of the park, namely forest fires due to dry land and high level of water pollution [3]. Forest fires occur every year in this park. Forest fires occur at a higher intensity in the dry season [4, 5, 6]. Forest fire causes damages to forest; therefore mitigation and adaptation activities are required. This is also related to government policies that prioritize the issue of forest fires [7].

Geographical information system and remote sensing have long been applied to create forest fire vulnerability map. Forest fire vulnerability map is a spatial model used to picture field condition that is related to risk of forest fire [5]. Through this map, activities of monitoring and prevention of forest fire can be conducted as early as possible. Forest fire vulnerability map is created by formulating forest fire factors. Several methods have been formulated to determine level of forest fire vulnerability. However, when they are applied to different locations, the accuracy is questionable due to different local conditions. Therefore, there is a need of a research on mapping levels of forest fire vulnerability in WKNP based on a formulation that is in accordance with local condition in WKNP.

2. Data and Methods

The study area is located in Lampung Province and covers an area of 125 621.3 ha (Fig. 1). As a national park, WKNP divided into 12 resort management. Every resort surrounded by bio-physical boundary. At all the WKNP was surrounded by sea, river, and canal. There were settlement, big plantation, and agricultural land around the national park.

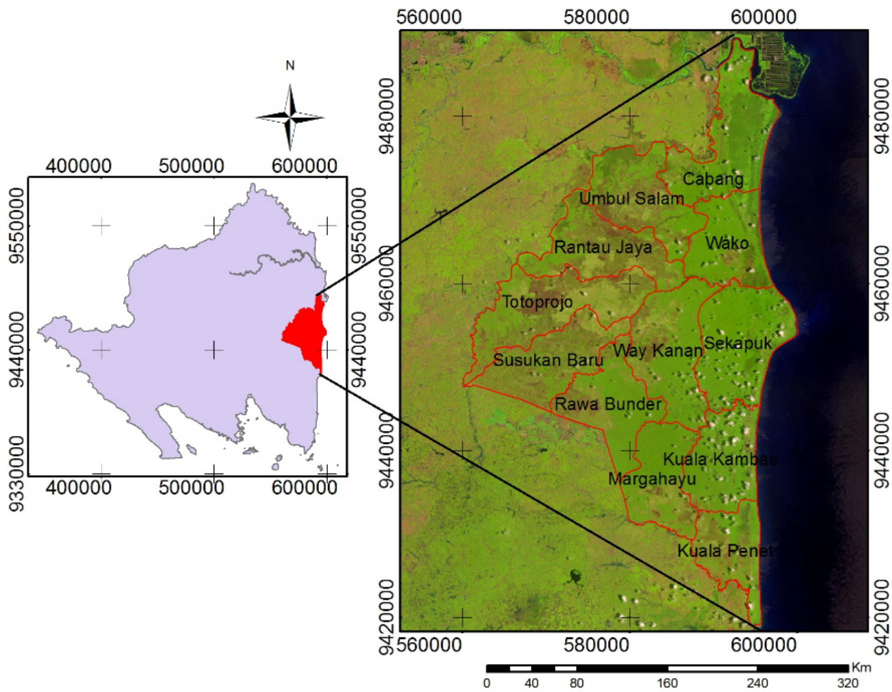

Fig. 1. Study location.

Data that used in this study collected from Landsat 8 image interpretaiton and completed by ground checking and secondary data. The Landsat used in this study was acquisited on October 2013, and the groundchecking was done on January-March 2015. Based on ground observation and interview result, there were determined factors that responsible for forest fires in the study area.

Factors that are used as variables include land cover, vegetation index, moisture index, surface temperature, distance from road, distance from river, distance from settlement, distance from paddy field, distance from dry land farm, and distance from plantation. The way of this determination of fire refers to the concept of fire triangle as described in Adinugroho et al. [8] that the combustion process occurs because of the presence of heat source (fire) as an igniter, available fuel, and oxygen in a simultaneous manner. Factors that are used in this study as variables to determine the formula of vulnerability of forest fire is the representation of the fire triangle.

The analysis of each variables were done using ArcGIS and Erdas Imagine software. After the data was analyzed and thematic maps from each variable were produced. Scores were given to each variable that was classified into each characteristic according to litterature review. Table 1 present the scoring of the variables.

In this study it was assumed that some variables have a higher influence on forest fire than others. It can be seen on Table 2 that present the characteristic of each variables on forest fire occurence points in WKNP. Fire point was collected by national park manager from Firecast from 2011-2014 with total 522 points. Variables that influence to triggering forest fire were bio-physic factor category i.e. land cover, NDVI, and NDMI. It was a basis for give a high weight to these variables to determine the level of forest fire vulnerability.

