Spatial analysis of hotspot data for tracing the source of annual peat fires in South Sumatera, Indonesia

A S Hamzah\textsuperscript{1}, Darmawan\textsuperscript{2}, B Sumawinata\textsuperscript{2}, Suwardi\textsuperscript{2}, G Djajakirana\textsuperscript{2}

\textsuperscript{1}Student of Soil Agrotechnology Study Program, Graduate School, IPB University, Jl. Meranti, IPB Dramaga Campus, Bogor, Indonesia
\textsuperscript{2}Department of Soil Science and Land Resources, Faculty of Agriculture, IPB University, Jl. Meranti, IPB Dramaga Campus, Bogor, Indonesia
basukis2@yahoo.com

Abstract. Forest and land fires in Indonesia have become the main national and global concern for the last decade. This disaster can cause enormous losses in the economic, social and environmental sectors because it occurs almost every year. The cause of these fires was always strongly believed to be of human activities (anthropogenic). A definite description of what activities most often cause fire incidences can be approximated by pointing out the initial fires that can be than correlated with kinds of activities that ignited the fires. The initial fires can be traced from hotspot data. Therefore, this study aimed to seek the initial fire locations in South Sumatera where there are activities of both small-scale farmers and big-scale industrial plantations on peatland and the adjacent non-peat areas. Daily hotspot data (MODIS) from 2014 to 2018 with a confidence level of more than 80\% of the South Sumatra wetland areas were used in this study. The result showed that the initial hotspots mostly detected on floodplains and coastal plains that are adjacent to the peatland that is called here as transitional land. The local community in these locations generally utilizes the land for rice or seasonal plant cultivation by burning the land (Sonor culture).

1. Introduction
Peatland fires in Indonesia have become a concern, nationally and globally. The frequency, number and severity of peatland fires in Indonesia have increased since the 1980’s [1]. The increasing incidence of forest and land fires occurred in the long dry season and closely related to climate anomalies, namely the El Niño-Southern Oscillation (ENSO) phenomenon such as in 1972-1973, 1982-1983, 1987, 1991-1992, 1994, 1997-98, 2002, 2006 and 2015 [2];[3]. The great fires which became a devastating disaster in Indonesia began in 1997/1998 and in the last decade, the disaster recurred in 2015 [2];[4];[5]. South Sumatera was recorded as the province with the largest fires, area of 646,298 ha [6]. The ignition of fire happened intentionally or unintentionally and it is aggravated by climate and physical environment [7]. The main causes of large-scale fires have been identified for land clearing and preparation by small-scale farmers, and several industrial land uses including forestry operations, timber plantations and agricultural plantations [8].

Hotspot data has been widely used as main data of fire identification. By the terminology, hotspot is an area of pixels in a satellite image data which is showing the areas having that have higher temperature than the surrounding areas captured by satellite sensor [9]. Global forest fire monitoring has been becoming very efficient by the availability of real time fire active data derived from Moderate Resolution Imaging Spectro-radiometer (MODIS) sensor on board of Terra-Aqua satellites with 1 x 1 km resolution. It has been widely used for national official hotspot monitoring and information, including Indonesia. It was also applied for Global burn scar estimation [10]. According to [11] the MODIS Active Fire Product User's Guide divides the three classes of confidence level (C) i.e. 0\% ≤ C ≤ 30\% (Low), 30\% ≤ C ≤ 80\% (Nominal), and 80\% ≤ C ≤ 100\% (High). For forest and land fires actually they can be more accurately determined by delineating a satellite images based on
burn scar. However, the MODIS data still can be used for this purpose especially those with high confidence level.

The aim of this study was to seek the initial locations as the source peatland fires in South Sumatera, where there are activities of both small-scale farmers and big-scale industrial plantations on peatland and the adjacent non-peat areas. The hotspots data was presented to show the areas that were detected repeatedly in years including those with low fire incidences. Thus, the results of this study were expected to provide a suggestion for the government of South Sumatra Province from different perspectives in monitoring and preventing fires on peatlands in the future.

2. Materials and Methods

2.1 Study Area

The location of this study (Figure 1) focused on wetlands located in the Province of South Sumatra, Indonesia. Administratively, this study were conducted at South Sumatra Province including: (a) Palembang City; (b) most area of Ogan Komering Ilir and Banyuasin Regencies; and (c) a small part of the northern part of Ogan Ilir and Muara Enim Regencies. The landforms of the study area were used as background (basemap) in clustering the distribution of the hotspots.

![Figure 1. The location of the study area](image)

2.2 Historical data of hotspots

Modis data set temporal was used to identification hotspot for a range of 2014 to 2018, especially the hotspots of the wetland areas in South Sumatera Province. The data set was downloaded as the Moderate Resolution Imaging Spectroradiometer (MODIS) Collection 6 Active Fire Product data from the official website of Fire Information for Resource Management System (FIRMS) NASA [12]. The coordinate of each hotspot was used to plot the hotspots on the basemap to show the spatial dimension. While, the temporal dimension of the hotspots was refered to the occurrence time in the data set.

