ASSESSMENT OF FIRE VULNERABILITY THROUGH HUMAN ACTIVITY BY USING ROAD DISTRIBUTION IN PEAT LAND OF INDONESIA

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ABSTRACT: Peat land is one of the largest CO2 emission source due to the fires and decomposition. Especially, tropical region has 10% of global peat soil. However, ground water table of tropical peat lands is decreased drastically by human activity for converting to agricultural use. Fire events on peat lands are continued for land clearance. Moreover, dryness of peat promotes fire occurrence. The objective of this study is to reveal vulnerability against fire of Indonesian peat lands by using analysis of relationship between location of fire and human accessibility. First of all, MOD14 of MODIS hotspot was used with method of extraction high temperature of surface. The loss of biomass is calculated by sum of above ground biomass and soil organic matter. Secondly, ground water table describing peat soil dryness was calculated by Keetch-Byram drought index (KBDI). Satellite-sensed data with precipitation (GSMaP) and land surface temperature (MTSAT) were used. Thirdly, vulnerability against fire is revealed by road distribution and detection of fire location. The reasons of fire are dryness of peat or human activity. This study investigated the distance to the road as an indicator of vulnerability peat area because human accessibility is considered as a possibility of fire. Finally, the reason of fire is classified by two cases. The one is natural reason such as dryness and the other is artificial way. In case of that the fire was occurred under drought condition and was far from road, it is considered to natural burning event caused by dryness. If fire was occurred even under moist condition and location was close from street, it is expected as human made fire. For reducing CO2 emission from peat lands of Indonesia, not only rewetting ground water table but also control of human disturbance are important. Thus, fire vulnerability analysis can be useful data on reducing CO2 emission of tropical peat lands.

1. INTRODUCTION

1.1 Tropical peat lands of Indonesia

Ecosystem of tropical region has importance to carbon cycle. Despite peat land covers only 3% of global land area, the carbon amounts are one-third of global soil organic carbon. Present peat lands are distributed mainly boreal area and tropical forest area. The tropical peat forest's organic matter is reported up to 70PgC, which accounts for 20% of global peat soil carbon and 2% of global soil carbon. If ground water table of peat lands is decreased, organic carbon of peat soil is decomposed rapidly then CO2 will be released more than before. Furthermore the dry condition of peat lands promotes fire occurrence. Fire event causes severe carbon emission and creates dense haze that contributing to make severe air pollution and health problems (Page et al., 2002). Central Kalimantan has the largest peat area and long history of peat forest fire. In 1997, there was fire event that occurs massive amount of carbon loss (Murdiyarso and Adiningsih, 2007). Furthermore, human activity can be major factor of fire occurrence because of timber logging and land clearance for converting agricultural land use. In deep rain forest area, human accessibility is pointed out as one reason of fire occurrence by forestry researchers (Cochrane, 2003). Therefore the objective of this study is to make map of fire vulnerability related on human accessibility. Mainly, we used road distribution for this assessment. Secondly, human effect such as drainage is considered at this time with water canal detection by using microwave satellite image.

1.2 Site Description

The target area of this study is Central Kalimantan in Indonesia. Particularly, Central Bahaur (3.22S, 114.12E) and Seruyan (3.26S, 112.3E) were chosen for validation of fire occurrence with drainage canal in result. FAO soil classification map (1km grid, category of HISTOSOL) was used as masking data for peat lands. According FAO, Indonesian peat lands area is distributed as 2.56×10^{11} (m^2).