In other site Rianawati [13], Itoyo [14], and Akbar et al. [15] has done the research and the result is the biggest factor that sparks forest fires in Indonesia is human activity. So the two different cases study of weighting were done. Equation 1 gives a high weighting (0.9) on human factor and 0.1 for natural factor and conversely, Equation 2 uses weights of 0.1 for human factor and 0.9 for natural factors.

$$y = 0.1 * (x1 + x2 + x3 + x4) + 0.9 * (x5 + x6 + x7 + x8 + x9 + x10) \quad (1)$$
$$y = 0.9 * (x1 + x2 + x3 + x4) + 0.1 * (x5 + x6 + x7 + x8 + x9 + x10) \quad (2)$$

Remarks:

y = Score of vulnerability of forest fire
x_1 = Land cover
x_2 = Surface temperature
x_3 = Normalized difference vegetation index (NDVI)
x_4 = Normalized difference moisture index (NDMI)
x_5 = Distance from road
x_6 = Distance from river
x_7 = Distance from settlement
x_8 = Distance from plantation
x_9 = Distance from dry land farm
x_{10} = Distance from paddy rice field

Variables were overlayed to define vulnerability to forest fire levels within the area. The forest area were classified into fire vulnerability classes: high, medium, and low vulnerability level based on total score (Table 3). Then, each fire vulnerability maps was compared with the actual area disturbed by the fire that present by forest fire occurence point. The agreement between the predicted high vulnerability area to forest fire and the actual burned area was assumed to be a validation test.

Table 1. Score of each variable.

Variable	Characteristic	Score	Vulnerability level	Literature
Land cover	Imperata grassland grass (dry)	5	Most vulnerable	Erten et al.[9]
	Forest (almost dry)	4	Vulnerable	
	Swamp forest (moist)	3	Moderate	
	Mangrove (moist)	3	Moderate	
	Swamp (almost wet)	2	Unvulnerable	
	Water body (wet)	1	Most unvulnerable	
NDVI	NDVI>0.35	5	Most vulnerable	Nurdiana and Risdiyanto [10]
	0.25<NDVI≤ 0.35	4	Vulnerable	
	0.15<NDVI≤ 0.25	3	Moderate	
	NDVI≤ 0.15	2	Unvulnerable	
NDMI	NDMI≤ 0.15	5	Most vulnerable	Nurdiana and Risdiyanto [10]
	0.15<NDMI≤ 0.25	4	Vulnerable	
	0.25<NDMI≤ 0.35	3	Moderate	
	NDMI>0.35	2	Unvulnerable	
Land surface temperature	Temperature>35 °C	5	Most vulnerable	Setyawan [11]
	30<Temperature≤35 °C	4	Vulnerable	
	25<Temperature≤30 °C	3	Moderate	
	20<Temperature≤ 25 °C	2	Unvulnerable	
	Temperature≤20 °C	1	Most unvulnerable	
Distance from road	Distance ≤100m	5	Most vulnerable	Jaiswal et al. [12]
	100m < Distance ≤ 200m	4	Vulnerable	
	200m < Distance ≤ 300m	3	Moderate	
	300m < Distance ≤ 400m	2	Unvulnerable	
	Distance > 400m	1	Most unvulnerable	
Distance from river	Distance ≤100m	5	Most vulnerable	Jaiswal et al. [12]
	100m < Distance ≤ 200m	4	Vulnerable	
	200m < Distance ≤ 300m	3	Moderate	
	300m < Distance ≤ 400m	2	Unvulnerable	
	Distance > 400m	1	Most unvulnerable	
Distance from cropland	Distance ≤1000m	5	Most vulnerable	Erten et al. [9]
	1000m < Distance ≤ 2000m	4	Vulnerable	
	2000m < Distance ≤ 3000m	3	Moderate	
	Distance > 3000m	2	Unvulnerable	
Distance from plantation	Distance ≤1000m	5	Most vulnerable	Erten et al. [9]
	1000m < Distance ≤ 2000m	4	Vulnerable	
	2000m < Distance ≤ 3000m	3	Moderate	
	Distance > 3000m	2	Unvulnerable	
Distance from rice field	Distance ≤1000m	5	Most vulnerable	Erten et al. [9]
	1000m < Distance ≤ 2000m	4	Vulnerable	
	2000m < Distance ≤ 3000m	3	Moderate	
	Distance > 3000m	2	Unvulnerable	
Distance from settlement	Distance ≤1000m	5	Most vulnerable	Erten et al. [9]
	1000m < Distance ≤ 2000m	4	Vulnerable	
	2000m < Distance ≤ 3000m	3	Moderate	
	Distance > 3000m	2	Unvulnerable	

Table 2. Characteristic of variable on fire point.

