Spatial typology of forest and land fire characteristics: case study in Central Kalimantan Province

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Abstract. Forest and land fire disasters globally has characteristics of landscape heterogeneity. In sustainable spatial planning requires typological information on spatial characteristics. So, it need to be known characteristics and group of forest and land fire disasters in Indonesia. This study objectives to build the typology of spatial characteristics of the forest and land fires vulnerability. The method was carried out using cluster analysis with Standarized Euclidean Distance. The result shown that the socio-economic growth factor with variables i.e. population, GDP per capita, increase the agriculture area expansion rate, deforestation rate, and length of road related to forest and land fires occurrences, with 2 typologies. Typology 1 was areas with high socio-economic growth along with high fire occurrences, and typology 2 was areas with the opposite conditions. Disaster management was suggested considering the basic characteristics of typology to determine land use zoning that based on these data variables.

1. Introduction
The phenomenon of Forest and Land Fires Disaster (FLFD) have impact on social, economic and environmental conditions. In long-term, an economic development increases global warming and the greenhouse effect [1, 2]. The Socio-economic development follows an inverted U-curve shape along environmental degradation, such as an global emissions of SO₂ continue to increase [3], CO₂ emissions [4], and air pollution [5-7]. This theory was developed from relationship between gini ratio and per capita income, that follows inverted U-curve shape [8]. A market institution fails to create prosperity in the long term. Thus, it’s requiring new ideas to overcome the problems [9]. Spatial planning agenda both directly and indirectly relates to the phenomenon of FLFD. Improving of sustainable spatial planning idea requires a preliminary study that related to the characteristics of spatial heterogeneity in the landscape. Moreover, it defines forest - land fires typology with those characteristics.

FLFD problems have relationship with potential trajectory of land-use change on a landscape. Trajectory of land-use change occurred in effort to increase land value and to do land value capture (LVC). According to Purnomo, Shantiko, Sitorus, Gunawan, Achdiawan, Kartodihardjo and Dewayani [10] land-use change is one of the manners to increase land value through actor networks that causes land fires. FLFD problems has a wide perspectives. The lack of clarity in understanding the context of fire problems leads to the adoption of policies that have a negative impact on the livelihoods, the environment, and the economy [11].

Typology model has an important role in spatial planning to understand general characteristics of typology. Typology model development can be based on the main driving factor, furthermore the general characteristics profile of each typology are identified [12]. The socio-economic such as GDP has a basic typology classification of spatial FLFD in regional scale such as in North American [13] and in Sumatera Island [14]. The research objectives was to build the typology of spatial characteristics of the forest and land fires vulnerability. Thus, the result related to socio-economic factors can be used as a reference in making the spatial typology of FLFD vulnerability for environment sustainable of spatial planning considerations.
2. Materials and Methods
The study was conducted in central Kalimantan. Geographically, Central Kalimantan is located between latitude of 0°45’ N, 3°30’ S and longitude of 111°-116° E. It has total area of 153564 Km² consisting of 13 districts and 1 city. The Province of Central Kalimantan was selected as the research location because of a long history of forest and land fires experiences. Fire disaster experienced in 1982-1983 continued on 1987, 1991, 1994, 1996-1998, that know as “Great Fire of Borneo” [11, 15] and recently FLFD occured in 2015.

2.1. Materials
Socio-economic and biophysical data were collected, These data were consist of population, population growth rate, percentage of poor people, Gini ratio, GDP per capita, GDP, the agricultural land expansion rate, population growth rate, deforestation rate, road density and the road length as predictor variables forming the typology of FLFD spatial characteristics (Table 1). The data obtained from the Statistics Central Bureau of Indonesia, Ministry of Environment and Forestry, Ministry of Agriculture, and Geospatial Information Agency. The study was conducted for 3 months from April 2019 to June 2019. The following map of the study site presented in Figure 1.