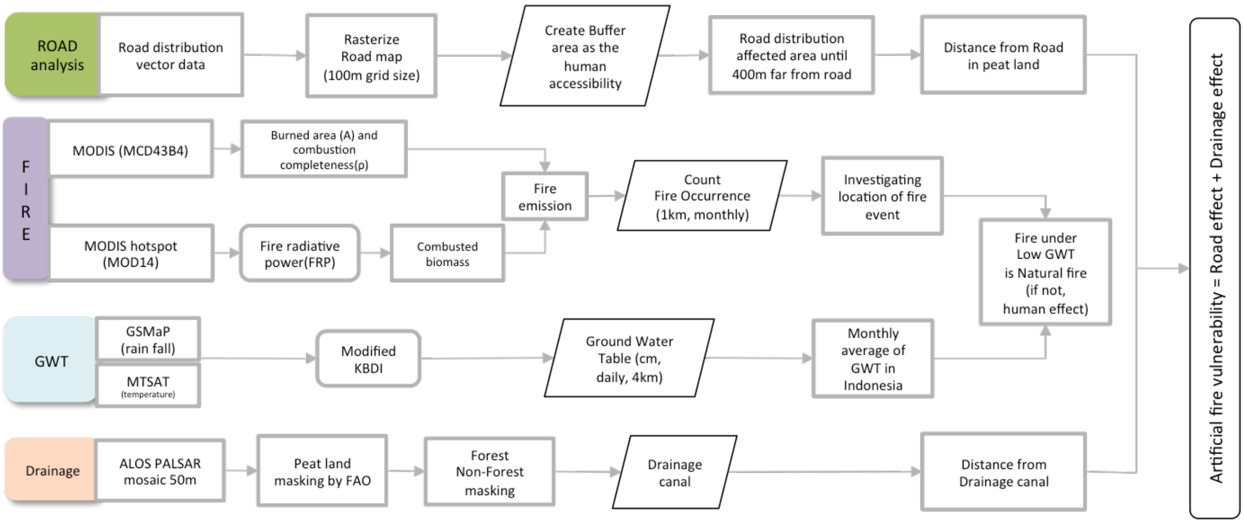

Figure 1. Flowchart of this study

2. DATA AND METHODOLOGY

2.1 Fire emission

Fire emission was from MODIS (MOD14, Thermal anomalies, MOD13, Vegetation Index) of 1km resolution. MCD43B4_NDVI data was used for quantifying burnt biomass via difference of vegetation cover. MOD14 hotspot was used for fire detection. The fire events can be divided two cases of burning for example Above Ground Biomass burning and Soil Organic Matter burning. For identify the soil organic matter we used VISIT model to assume. Then the fire emission factor was multiplied. From this data, fire occurrence was counted monthly as well.

2.2 Ground water table estimation

Ground water table was estimated by KBDI (Keetch-Byram Drought Index). This is proposed for prediction of wild fire in 1968 in U.S.. This index uses precipitation and temperature for calculating evapotranspiration (Keetch and Byram, 1968). In 2010, Takeuchi et al., modified KBDI to estimate ground water table in tropical region. Equation (1) shows mKBDI (modified KBDI) (Takeuchi et al., 2010). In this study, GSMaP (10km mesh) was used for precipitation and MTSAT was used for land surface temperature (4km mesh). Unit of ground water table is "cm" and daily product can be used with open to public.

$$mKBDI = \{mKBDI0-3.94\times r+(1800-mKBDI0)*(0.968\exp(0.0875T+1.5552)-8.3)\}/\{1000\times(1+10.88\exp(-0.001736R))\} \quad (1)$$

$$GWT = -0.0045\times mKBDI \quad (2)$$

2.3 Road distribution and fire occurrence

Road distribution data of whole Indonesian area was provided by Dr. Sonidarmawan. Data resolution is 1/25000. First of all, this vector data was converted to raster data for computing distribution of distance from road (Figure 4). Secondly, in peat region, distance from road is calculated. Finally, fire vulnerability is estimated. This road distribution in Indonesia is useful for analyzing human effect on the place where close to road because of peat land accessibility is low.