Human Factors		Bio-physic Factors	
Variable	Total of Fire Point	Variable	Total of Fire Point
Distance from Road		Land Cover	
≤100m	65	Imperata grassland	361
100m - 200m	83	Dry land forest	81
200m - 300m	28	Swamp forest	21
300m - 400m	72	Swamp	37
Distance from River		Land Surface Temperature	
≤100m	0	20-25	334
100m - 200m	1	<20	166
200m - 300m	2	NDVI	
300m - 400m	2	≤ 0.15	215
Distance from Settlement		0.15 - 0.25	241
≤1000m	3	0.25 - 0.35	43
1000m - 2000m	29	> 0.35	1
2000m - 3000m	40	NDMI	
> 3000m	450	> 0.35	330
Distance from Paddy Field		0.25 - 0.35	114
≤1000m	5	0.15 - 0.25	56
1000m - 2000m	43		
2000m - 3000m	43		
> 3000m	431		
Distance from Plantation			
≤1000m	4		
1000m - 2000m	9		
2000m - 3000m	13		
> 3000m	496		
Distance from Dry Crop Land			
≤1000m	5		
1000m - 2000m	17		
2000m - 3000m	22		
> 3000m	478		

Table 3. Level of forest fire vulnerability.

y Score	Vulnerability Level
$y_{min} \leq y < (\bar{y} - ½SD)$	High
$(\bar{y} - ½SD) \leq y < (\bar{y} + ½SD)$	Medium
$y \geq (\bar{y} + ½SD)$	Low

3. Results and Discussion

3.1. Land cover of WKNP

Types of land cover present available fuel for fire [16]. Land cover classes are distinguished by levels of dryness of vegetation constituents which refers to Erten et al. [9], namely Imperata grassland grass, forest, swamp forest, mangroves, swamps and water bodies. Classification was done by using a supervised classification with maximum likelihood classification method. The classification produce the not classified/unclassified pixel, cloud, and cloud shadows class. These make hole on the map. These class also use in other map (land surface temperature, NDVI, and NDMI), so these not analyzed. The overall classification accuracy value od the classification is 95.17%, that mean the classification can be received [17].

Land cover of WKNP was dominated by dry land forest (Fig. 2). Since 1996 forest cover in WKNP has been the highest proportion, but the area was reduced [18]. It caused by land cover change in WKNP that reached 51 657.3 ha on 2002-2010 [18]. The decreasing area of forest cover followed by increasing of Imperata grassland area. From the classification result the forest cover 45% of WKNP area and Imperata grassland 33%. When the forest is damaged, Imperata grassland grassland will grow to replace it [19].

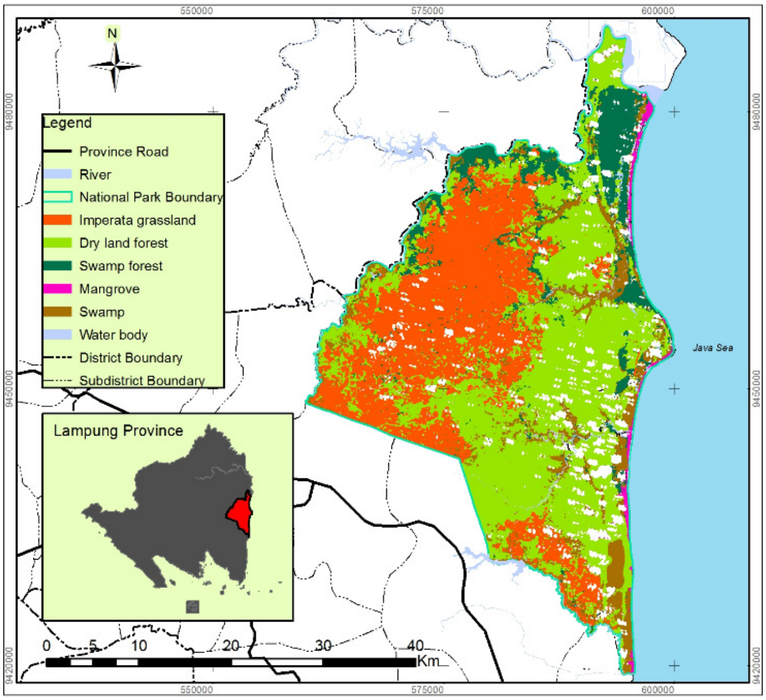

Fig. 2. Presentation of land cover of Way Kambas National Park.

3.2. Land surface temperature of WKNP

Land surface temperature is a good indicator associated with water content of a fuel [10]. Surface temperature of WKNP is from 16–26°C and most under 25°C (Fig. 3.). Its distribution is influenced by the condition of topography which is fairly flat. Vlassova et al. [20] stated that the surface temperature is influenced by topography that determines the angle of solar radiation.