![Figure 1. Study area, showing districts in Central Kalimantan Province](image)

| Independent Variables | Unit |
|------------------------|------|
| Population(X₁)         | People |
| Population growth rate(X₂) | People/years |
| Percentage of poor people(X₃) | % |
| Gini ratio(X₄)         | Ratio |
| GDP per capita (X₅)    | Million/people/years |
| GDP(X₆)                | Million /years |
| The agricultural land expansion rate (X₇) | Hectar/years |
| Deforestation (X₈)     | Hectar/years |
| Road length (X₉)       | Km |
| Road Density km/km² (X₁₀) | Km/km² |
| Elevation(X₁₁)         | M Above Sea Level |
| Slope (X₁₂)            | % |
2.2. Methods
The spatial characteristic typology of FLFD vulnerability in Central Kalimantan Province was built into 4 (four) stages. The first stage was to analyze hotspots data, starting from 2008 - 2018 that they were produced by the Ministry of Environment and Forestry. Furthermore, digitize a map on-screen both the hotspot data and the actual burned area from Landsat imagery (date from 2008 to 2018) with. The second stage was to identify the predictor variables of forest and land fires through historical literacy studies of forest and land fires. The third was to determine the smallest unit of object analysis. And the fourth stage was to conduct typology development using the standardized hierarchical cluster method. The main objective of cluster analysis was to group districts based on the similarity of spatial characteristic by using the variables that presented in Table 1.

3. Result & Discussion
Correlation test predictor variables forming the typology of FLFD spatial characteristics to FLFD

The study examined several predictor variables from socio-economic and biophysical factors related to FLFD. Then, the results will be used as a basic of spatial typology classification. We got five variables from 12 predictor variables, which significantly correlated to FLFD. These variables namely population, GDP per capita, the agricultural land expansion rate, deforestation rate and road length, as presented in Table 2. The variable relationship pattern to FLFD area was presented in Figure 2.

| Table 2. Correlation Test of predictor variables with FLFD |
|-----------------------------------------------|
| X1 | X2 | X3 | X4 | X5 | X6 | X7 | X8 | X9 | X10 |
|-----------------------------------------------|
| Y  | 0.656* | -0.682** | 0.641* | 0.722* | 0.788** |
| X1: Population; | X2: GDP per capita; | X3: The agricultural land expansion rate; | X4: Deforestation/year; | X5: Road length; |
|*: Significance level 95%; |**: Significance level 99% |

The relationship between population, GDP per capita, the agricultural land expansion rate, deforestation rate, and road length to FLFD forms specific characteristic patterns. The relationship between populations to FLFD shows a linear pattern (Figure 2 (a)). This pattern indicates that increasing population is one of the driving factors for the high potential of FLFD.

The trajectory land use change indicates that the deforestation process had a positive relationship to demographic transition [12]. Furthermore, the relationship between deforestation rate and FLFD had a logarithmic pattern with a positive correlation (Figure 2(b)). Increasing deforestation would increase a number of combustible materials. Other driving factors such as increasing population growth make high potential occurance of FLFD. This result showed that land fire events related to Land Use and Land Cover Change (LULCC). It seems that the FLFD process was aims to transfer of land use forms to improve socio-economic conditions, but the impact would be decreasing environmental quality in the form of FLFD vulnerability.

The increasing of FLFD was related to GDP per capita that was following a logarithmic pattern with a negative correlation(Figure 2(c)). Large burned land areas occurred in administrative region with low GDP per capita, and the contrary. This result shown that the regions that have population pressure with low-income conditions tend to have FLFD vulnerability. This condition was related to the efforts of the people improve their livelihoods through agricultural cultivation. The agricultural land expansion rate was one of the driving factors that was associated with the potential vulnerability of FLFD. The increasing of FLFD was directly proportional to the agricultural land expansion rate with a logarithmic pattern (Figure 2(d)). There was a land use change trajectory from the forest into
other usages, one of others is agriculture through the slash and burn stage, that is strongly related to the vulnerability of FLFD.