2.4 Drainage canal detection

Advanced Land Observing Satellite Phased-Array Synthetic-Aperture Radar (ALOS PALSAR) 50m mosaic data was used to detect drainage canal. This sensor is microwave sensor. Surface roughness can be detected by microwa-

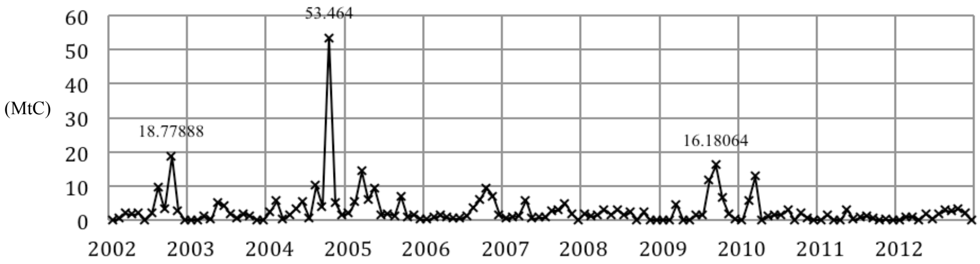

Figure 2. Monthly fire emission from whole peat lands in Indonesia (MtC/month) from 2002 to 2012

ve. Cannel line of non-forested area was extracted by canny edge detection method of Image-J. Forest area and non-forested area data is JAXA PALSAR FNF. Only non-forest area was chosen because of drainage canal is done by human activity.

2.5 Methodology for fire vulnerability

First of all, fire vulnerability of peat land in Indonesia was represented with counting fire occurrence (chapter 2.1). In this study, fire emission was calculated on Indonesia by 1km grid image in every month, so fire distribution could be detected on the map with particular location and time series. After investigating the location of peat fire by using fire occurrence, relationship with drought was surveyed by ground water table data (chapter 2.2). Especially, for this time, area averaged ground water table of Indonesia was used monthly for comparing with fire occurrence. In case of low ground water condition, detected fire was classified as a natural fire event. However, in case of high ground water table, the fire occurrence was considered as an artificial fire event. Furthermore, in this study, road distribution (chapter 2.3) was used for revealing whether the fire was detected at near from road or not, and if the fire was detected near from road, that fire have possibility of event caused by human activity. Drainage canal distribution can be used in this human accessibility analysis (chapter 2.4) because of some peat lands have roads sparsely due to their weak ground structure characteristic. However, drainage canal can represent human effect even there is no road system in peat lands. This study checked whether fire area was detected in drained peat lands or not. If fire location was matched to drainage canal distribution, it is classified as fire event of human activity. Finally, fire vulnerability is created by calculation of distance from road (equation (3)) and drainage canal map because of the human accessibility can be an indicator of peat forest fire in Indonesia. The buffer area of road effect is 400m from road.

$$\text{Fire vulnerability} = \sqrt{(x-a)^2+(y-b)^2}+(DA) \quad (3)$$

where, road (a,b), peat area (x,y) and drained area (DA)

3. RESULT

3.1 Annual fire emission

Fire emission of Indonesia from 2002 to 2012 was shown in Figure 2. This result is extracted only on the peat lands area. As shown in the Figure 2, the amount of fire emission is related with climate factor because 2002, 2004, and 2009 were El niño year. Especially, severe El niño, called El niño modoki (Ashok, 2007), happened in Indonesia in 2004. In dry season, if land surface temperature would be increased, ground water table would be decreased because of the enhancing of evapotranspiration.

3.2 Relationship between ground water table and fire occurrence

Relationship between ground water table and fire occurrence was shown in Figure 3. As described in Figure 2, even ground water table is changing temporally, however, fire emission does not have any temporal change. It was based on some events. Especially, Figure 3 shows result of regression analysis between monthly average of ground water table and fire occurrence in whole peat lands of Indonesia, R^2=0.76655. According this result, fire occurrence increasing is related with ground water table decreasing along log function (y=-0.081ln(x)+0.2864). Several researchers are also agreeing meaningful relationship between dryness and fire event (Jaenicke et al., 2011).

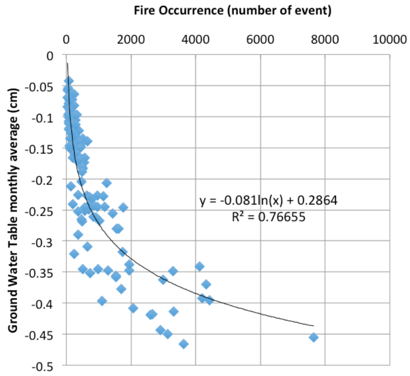

Figure 3. Regression analysis between ground water table and fire emission from 2002 to 2012

3.3 Road distribution

Rasterized road distribution map is represented in Figure 4 with 100m of spatial resolution. Road system shows regional differences. Some cities have complex road system, however, rural area has only few or no road. This study focused on peat lands, so complex road system will be excluded when peat area masking is done. In Figure 4, two peat lands are zoomed in for comparing road distributions. As shown in result, every peat lands have different road system. Therefore, firstly, the relationship between fire occurrence and road location have to be investigated on region by region.