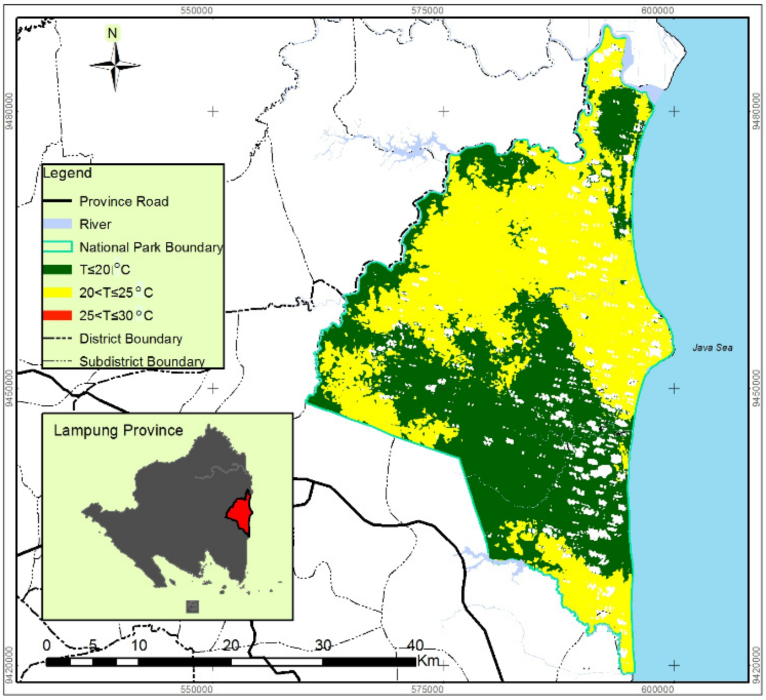

Fig. 3. Distribution of surface temperature in Way Kambas National Park.

3.3. Normalized Difference Vegetation Index (NDVI) of WKNP

Vegetation index is a representation of the level of greenness of vegetation and litter [21]. NDVI values range between -1 and 1. The condition of low vegetation index causes fire [22]. Resulted from image analysis, WKNP area has a highest NDVI value 0.56. Most of WKNP area has NDVI value above 0.35 (Fig. 4.).

3.4. Normalized Difference Moisture Index (NDMI) of WKNP

Normalized moisture index show the moisture level of vegetation [23]. Jin et. al [24] used it for detecting forest type and intensity disturbance in biomes. By the Sahu [25] research result the high value of NDMI indicates the existence of more soil moisture and the contrary lower value denote low soil moisture. The value of NDMI is about -1 to 1. Negative value show the moisture of non vegetation. The highest NDMI value of WKNP is 0.4 (Fig. 5).

3.5. Distance from access and center of community activities

The risk of forest fire is directly proportional to the intensity of human activity in and around the forest area [16]. The closer the forest to areas with intensive human activity, the more prone it is to forest fire. Erten et al. [9] also explained that forests near settlements are prone to fires.

Distance from accessibilities includes distance from roads and distance from rivers. The limit which is used as the longest distance to the access was 400 m. For distance from center of human activities (settlement, paddy fields, plantation, and dry land farm) the limit was 3 000 m. The determination of these limits is made by referring to Erten et al. [9] and is adapted to conditions at the field. Most of WKNP area included to far from accessibilties and human activities center category (Fig. 6.).

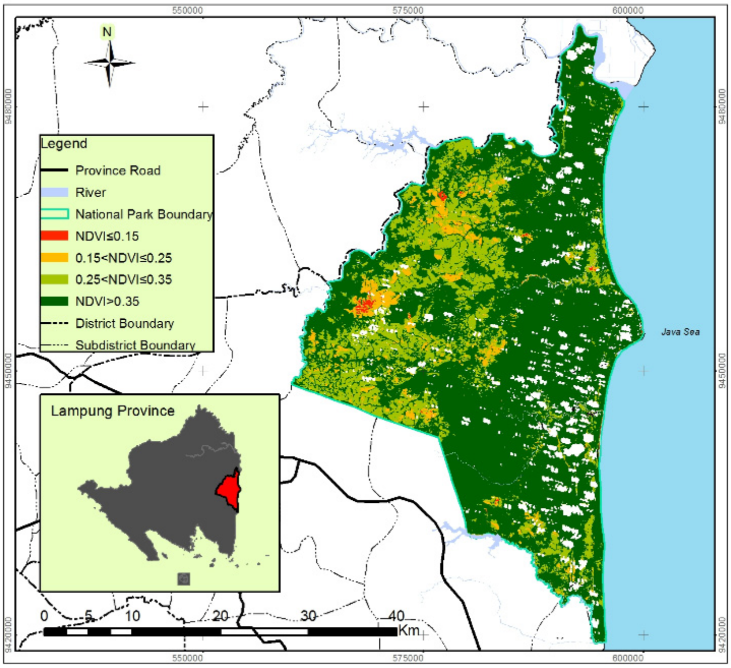

Fig. 4. Distribution of vegetation index value in Way Kambas National Park.

