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Spatio-Temporal Typology of Land and Forest Fire in Sumatra

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Abstract

The characteristic of land and forest fires occurred in Indonesia are varied widely, following the variation of time within a year and geographic location. This paper describes how the spatio-temporal of forest and land fire typology was developed. The main objective of this study was to develop a spatio-temporal typology of forest and land fire by considering several key indicators that directly related to the density of active fire occurrence, such as percentage of forest area (x_1), population density (x_2), ratio of forest area to population (x_3), ratio of plantation area to population (x_4), ratio of agriculture area to population (x_5), GRDP (x_6), population growth (x_7), deforestation growth (x_8), plantation growth (x_9) and dry agriculture growth (x_{10}) as well as MODIS-based fire hotspot. The typology analysis was performed using clustering techniques with Euclidean distance dissimilarity measure, where the grouping process was drawn with single linkage method. The temporal analysis showed that the highest occurrence of the fire hotspot was mainly found in the third quarter. It was found that the forest and land fire typology could be developed into three classes using variables x_6 and x_7 with overall accuracy of 78.15% or x_1-x_6-x_7 with overall accuracy of 78.8%. No accuracy improvement was obtained when the typology was developed using five variables x_1-x_3-x_4-x_6-x_7.

Keywords: *forest fire, land fire, MODIS, typology, spatio-temporal*

1. Introduction

Anthropogenic fires increased obviously in the past two decades. This phenomenon has attracted international attention due to its environmental and economical impacts, especially after the disaster of El Niño Southern Oscillation (ENSO) 1997/98 scorching forest area of about 25 million hectares worldwide [1]. In the period of 2001-2005, the estimated global areas of the fire were ranging from 2.97 to 3.74 million km^2 [2]. Fires are expected to always occur in the future with an increasingly alarming rate.

Southeast Asia is part of the world that been suffering from a high rate of deforestation and forest degradation. The main triggering factors are mainly the agricultural expansion using slash-and-burn technique, land preparation using fire prior to plantation and land encroachment using fires. Under climate change scenarios in the future and fire management practices today, Indonesia's tropical rain forests are more susceptible to fire [3]. This environmental crisis is repeated year by year, as a few hundred businesses and a few thousand farmers seek to profit from land and plantation speculation practices, while tens of millions of Indonesians and neighbors countries suffer health costs and economic disruptions.

The big fire episodes in Indonesia has been occurred since 1982/1983, then repeatedly in 1997/1998, 2006, 2009, 2014 and 2015 with varying scale and intensity. The big fire in 1997/1998 in Indonesia known as 'the disaster of the century' [4], while the fire episode in 2015 labelled as 'crimes against humanity'. Fire in 1997/1998, especially in fire-prone provinces in Sumatra and Kalimantan, burnt an area of 11.7 million ha [5] while the fire season in 2015 burnt area estimated of 2.1-2.6 million ha [6]. The forest fires and haze those year have also constrained GDP growth, costing Indonesia an estimated IDR 221 trillion (USD 16.1 billion; 1.9% of GDP) which is more than twice the reconstruction cost after the 2004 Aceh tsunami [7].

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Haze has also contributed to the death of 19 people and more than 500,000 cases of acute respiratory infections.

To overcome the problem of fires, especially for mitigating, understanding the typology and driving forces of fire is essential. Information on the spatio-temporal occurrence of fire is also very important to know especially the distribution pattern in various land cover in a certain period of time, especially at the height of the fire season.

The study results of Jaya [8] in Riau Province noted that human activities such as land preparation for agriculture and settlement using fire were found as main sources of forest and land fire. Additionaly, thestudy of Kayoman [9] also shows that the causes of forest and land fires in West Kalimantan were mainly came from human activities which were varied according to the distance from the town and roads, land use, land cover and rainfall. Samsuri [10] also recognized that the main factor affecting the land and forest fires in Central Kalimantan was land system type, land cover types, soil types and function of the area with R^2 of 54%.