3.4 Regional validation with drainage canal of peat lands

This study distinguished reasons of fire as two factors natural drought and the drought caused by human. In methodology, it was noted that road system is used for assessment of human accessibility. In result 3.2, the relationship of fire occurrence and ground water table declining was revealed. Especially, 2004 shows the biggest fire emission because of El niño modoki. However, through comparison of the fire occurrence in 2004 region by region, Central Bahaur in Central Kalimantan was found as a large fire occurrence even there was no road. For that reason, this study focused on the possibility of a factor of fire event excepting dryness, for example, drainage canal. On the tropical peat lands, many drainage canals are established for converting to agricultural use, i.e. oil palm, cropland and so on. As the result, several drainage canals were represented in Central Bahaur (Figure 5). Especially, Table 1 shows monthly ground water table and fire occurrence of target region. From June to November 2004 has dry season on Central Bahaur and fire event of wide area was also detected in here. However, in February 2004, even its ground water table was high, there is a fire occurrence as well. In Seruyan, January 2004 had one fire occurrence although the ground water table was higher than 0. It means these fire events of January and February are not only caused by natural drought but also human activity because of ground water table was not decreased seriously. Furthermore, detected drainage canal is supporting a theory of manmade fire event in Jan. and Feb. 2004.

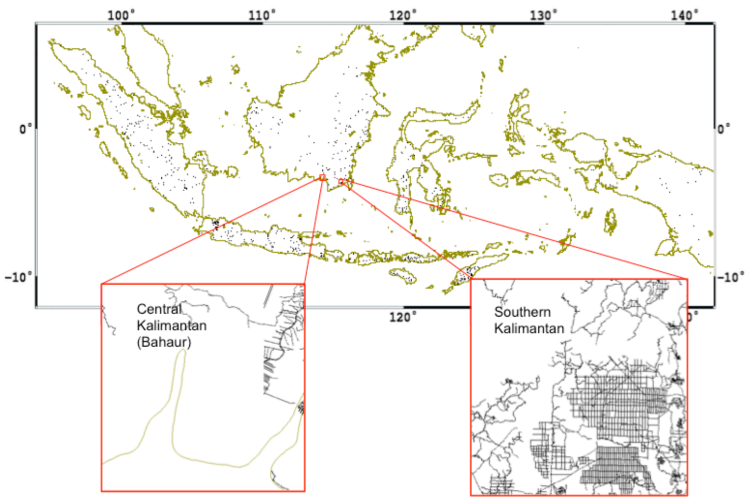

Figure 4. Result of rasterized road distribution with spatial resolution of 100m from vector data