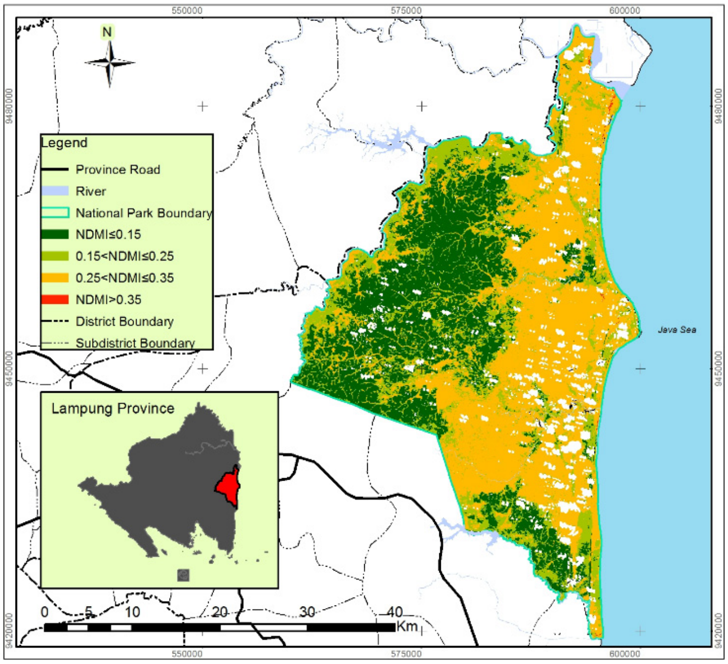

Fig. 5. Distribution of moisture index value in Way Kambas National Park.

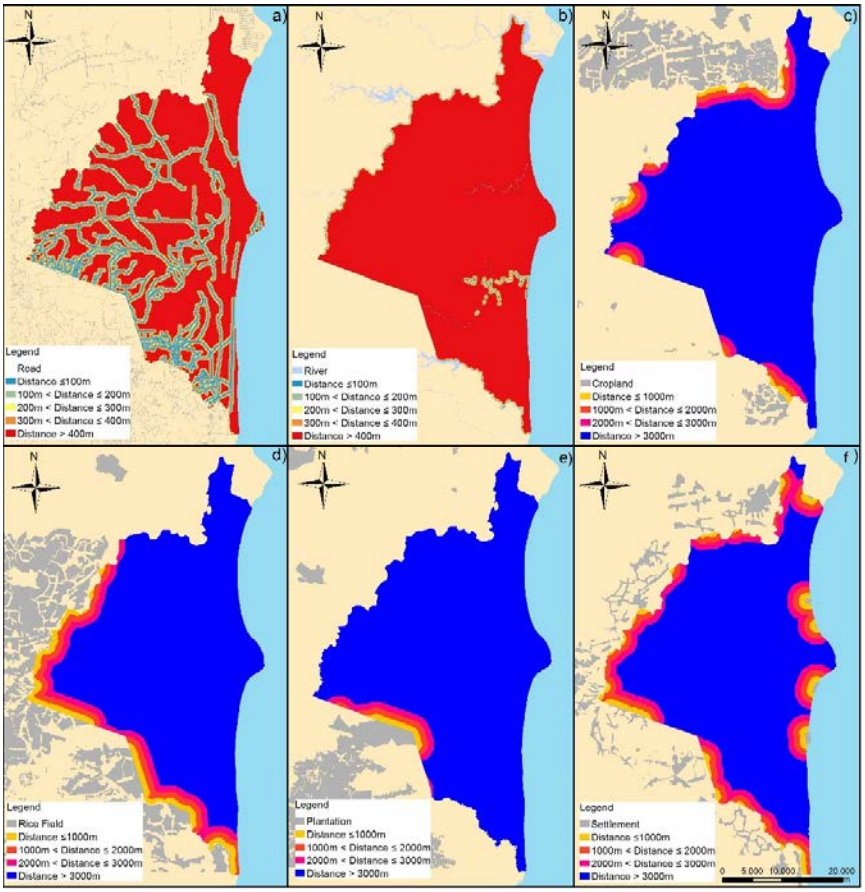

Fig. 6. Distance from access and center of community activities: (a) road, (b) river, (c) dry land farm, (d) paddy field, (e) plantation, (f) settlement.