Socio-economic improvement was occurred related to accessibility improvement. The relationship of road length to the FLFD occurrence followed a linear pattern with a direct proportionality (Figure 2 (e)). The Areas that had a higher number of road length have a high potential for FLFD vulnerability.

![Graphs showing the relationship between five driving factors towards FLFD](image)

**Figure 2.** Relationship between five driving factors towards FLFD

**Typology class of FLFD vulnerability**

Further analyses of correlation test was hierarchical dendrogram of selected variables. Afterward, ANOVA conducted to find out the significance between groups. This analyses produced 2 typology classes, the so called typologies 1 and typology 2. Typologi 1 includes areas that have characteristics of high FLFD vulnerability characteristics and Typology 2 comprises areas that have low FLFD vulnerability characteristics. Typology classification based on each selected variable that has different
levels of accuracy on the FLFD occurrences. The results recapitulation of the accuracy test of these 2 classes is presented in Table 3. From the hierarchy formed can be described the closeness of regions based on the used characteristics as analyses variables.

Table 3. Recapitulation of predictor accuracy test of FLFD

| Classified based on predictor variables | Assesment Accuracy (%) |
|----------------------------------------|-------------------------|
| Population (X₁)                        | 79                      |
| GDP per capita (X₅)                    | 79                      |
| The agricultural land expansion rate (X₇) | 86                      |
| Deforestation rate (X₈)                | 64                      |
| Road length (X₉)                       | 71                      |
| Population (X₁) * The agricultural land expansion rate (X₇) | 79 |
| The agricultural land growth rate (X₇) * GDP per capita (X₅) | 86 |
| The agricultural land growth rate (X₇) * Deforestation rate (X₈) | 71 |
| The agricultural land growth rate (X₇) * Road length (X₉) | 86 |

The agricultural land expansion rate variable has the highest of test accuracy to FLFD occurrence by 86%. The regions that included typology 1 were Katingan, Kotawaringin Timur, Kotawaringin Barat, Seruyan, Pulang Pisau, Kapuas, and Barito Selatan Regency. Furthermore, the areas included in typology 2 were Murung Raya, Gunung Mas, Palangka Raya, Barito Utara, Barito Timur, Sukamara, Lamandau. These area had characteristics of population, the agricultural land expansion rate, deforestation rate and road length that tend to be low, while the tendency of GDP per capita was high. The results of grouping 2 typology classes were compiled by the FLFD vulnerability typology profile. This profile shown in Table 4.

Table 4. FLFD vulnerability typology profile

| Characteristics                                      | Typology 1 | Typology 2 |
|------------------------------------------------------|------------|------------|
| **Socio-Economic Conditions**                        |            |            |
| Demographic transition                               | High       | Low        |
| Population (people)                                  | (251268)   | (108344)   |
| Population growth rate (thousand people year⁻¹)      | (5305)     | (2080)     |
| GDP per capita (million people⁻¹ year⁻¹)             | Low (31.5) | High (42.8) |
| **Biophysical changes**                              |            |            |
| The agricultural land expansion rate (thousand Ha year⁻¹) | High (21.9) | Low (5.7) |
| Fluctuations of the agricultural land expansion rate | Medium     | Low        |
| Highest value (thousand ha year⁻¹)                   | (92)       | (19)       |
| Lowest value (thousand ha year⁻¹)                    | (2.6)      | (0.3)      |
| Deforestastation rate (ha year⁻¹)                    | High (9183) | Low (4816) |
| Accessibility                                        | High       | Low        |
| Road length (km)                                     | (15295.5)  | (6109.3)   |
| Road density (km/km²)                                | (1.2)      | (0.9)      |

Note: the calculation listed is calculated from the average data

The typology profile was elaborated with the latest data of land cover, forest area, elevation and distance of road (Figure 3). Elaboration between typologies class with land cover in the study site shows that there is no significance difference land cover of each type, however areas of typology 1 are more dominated by shrubs and agricultural land covers, whereas typology 2 was dominated by forest cover. It indicates that in the studied area were in transition experiences. Forest transition was
influenced by demographic transitions, biophysical changes and economic growth [12]. Then related to fire occurrence according to [16], the fires are an indicator of land degradation that changes land cover.