2.3 Data Pre-processing and Analysis

Pre-processing and spatial analysis were done using ArcGIS version 10.2. The dataset was used in analysis that have high accuracy only those have a high confidence level of more than 80%. On pre-processing step, the landforms of the study area were classified by extracting data of Indonesia Land System Map [13], and peat areas of Indonesia Peatland Map [14]. The result class of the previous step were then reclass in 3 zone of landform, namely central, flood, and tidal zones. From a stratigraphic standpoint, the central zone is attributed to the peat-covered terraces that is located in the centre part of the lowlands. The flood zone is the highest part in toposequence of the lowlands. The tidal zone is the lowest part of lowland in toposequence that is located in the coastal plains [15].
The selected daily hotspot data are plotted on the three zonal landforms to describe the distribution of hotspots in the study area. Subsequently, identifications were carried out on hotspot data that have been plotted to trace the location of the earliest detected hotspots. These steps were done at locations where the hotspot data showed large and extensive fires which were characterized by a tight pattern of hotspots and broad clustering, especially in 2014 and 2015 where the greatest fires occurred. The technique of identification and presentation is done by calculating the number of hotspots and the order of their emergence based on the date in the areas detected which is represented by a certain area (defined as square areas with an area of around 2778 square kilometre).

3. Results and Discussions

![Figure 2](image)

**Figure 2.** The cumulative number of hotspot based on the coverage of the last 5 years

The total hotspots (MODIS data) in 2014-2018 amounted to 26226 in the study area, while the selected hotspots were 12644. The largest occurrence of hotspots in 2014-2018 occurred in 2014-2015, and the peak was detected in 2015 as shown in Figure 2. The highest incidence of forest and land fires in 2015 was initiated by long drought and El Nino phenomenon. The strong El Nino phenomenon occurred in August 2015 to March 2016. During the strong El Nino in that year, the atmospheric conditions were divided into two parts: (1) dry season months (August - October); and (2) rainy season months (November - March) [3].

3.1 Tracing source and distribution of hotspots in years with great fire incidences

![Figure 3](image)

**Fig. 3.** Hotspot data based on temporal dimension in 2014 and 2015

Figure 3 shows that the hotspot incidence in 2014 and 2015 where most of the hotspots existed from August to November and the peak in the range of September - October. Table 1 shows the accumulative hotspot that are group for each landform. The years with large fires related to the large
number of hotspots on peatlands, and vice versa that the hotspots were slightly detected in the year with a low incidence of fires. The data in this table cannot be used as a guide to detect the fire origins in the large peat fires of 2014 and 2015. Spatial hotspots in Figure 4a and 5a showed that hotspots were mostly detected on peatlands in the range of 2014n to 2015. The great fires occur because the long dry season causes uncontrollable fire propagation, where climate (such as rainfall distribution and El Nino phenomenon) is the main factor that aggravates it.

The initial hotspots detected in the study area in 2014 and 2015 (Figure 4b and 5b) were mostly on locations with flood zone and tidal zone that are adjacent to peatland that called as transitional area. Figure 4c, 4d, and 4e showed that hotspots in 2014 spread for 20 days from flood zone to central zone. In the other hand, hotspots started to recurred on tidal zone on the north-east part (Figure 4f and 4g). Similar thing was also happened in 2015 where the fires source was from tidal zone (Figure 5b, 5c, and 5d). Hotspots distribution was showed that initial fires source was not on the peatland, but on transitional land (flood zone or tidal zone). The transitional land was used by local community to cultivate seasonal plants to fulfil their needs (eg. Sonor culture).

The initial hotspots detected in the study area in 2014 and 2015 (Figure 4b and 5b) were mostly on locations with flood zone and tidal zone that are adjacent to peatland that called as transitional area. Figure 4c, 4d, and 4e showed that hotspots in 2014 spread for 20 days from flood zone to central zone. In the other hand, hotspots started to recurred on tidal zone on the north-east part (Figure 4f and 4g). Similar thing was also happened in 2015 where the fires source was from tidal zone (Figure 5b, 5c, and 5d). Hotspots distribution was showed that initial fires source was not on the peatland, but on transitional land (flood zone or tidal zone). The transitional land was used by local community to cultivate seasonal plants to fulfil their needs (eg. Sonor culture).

Figure 6 showed the Sonor farming system in Simpang Tiga village. Sonor culture is a traditional rice planting system in the areas of flood zone, which is only carried out during the long dry season (at least between 5-6 dry months). The Sonor farming system is considered practical and inexpensive by the community because it does not require maintenance, fertilization and treatment. The culture of Sonor in the Province of South Sumatra is closely related to peat fires that happened in these areas. Those lands in the dry season are overgrown with shrubberies and wild grasses. Hence, land clearing by burning must be done to be able to plant rice.