Road accesses in this research include roads outside the park, the park's main road, and patrol roads and other lanes used by perpetrators of illegal activities. Historically, in 1999 before it was designated as a national park, this area had been designated as a nature conservation area since the Dutch colonial era. However, in the period of 1974–1968 the area suffered a fairly severe damage as a consequence of the opening of this area for forest concessions (HPH). There were three large concessions which had completed their licenses in 1972, but their operations still continued illegally. The concessions activities had left the area in a bare condition so that it was easily covered with Imperata grassland and also a network of roads. The road network was then used by forest police patrols and partners of the national park. Besides it was also utilized by perpetrators of illegal activities.

River accesses are major rivers in the park and those that situated as boundaries with the park's buffer villages. The three rivers flow into Java Sea, thus they are not utilized only by people of the park and the community from the park's buffer villages but also by fishermen from other places in the area who stop by the park. Historically, the big rivers (especially Way Pegadungan River) were used not only by the fishermen but also by the people who transport illegal logs.

In the era when forest encroachment was still conducted by forest concession companies, the park was also encroached by local indigenous people who claimed the area as their customary land. The local community established settlements with a population of more than 2 000 inhabitants in the park area. The residents built homes and farms to form a village, and in the end they were translocated in 1984. But efforts to clear out the area from human population took a long process which was until 2000. Even for the settlement of fishermen on the coast, the removal was completed in as late as 2010. And even, the fishermen settlement has been rebuilt up until now despite it was burnt in

2010.This fishermen settlement furthermore is incorporated in the assessment of factor of distance from settlement other than the community settlement in 37 buffer villages.

In the vicinity of human settlements there are paddy fields, dry land farms and plantations. The plantations include PT Nusantara Tropical Fruit at the park's border and local community's gardens which are generally covered with rubber vegetation. In addition to settlements, the paddy fields, dry land farms, and plantations also become the center of community activity because most of the villagers are farmers.

3.6. Vulnerability of forest fire in WKNP

Result of analysis by using Equation 1 that give a high weight for human disturbance factors shows that 5 024.9 ha of WKNP area (4%) has a high level of vulnerability to forest fires, 8 793.5 ha (7%) medium vulnerability level, and 111 803 ha (89%) low (Fig. 7.). Results of validation shows that 470 points located in low vulnerability class (90%), 33 points in medium vulnerability class (6%) and only 19 points (4%) located in a high level of vulnerability class.

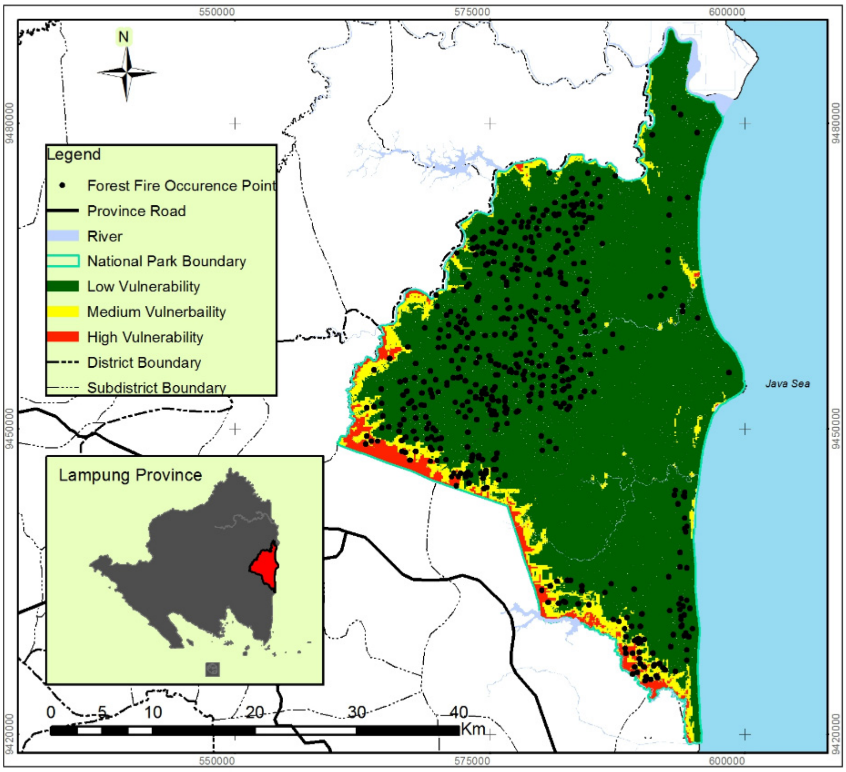

Fig. 7. Map of vulnerability to forest fire based on Equation 1.