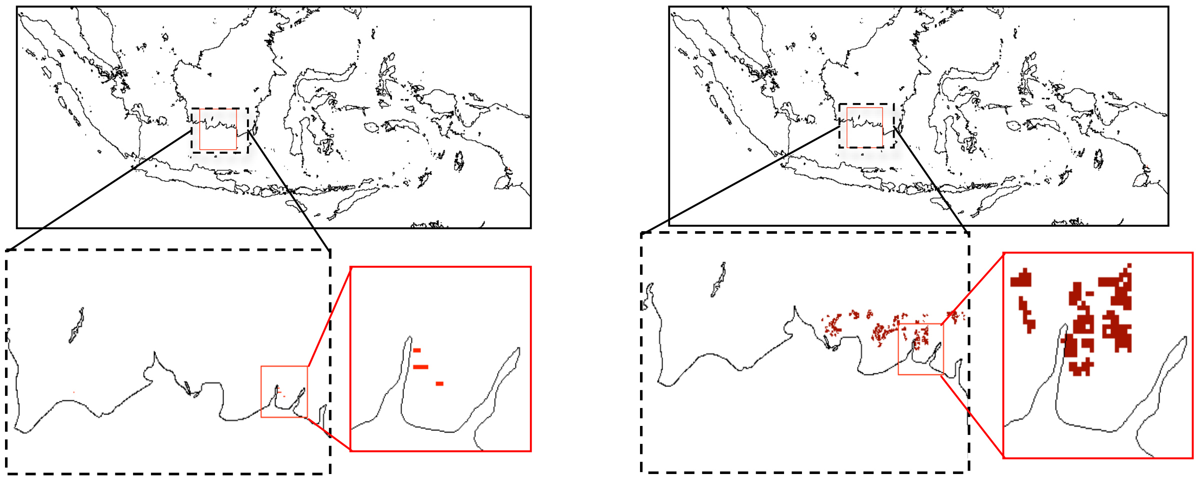

Figure 5. (left) Result of fire detection from soil organic matter in June, 2004
(right) Drained area by drainage water canal in Central Kalimantan

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Table 1. Validation of monthly fire occurrence with monthly ground water table

	Ground Water Table (cm)		Fire Occurrence	
	Central Bahaur (3.22S, 114.12E)	Seruyan (3.26S, 112.3E)	Central Bahaur (3.22S, 114.12E)	Seruyan (3.26S, 112.3E)
Jan. 2004	-4.79	0.61	×	○
Feb. 2004	-2.16	-0.53	○	×
Mar. 2004	-2.24	-2.91	×	×
Apr. 2004	-5.26	-7.27	×	×
May. 2004	-7.27	-10.99	×	×
Jun. 2004	-10.05	-15.1	○	×
Jul. 2004	-16.01	-17.54	×	×
Aug. 2004	-20.23	-21.4	×	×
Sep. 2004	-20.82	-21.45	×	×
Oct. 2004	-20.96	-21.33	×	×
Nov. 2004	-11.67	-4.85	×	×
Dec. 2004	-4.16	-0.19	×	×

4. CONCLUSION

Relationships between fire occurrence, drought, and road distribution were investigated in this study. Vegetation index and soil organic matter with MODIS hotspot data were used for estimating fire emission. Fire emission from Indonesian peat land was changed along climatic factors for examples, El niño, La niña etc. In peat lands of Indonesia, fire events were counted for revealing fire occurrence and compared with average of ground water table on whole Indonesian peat lands. As the result, fire occurrence is related with dry condition of peat lands strongly, if ground water table was declined, fire occurrence would be increased extremely along natural logarithm formula (ln(x)). However, in Indonesia, there are not only fire events by natural drought but also by human made events. This study tried to make manmade fire vulnerability map by road distribution. Human accessibility would be related with distance from road in peat lands. First of all, vector data of road distribution was rasterized to grid data with 100m of spatial resolution. As the result, characteristics of road distribution of peat area are varied according region by region. After making raster data of road map, the fire location, detected from MODIS hotspot, was compared with road distribution in Central Kalimantan. Especially, June 2004 has a most severe record of fire occurrence on the period of this research from 2002 to 2012. As the case of fire event of drought, June 2004 was selected for regional validation on Central Bahaur and Seruyan in Central Kalimantan. Large area of fire occurrences were detected in Central Bahaur in June 2004, despite, here has no road in peat area. After comparison with ground water table, this was implied that the reason was the dry condition. However, in Jan. and Feb. 2004, fire events were detected even severe drought was not shown. On the other hands, the drainage canal affecting area, which was calculated by ALOS PALSAR, was exactly matched with fire occurring area. It implies these fire events on Jan. and Feb. 2004 were not caused by only natural reason but it may be occurred by human activity as well. Accordingly, the possibility was found in Central Kalimantan that artificial fire vulnerability can be promoted by road and drainage canal distribution from this study. For future works, the vulnerability map of artificial fire event, expanded to whole tropical peat lands in Indonesia, will be created based on this road distribution result with 100m of spatial resolution, and then, drainage canal distribution will be added for assessing fire vulnerability as well.

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