The objective of this study was to develop spatio-temporal typology of land and forest fires based on key indicators that are directly related to the density of forest fires within regency/city in Sumatra. Information about the causes of forest fires and the eco-drivers factor is indispensable in formulating policies to effective fire prevention [11]. In this study, the authors developed the typology of land and forest fire in Sumatra using spatio-temporal approach on the basis of the MODIS active fires. The MODIS data was quite useful in characterizing spatial patterns in fire occurrences as well as some fire regime attributes [12]. A study [13] at African sahara using MODIS temporal characterization showed similar fire densities between the protected areas and the buffer areas, but on the contrary clear differences were observed in terms of their fire intensity. Furthermore, MODIS product could also used to create a fire return interval (FRI) map for the region, showing the areas that burn most frequently [14]. The results of this research may be a consideration both scientifically and practically for policy makers to control land and forest fires, so that the land and forest fires in the future can be prevented and minimized.

2. Research Method

The study area is located at 95°E−102°E and 6°S−6.2°N, as shown at Figure 1. Administratively, this island consisted of 10 provinces and 151 regencies/cities, which total area of 473,223 km^2. Sumatra is the 3rd biggest island in Indonesia having very high deforestation and forest degradation rate as well as suffering from annual land and forest fire.

The weather in Sumatra region is relatively hot and humid all year round, and the dry season period is mainly from June to October, during which most of vegetation biomass burning take place. Mostly, the dry seasons in the study area are attributed to the ENSO [15], however, even during the dry season period in normal year, rainfall might be high in many parts of the region [16].

Typology development was conducted by using the clustering approach for selected socio-ecological drivers namely the percentage of forest area (x_1), population density (x_2), ratio of forest area to population (x_3), ratio of plantation area to population (x_4), ratio of agriculture area to population (x_5), GRDP (x_6), population growth (x_7), deforestation growth (x_8), plantation growth (x_9) and dry agriculture growth (x_{10}). The purpose of clustering is to group similar objects in the same cluster, so we need to measure of how similar or dissimilar an object. In this case the similarity measure used is the distance between pairs of objects. Objects with a shorter distance between them would be more similar to each other than to mate with a longer distance [17]. In this study the used measure of similarity was the Euclidean Distance.

Euclidean distance is defined as the length of a straight line connecting the two objects that having a fixed geographical position [18] that may simply calculated using the Cartesian coordinate system. For more than two variables (*k)*, the Ecuclidean distance of two clusters (x_i, x_j), can be written using the following formula [19]:

$$D_{ij} = \sqrt{\left[\sum_{i=1}^{i=n}\left(x_{ik} - x_{jk}\right)^2\right]}$$

Dij = Euclidean distance of cluster *i*th and *j*th
i, j = the cluster *i*th and cluster *j*th

k = variable number
n = number of variable

The grouping process was conducted using agglomerative hierarchical clustering with single linkage method, where the distance between clusters was on the basis of the closest distance of the cluster member. Then, determination of the number of clusters is conducted by dendogram, which is a graphical tool for presenting the results of clustering. The number of cluster and the indicator variables recognized are expressing the forest and land fire typology derived.