Results of mapping vulnerability of forest fires by using Equation 1 and Equation 2 are contrasting. Result of analysis by using Equation 2 that use a high weight for bio-physic factors shows that 42,711.2 ha of WKNP area (34%) has a high level of vulnerability to forest fires, 65,323.1 ha (52%) medium, and 16,330.8 ha (13%) low (Fig. 8.). The validation results show that 381 fire points located in a high level of vulnerability to fire (73%), 95 points in medium level (18%) and the lowest 46 points are in locations where the level of vulnerability to fire is low (9%).

Based on the map using Equation 2, WKNP has high to medium level of vulnerability to forest fire. There were 5 resorts with high vulnerability, namely Umbul Salam, Rantau Jaya, Totoprojo, and Susukan Baru. High weight that used in Equation 2 depict the high influence of bio-physic factors to forest fire. Table 4 present the dominant bio-physic characteristic of each resorts.

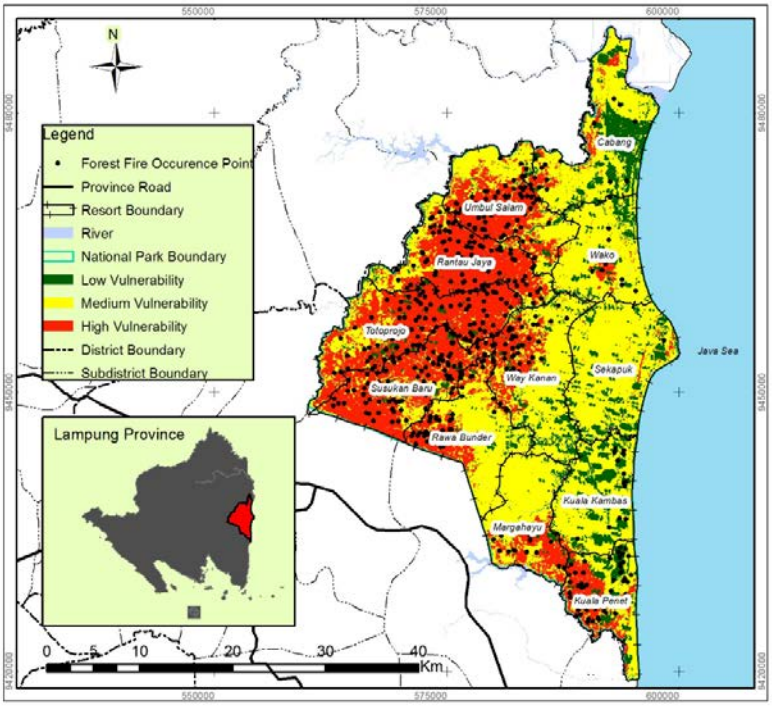

Fig. 8. Map of vulnerability to forest fire based on Equation 2.

Table 4. Characteristic of resorts in WKNP.

Resort	Level of Vulnerability	Dominant Bio-physic Characteristic
SPTN I Way Kanan		
Wako	Medium	Dry land forest, surface temperature 20-25 °C, NDMI 0.25-0.35, NDVI >0.35
Way Kanan	Medium	Dry land forest, surface temperature <20°C, NDMI 0.25-0.35, NDVI >0.35
Rawa Bunder	Medium	Dry land forest, surface temperature <20°C, NDMI 0.25-0.35, NDVI >0.35
Susukan Baru	High	Imperata grassland, surface temperature <20°C, NDMI <0.15, NDVI 0.25-0.35
SPTN II Bungur		
Cabang	Medium	Swamp forest, sureface temperature 20-25 °C, NDMI 0.25-0.35, NDVI >0.35
Umbul Salam	High	Imperata grassland,surface temperature 20-25 °C, NDMI ≤0.15, NDVI >0.35
Rantau Jaya	High	Imperata grassland, surface temperature 20-25 °C, NDMI ≤0.15, NDVI >0.35
Totoprojo	High	Imperata grassland, surface temperature 20-25 °C, NDMI ≤0.15, NDVI >0.35
SPTN III Kuala Penet		
Sekapuk	Medium	Dry land forest, surface temperature 20-25 °C, NDMI 0.25-0.35, NDVI >0.35
Kuala Kambas	Medium	Dry land forest, surface temperature <20°C , NDMI 0.25-0.35, NDVI >0.35
Kuala Penet	Medium	Swamp, surface temperature 20-25 °C , NDMI 0.15-0.25, NDVI >0.35
Margahayu	Medium	Dry land forest, surface temperature <20°C , NDMI 0.25-0.35, NDVI >0.35

All resorts with high vulnerability to forest fire dominate wit Imperata grassland landcover. Research results of Saharjo and Watanabe (1997) as presented in Septicorini [26] showed that the Imperata grassland is a fuel material with lowest content of silica-free ash. This means that the Imperata grassland is a fuel material that is very easy to be burnt compared to others such as shrubs and tree species.