### Table 1: The number of hotspots in the study area on peat and non-peat landforms based on time dimension.

| Year | Landform | Jan | Feb | Mar | Apr | May | June | July | Aug | Sep | Oct | Nov | Des | Total |
|------|----------|-----|-----|-----|-----|-----|------|------|-----|-----|-----|-----|-----|-------|
| 2014 | A        | -   | -   | -   | -   | 2   | 2    | 10   | 1067| 1056| 254 | -   | -   | 2391 |
|      | B and C  | -   | 2   | 1   | 3   | 1   | 9    | 19   | 146 | 303 | 316 | -   | -   | 800  |
|      | Total    | -   | 2   | 1   | 3   | 3   | 11   | 29   | 1213| 1359| 570 | -   | -   | 3191 |
| 2015 | A        | -   | -   | -   | 3   | 1   | 8    | 110  | 2484| 5013| 317 | -   | -   | 7936 |
|      | B and C  | -   | 5   | 1   | 1   | 8   | 8    | 26   | 115 | 709 | 445 | 70  | 1   | 1389 |
|      | Total    | -   | 5   | 1   | 1   | 9   | 34   | 225  | 3193| 5458| 387 | 1   | 1   | 9325 |
| 2016 | A        | -   | -   | -   | -   | -   | 2    | -    | -   | 1   | -   | -   | -   | 3    |
|      | B and C  | -   | -   | -   | -   | -   | 3    | -    | -   | -   | -   | -   | -   | 3    |
|      | Total    | -   | -   | -   | -   | -   | 5    | -    | -   | 1   | -   | -   | -   | 6    |
| 2017 | A        | -   | -   | -   | -   | -   | -    | -    | -   | -   | -   | -   | -   | -    |
|      | B and C  | -   | -   | -   | -   | -   | 4    | 3    | 14  | 2   | -   | -   | -   | 23   |
|      | Total    | -   | -   | -   | -   | -   | 4    | 3    | 14  | 2   | -   | -   | -   | 23   |
| 2018 | A        | -   | -   | -   | -   | -   | 1    | -    | 6   | 16  | -   | -   | -   | 23   |
|      | B and C  | -   | 1   | 1   | -   | -   | 2    | 5    | 34  | 33  | -   | -   | -   | 76   |
|      | Total    | -   | 1   | 1   | -   | -   | 3    | 5    | 40  | 49  | -   | -   | -   | 99   |

Notes:  
A = Centre zone, peat land area  
B = Flood zone, floodplains area  
C = Tidal zone, coastal plains area  
(-) = No hotspot
Figure 4. (a) Hotspots distribution based on spatial dimension in 2014; (b) Tracing for source of fires based on date of hotspots incidence on September 01st – 15th; (c) September 01st – 30th; (d) September 1st to October 5th; (e) September 1st to October 10th; (f) September 01st to October 31th; (g) September 01st to November 30th.
Figure 5. (a) Hotspots distribution based on spatial dimension in 2015; (b) Tracing for source of fires based on date of hotspots incidence on August 01st – 31st; (b) August 01st to September 10th; (c) August 01st to September 30th; (d) August 1st to November 30th
3.2 Distribution of Hotspots during years with low fire incidences

Hotspots distribution in 2016 to 2018, were also the concerned in this study. In these years, the number and distribution of the hotspots were much lower indicating low incidence of forest and land fires. Figure 7 showed that the hotspots occurred from July to October in these years, and the peak occurred on September to October. All the data of 2016 – 2018 showed that the hotspots were always found every year in some locations in tidal zone and flood zone (Figure 9) and rarely found in central zone (peatland). Eventhough, there were hotspots found in peat area, spatially, they were closer to the transitional land between mineral and peat soil as shown in Figure 8a. Even, in 2017 there was no hotspots detected in peatland (Figure 8b).

![Figure 6. Sonor farming system in South Sumatera Province](image)

![Figure 7. Hotspot data based on temporal dimension in 2016, 2017, and 2018](chart)
Figure 8. Hotspots distribution based on spatial dimension in, (a) 2016, (b) 2017, and (c) 2018.
The same fires occurrence reoccurred in 2018 (Figure 8c) with an increasing number and distribution of hotspots compared to the 2016 – 2017 data. Even though, there were hotspots located on the peatland, but the number was much higher in the non-peatland area. The focus location for this study was in Padamaran, Kayu Agung, and the surroundings, and the north part of Muara Enim Regency and Ogan Ilir Regency, where hotspots were always detected in these locations. These locations are not peatland, but located in the flood zone landform. The local community in these locations generally utilizes the land for rice or seasonal plants cultivation by burning the land (Sonor culture).