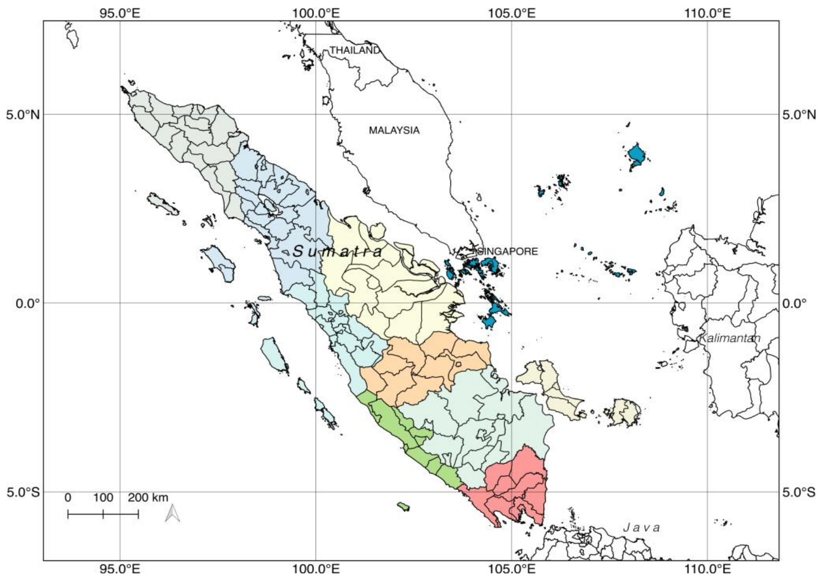

Figure 1. Study area

3. Results and Analysis

3.1. Spatial and Temporal Pattern of Fire Hotspot

During year of 2006 to 2015, the cummulative hotspot occured in Sumatra was 255.281 which means that 40% of total of Indonesia. Figure 2 shows the cumulative fires occurred in the period of 2006−2015, where the highest was recognized in 2006, 2009, 2014 and 2015. This is the highest active fire for the last ten years with 47,867 fires counted, increasing more than 600% from year of 2010, as the year with the lowest number of hotspot. Fire season in Sumatra extends from February to March and from June to October (Figure 3). The first fire season primarily occured in Riau province which recorded more than 14%, and the second fire season recorded more than 75% of total fires. MODIS Aqua captured 62% of the fires relative to MODIS Terra with 38%, suggesting that most of the fires occur during the afternoon. The peak of fire season in 2015 occured during September with 35% of fires, June (3%), July (9%, August (10%) and October (32%) respectively. At the end of October, the rainy season began and replaced the haze with clear air.

The fire hotspot density in Sumatra showed that two provinces namely Riau and South Sumatra had highest number consistently during 2006 to 2015 (Table 1). Riau province experienced fire hotspot density above the average for the whole 10 years and South Sumatra recorded 8 years above the average. The highest hotspot density (0.4861 occurrence per km^2) reached in 2015 in South Sumatra followed by Riau (0.372 occurrence per km^2) in 2014 when a short but high intensity fire season occured in several regencies in Riau.