Elaboration with forest area and elevation were indicated that the FLFD occurrence had no effect on these factors. The fire will spread in all directions during FLFD occurrence. However, the potential level can be different due to the influence of anthropogenic factors. It was conducted limitation access in a protected area which had a high vulnerability. The proximity to the road had a different picture as compared with these two factors. The FLFD in typology 1 tends to be in areas that were close to access to roads. So that, it could be restricted to accessibility development in protected areas which had a high vulnerability. Furthermore, control priority was conducted to the cultivated area with high accessibility characteristic.

![Figure 3. Elaboration of typology classes with biophysical factors and forest areas](image)

**Figure 3.** Elaboration of typology classes with biophysical factors and forest areas

**Strategy of spatial planning**

Spatial planning strategy based on fire disaster can be done through many scenarios. This paper focused on two scenarios namely typology development; and determining right, restriction and responsibility in spatial utilization [17]. FLFD with high intensity is an indicator of low level of responsibility, then it can be related to arrangement of right and restriction strategy. The paper strongly related to emphasis on restriction strategy which inline with the analysis result.

The study recommends the development of a typology model based on population, GDP per capita, agricultural land expansion rate, deforestation rate, and road length. The variable can be used to as variables in standing alone or interacting with the other. This have been considered by accuracy test and the data availability. In terms of land management in regional development, disaster
mitigation is important. The typology development facilitates the FLFD mitigation effort and has the ultimate goals to be zero fire in each typology.

The second scenario can be done through restriction in spatial utilization and accessibility. From the analysis, we knew that agricultural land expansion rate per year run into fluctuate. The forest transition process to be agricultural land has a high fire vulnerability. Management control, when a sharp increase of FLFD occurrences will be relatively difficult to overcome. It will occur when the plant rotation takes place simultaneously.

The land use efficiency and proportional land use changes per year can be a key success of declining the FLFD. Meso spatial planning design in landscape should have similar portion of land in each plant rotation. The design reflects sustainable natural resources management in a landscape. Improving the technology of land clearing by minimizing burning can be one of the big support in suppressing the FLFD.

Restriction of land expansion and accessibility in spatial planning can be a reference for areas that have not experienced of FLFD as disaster mitigation. While, areas that have experienced of FLFD need to be reorganized of land management. Spatial planning plays an important role in guiding land use change, one of which is sustainable agricultural expansion; which involves maintaining forest cover and local food production [18]. The FLFD plays an important role in ecosystems and climate change, which affects the structure and composition of vegetation and carbon dioxide emissions. The FLFD are driven by climate conditions and land use effect [19, 20] and the existing policy [21]. Emerging strategies for ecosystem management and disaster risk mitigation provide hope for betterment of human civilization.

4. Conclusions

The vulnerability FLFD typology development based on socio-economic and biophysical factors has good accuracy in the typology class separation. Using variables such as population, GDP per capita, agricultural land expansion rate, deforestation rate, and road length are options in the separation of the typology class. It will be related to the availability of continuous data in supporting typology development. The typology separation showed the potential degree of FLFD vulnerability occurrence. The typology development model based on agricultural land expansion rate can be the best variable, that has an accuracy of 86% on FLFD occurrence.

The development model of typology is needed to landscape clustering for early warning related to potential FLFD. It can be also used to reference for landscapes management which have experienced transition. Furthermore, meso spatial planning strategy can apply land use and land utilization along with effective and efficient accessibility.

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