Imperata grassland also grows in previously opened land where there are road networks. The road network facilitates the perpetrators of illegal activities in WKNP to operate and trigger a fire which is supported by the highly flammable condition of Imperata grassland. As stated by Schindler *et al*. (1989) in the FWI [27] that forests that have been logged, which are degraded and overgrown by bushes, are far more vulnerable to fire than natural tropical rain forests. It is evident also from reports of forest police patrol of WKNP that illegal hunters burn Imperata grassland for attracting wildlife (especially deer and hare). The burning of Imperata grassland will later trigger the growth of new vegetation which is favoured by the wildlife, so the wildlife will come to feed on young shoots [28]. This will makes it easier for the hunters to hunt the wildlife.

Surface temperature, NDVI and NDMI have not realy specific. Research results of Vlassova et al. [20] showed that all categories of fire severity have average surface temperature of 30 °C, the higher severity of fires occurred at high surface temperatures and low NDVI. These variabels influent by the image condition that also influent by climate factor. Landsat image that used in this study was acquisited on October 2013, which is categorized as wet month based on rainfall data (Fig. 9).

But even there is little atmosphere disturbance, the validation of the vulnerability classification using Equation 2 was good (73%). It does not affect as stated by Syaufina and Sukmana [29] that the climatological conditions only give a slight influence on the fire. The surface temperature is a climatic factor that is analyzed from the image. Even using another climate data, such as intensity of rainfall per month, these factors didn’t exhibit substantial influence. There is a prediction if better image that acquisite on dry month would show the better classification of vulnerability to forest fire in WKNP.

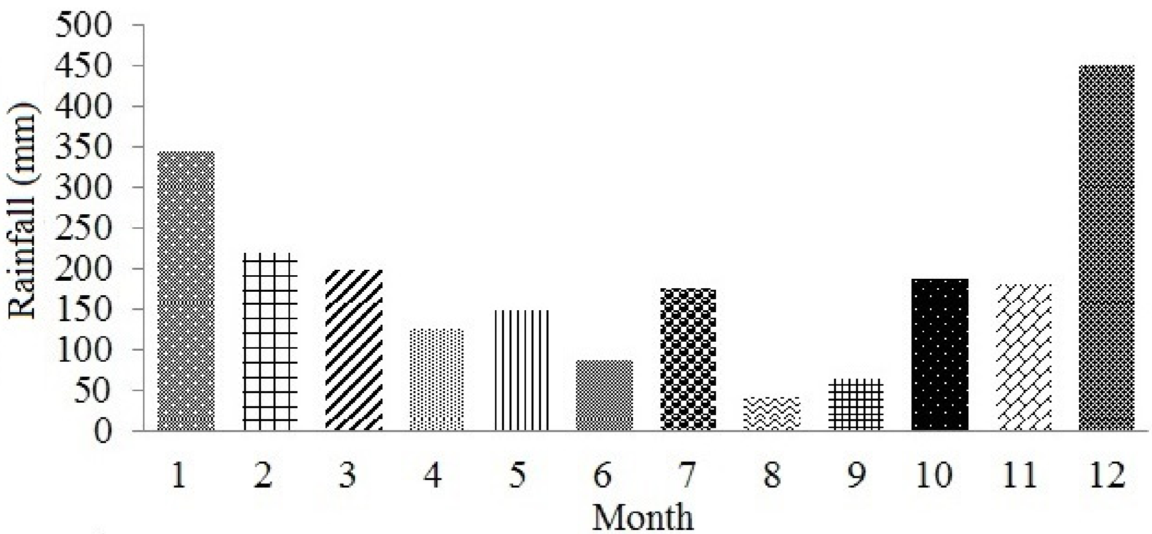

Fig. 9. Way Kambas National Park monthly rainfall on 2013.

4. Conclusion

Until now the cause of forest fires is still a topic of debate [15]. Forest fire prevention strategy is unique and requires a study of the region in advance [30]. For WKNP, to map the vulnerability level of forest fire, Equation 2 can be used. The results of this study shows that in WKNP natural factor (availability of fuel material) has an important role in triggering the occurrence of forest fires caused by human activity, especially in dry seasons. Availability of access encourages people carrying out illegal activities in WKNP area. Not a few of those illegal activities ultimately trigger a forest fire. Management of fuel material in WKNP needs to be improved to prevent the occurrence of fire, especially in areas that have high levels of vulnerability to fire.

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