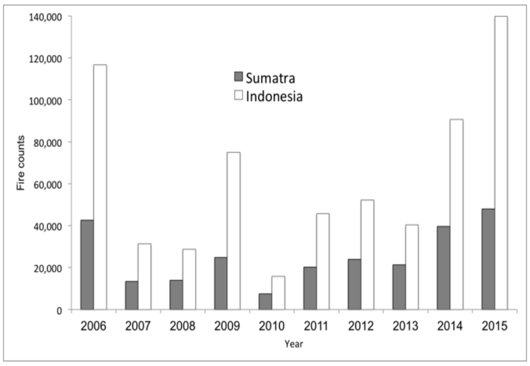

Figure 2. Fire counts at Sumatra and Indonesia during 2006-2015

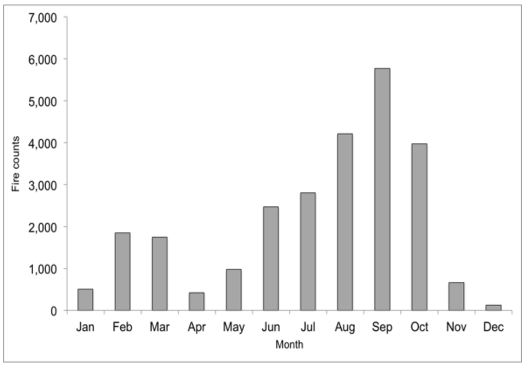

Figure 3. Mean fire seasonality in Sumatra during 2006-2015

Table 1. Fire hotspot density in Sumatra provinces

	Hotspot density (occurrence per km^2)									
Province	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
NAD	0.009	0.007	0.011	0.020	0.009	0.015	0.021	0.019	0.030	0.006
North Sumatra	0.033	0.021	0.015	0.025	0.013	0.015	0.014	0.018	0.041	0.015
West Sumatra	0.028	0.008	0.017	0.014	0.003	0.010	0.013	0.006	0.006	0.009
Riau	0.193	0.071	0.098	0.189	0.072	0.118	0.135	0.260	0.372	0.125
Riau Islands	0.004	0.003	0.002	0.004	0.004	0.002	0.003	0.003	0.012	0.003
Jambi	0.083	0.031	0.032	0.032	0.007	0.033	0.048	0.021	0.026	0.115
Bengkulu	0.012	0.005	0.006	0.004	0.001	0.006	0.005	0.002	0.003	0.007
South Sumatra	0.305	0.065	0.044	0.108	0.016	0.126	0.144	0.029	0.164	0.486
Bangka Belitung	0.021	0.007	0.010	0.020	0.004	0.008	0.014	0.005	0.016	0.034
Lampung	0.047	0.012	0.008	0.011	0.002	0.017	0.016	0.004	0.016	0.027

The average hotspot density during last ten years indicated there were four provinces with lowest hotspot density namely Nanggroe Aceh Darussalam (NAD), West Sumatra, Bengkulu and North Sumatra. This indicator related positively with average burned area recorded officially by MoEF with 42 ha, 72 ha, 91 and 564 ha in respective provinces as shown in Table 2.

Table 2. Burned area in Sumatra provinces

	Burned area (ha)									
Province	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
NAD	-	24	13	43	5	-	13	-	156	-
North Sumatra	317	131	170	848	80	5	1.181	295	2.435	177
West Sumatra	-	17	234	7	56	-	4	-	114	-
Riau	-	38	109	275	26	75	1.060	1.078	2.966	4.041
Riau Islands	-	-	-	-	-	-	-	-	-	-
Jambi	1.228	55	115	14	3	89	11	199	2.230	19,528
Bengkulu	-	-	-	-	-	1	-	-	-	181
South Sumatra	18	-	84	51	-	85	-	484	8.103	30,985
Bangka Belitung	-	27	-	-	-	-	-	-	-	-
Lampung	-	2.532	2.956	-	106	31	-	-	23	19,696

The burned area collected from officially reports to Ministry of Environment and Forestry which based on direct field observation to each fire location and measured by available devices manually. For example, during 2015, this method resulted 74,067 ha of burned area while using remote sensing method the burned area estimated about of 814,659 ha [6].

3.2. Fire Hotspot Distribution and Driving Forces

The average of fire hotspot density during 2006−2015 at 151 regencies varied from 0 as minimum value to 0.4518 (occurrence per km^2) as maximum value. With 8 equal-interval classes we obtained that there was 127 regencies belong to class I (fhd=0−0.0565). The " hot spot" were found in 4 regencies. There were 17 regencies included in class II (fhd =0.0570−0.1130), two regencies in class III (fhd=0.1135−0.1694), and IV (fhd=0.1699−0.2259), and one regency in each class V (fhd=0.2264−0.2824), VI (fhd=0.2829−0.3389) and VIII (fhd=0.3954−0.4518).

The fire hotspot density information as shown in Figure 4 concluded that Riau, Jambi and South Sumatra were among the most prone area in Sumatra. Nanggroe Aceh Darussalam, North Sumatra, West Sumatra, Kepulauan Riau and Bengkulu provincies may classify as non-prone area.

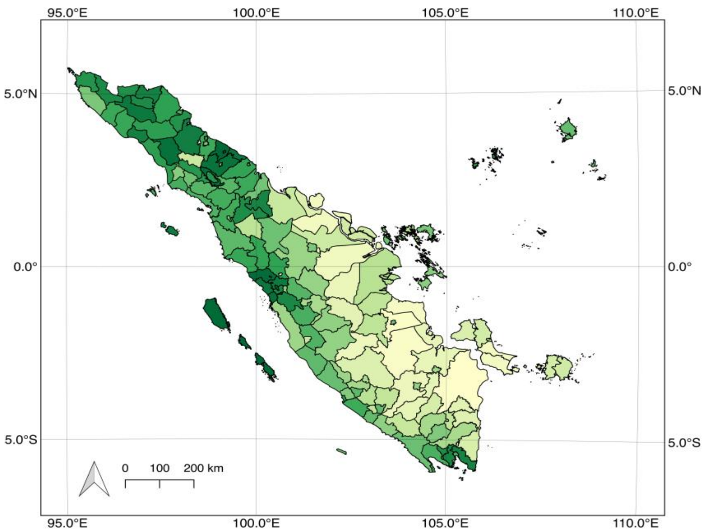

Figure 4. Fire hotspot density distribution in Sumatra 2006-2015

It was clearly displayed that the human activities factor gives higher influence for causing a wildfire than the physical-environmental factor [20]. This study found that increasing of percentage of forest area (x_1) will decrease the fire hotspot density as the undisturbed forest relatively resistance to fire. Population density (x_2) was not contributed significantly to fire hotspot density whilst increasing ratio of forest area to population (x_3) may decline fire hotspot density. It was also noted that ratio of plantation area to population rate (x_4) could raise fire hotspot density as well as GRDP (x_6) and population growth (x_7). The ratio of agriculture area to population (x_5) was not significantly influenced to the fire hotspot density as well as deforestation growth (x_8) and plantation growth (x_9). Increasing of dry agriculture growth (x_{10}) tend to decrease fire hotspot density which is generally indicated that activity was not involving fire.

3.3. Climate Variation

To find out the influence of climate at each regency/city to the occurence of fire, we extracted the rainfall data from 40 weather station within Sumatra and processed using Inverse Distance Weighted (IDW) method which interpolate the number of rainfall from all stations in Sumatera The climate type classification used is Schmidt-Fergusson which considered the ratio between dry-month to wet-month during the last 10 years period.

The data analysis found that regency/city in Sumatra include 4 climate type namely very wet (A), wet (B), rather wet (C) and D (medium). Types A found in 23 districts/cities (15%), type B is the type of majority regencies with recorded 102 (68%), climate type C was recorded in 25 regencies/cities (17%) and type D is only found in Lhokseumawe city influenced by the strait of Malacca.

Table 3. Chi-test on climate variation

Type	Q1		Q2		Q3		Total	
	Observation value	Expected value	Observation value	Expected value	Observation value	Expected value	Observation value	Expected value
A	0.7846	0.4192	0.4315	0.4626	0.4935	0.8278	1.7096	1.7096
B	0.1433	0.3952	0.5117	0.4362	0.9571	0.7806	1.6120	1.6120
C	0.0798	0.1932	0.1687	0.2132	0.5394	0.3815	0.7879	0.7879
Total	1.0076	1.0076	1.1120	1.1120	1.9899	1.9899	4.1095	4.1095

Probability = 0.937; Chi-sq count = 0.130; Chi-sq table = 5.991

The Table 2 shows that based on the chi-square test of observation value and expected value of the hotspots density per ha in Q1, Q2 and Q3, the fire density fluctuations in Sumatra was not depended on the type of climate (Chi-sq calculation less than Chi-sq tables) or with a probability value greater than 0.95.

3.4. Land and Forest Fire Typology

We used fire hotspot density with administrative boundary layer for this study to develop fire topology considering that is a regulation mandate that the fire occurences in each regency will be the responsible of the Head Regency. In addition, the number of hotspot in regency will be the part of performance of Head Regency.

MODIS fire datasets during year of 2015 at Sumatra was groupped by 151 regencies and 12 months for spatio-temporal analyzing. The data then classified in three class: low, moderate and high. The study resulted that 95 regencies classified as low, 17 moderate and 39 high.

In order to identify the period of the peak of fire season in each regencies, we groupped the data into quarterly, Jan−Apr (Q1), May−Aug (Q2) and Sep−Dec (Q3). The data then combined with class of typology (I for Low, II for Moderate and II for High) to find out the maximum number reached in a quarter. The maximum fire hotspot density for each regencies none in Q1. It was reflected that eventhough the fire season also occured in Feb−March in particular regencies in Sumatra, the fire season in Q2 and Q3 was higher (>50%).

The data analysis found that using five variables namely percent forest cover (x_1), the ratio of forest with population (x_3), the ratio of the plantation with population (x_4), the GRDP (x_6) and the population growth rate (x_7) resulted 3 class typology with variants between classes generated at 85.23%. The results with 3 variables (x_1, x_6 and x_7) resulted 5 class typology with interclass variance of 91.20%. Then, by using two variables (x_6 and x_7) resulted 3 class typologies with variance between classes generated at 97.60%.

On the basis of the dendrogram obtained using Single Linkage Method, three typology of land and forest fire using only two variables x_6 and x_7 provide overall accuracy of about 78.15%. No significant accuracy improvement was obtained when this typology was developed using five variables x_1, x_3, x_4, x_6 and x_7.

From the study results obtained previously, the spatio-temporal land and forest fire typology in this study site may be groupped into three typologies, i.e., low (I), medium (II), and high (III) with two key variables (x_6 and x_7) as determinant driver. The average of fire hotspot density of each typology was 0.551, 0.694 and 1.101, which means there will be 1 fire hotspot within 2 km^2, 3 fire hotspot in 2 km^2, and 1 single fire hotspot in area of 1 km^2 respectively.

The land and forest fire typology in Sumatra as shown in Figure 5 classified that 148 regencies were assigned as typology I, while only 1 regency includes in typology II and 2 regencies classified as typology III. The most prone area was Riau province where 3 regencies namely Siak, Kepulauan Meranti and Bengkalis were the most priority areas in order to mitigate the fire occurences. In terms of fire hotspot frequency, it was recorded 1,376 in Bengkalis, 275 in Kepulauan Meranti and 562 in Siak during year of 2015. Actualy, Pelalawan regency recorded the highest number of hotspot with 1,784, however this regency area is four times larger comparing to Kepulauan Meranti.

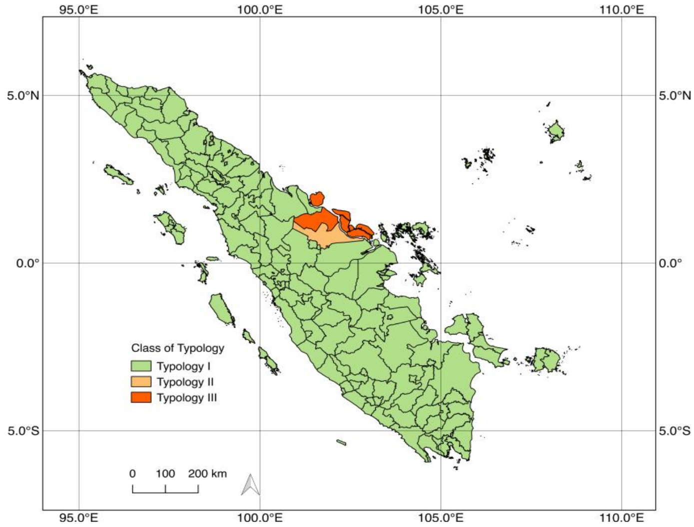

Figure 5. Spatio-temporal typology of land and forest fire in Sumatra

4. Conclusion

From the foregoing findings and discussions, the study concludes the following. The empirical hotspot density distribution either temporarily or spatially, the regencies and cities in Sumatera island could be catagorized in three typologies, namely low (I), middle (II) and high (III). The low typology spread out from the northern to the west-southern parts of the island covering 148 districts and cities, while the middle topology found only in Siak Regency, Riau province and the high topology was found in two districts namely Bengkalis and Meranti Island regencies of Riau province. Temporarily, the highest fire season peak always occurred in Q3 in most regencies. The study also concludes that the key indicators for establishing the land and forest fire typology are GRDP (X_6) and population growth (X_7).

The study suggested that by referring to the spatio-temporal distribution of land and forest fire, the government may setting up the priority scale of fire prevention activities within a certain regencies and time period. The moderate and high tipologies were found in Riau Province while the rest were belonged to the low typology.

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