Many policies such as UU No. 32 Tahun 2009 pasal 69 ayat (1) huruf h, PP No. 71 Tahun 2014, and Permen Lingkungan Hidup No. 10 Tahun 2010 forbid the land clearing by burning. However, land clearing by burning is allowed for area less than 2 ha with conditions that people should inform the headman or the related institution. Permit will not be given in a long dry season. Nevertheless, land clearing practice by burning the land is still done illegally by the local people to fulfil their needs. Therefore, the effective way to solve the forest and land fires is removing the source of fire, such as offering activities that can generate economic benefits in other sectors to increase the welfare of the local community, facilitating of the mechanization at low prices, and socialization of the fires hazards.

4. Conclusion
Hotspot distribution based on temporal data in 2014 – 2018 showed that the peak of fires frequently happened from September to October. During the great fires in 2014 and 2015, forest and land fires occurred in many places, including peatland, but the fire sources were mostly from the floodplains utilized by the local community for seasonal plant cultivation (eg. Sonor culture). In the years with much lower amounts of fires i.e. the year 2016, 2017 and 2018, the fires very rarely occurred on peatlands.

References
[1] Meijaard E, Dennis R 1997 Forest Fires in Indonesia: Bibliography and Background Information Amsterdam (Netherlands: World Wide Fund for Nature)
[2] Harrison M E, Page S E, Limin S H 2009 The global impact of Indonesian forest fires Biologist 6 (3) 156-163
[3] Athoillah I, Sibarani R M, Doloksaribu D E 2017 Spatial analysis of the 2015 strong El Nino and the 2016 weak La Nina (their influence on humidity, wind and rainfall conditions in Indonesia). J. Sains dan Teknologi Modifikasi Cuaca 18 (01) 33-41
[4] Page S E, Siegert F, Rieley J O, Boehm H V, Jayak A, Limin S H 2002 The amount of carbon released from peat and forest fires in Indonesia during 1997 Nature 420: 61-65
[5] Heymann J, Reuter M, Buchwitz M, Schneising O, Bovensmann H, Burrows J P, Massart S, Kaiser J W, Crisp D 2017 CO2 emission of Indonesian fires in 2015 estimated from satellite-derived atmospheric CO2 concentrations J. American Geophysical Union 44 1537–1544
[6] [Menlhk] Ministry of Environment and Forestry Republic of Indonesia 2015 Recapitulation of Forest and Land Fire Area (ha) Per Province in Indonesia 2014-2019 [Online] [Accessed in July 09, 2019] Available on: http://sipongi.menlhk.go.id/pdf/luas_kebakaran

[7] Mapilata E, Gandasasmita K, Djajakirana G 2013 Analisis Daerah Rawan Kebakaran Hutan dan Lahan dalam Penataan Ruang di Kota Pangka Raya Provinsi Kalimantan Tengah Majalah Ilmiah Globe 15 (2) 178-184

[8] Watts J D, Tacconi L, Hapsari N, Irawan S, Sloan S C, Widiastomo T 2019 Incentivizing Compliance: Evaluating the Effectiveness of Targeted Village Incentives for Reducing Burning in Indonesia Forest Policy and Economics 108 Doi https://doi.org/10.1016/j.forpol.2019.101956

[9] Usman M, Sitanggang I S, Syaufina L 2015 Hotspot distribution analyses based on peat characteristics using density-based spatial clustering Proc. Environmental Sciences 24 p 132 – 140

[10] Giglio L, van der Werf G R, Randerson J T, Collatz G J, Kashibhatla P 2006 Global estimation of burned area using MODIS active fire observation Atmos. Chem. Phys. 6 (9) 57-74

[11] Giglio L 2015 MODIS Collection 6 Active Fire Product User's Guide Revision A. Maryland (US): Department of Geographical Sciences, University of Maryland

[12] [FIRMS] Fire Information for Resource Management System 2019 Fire Archive Download Earthdata [Online] Available on: https://firms.modaps.eosdis.nasa.gov/data/download/DL_FIRE_M6_52094.zip. [Accessed in May 09, 2019].

[13] [RePPProt] 1988 Land Resources Department/Bina Program: Review of Phase I Results Sumatra from Regional Physical Planning Programme for Transmigration (RePPProt) Volume One Main Report (Jakarta: Land Resources Department, Overseas Development Natural Resources Institute, Overseas Development Administration, London, United Kingdom and Direktorat Jendral Penyiapan Pemukiman, Departemen Transmigrasi, Indonesia)

[14] Ritung S, Wahyunto, Nugroho K, Sukarman, Hikmatullah, Suparto, Tafakresnanto C 2011 Indonesian peatland map at the scale 1:250,000 (Bogor: Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian)

[15] Furukawa H 1994 Coastal Wetland of Indonesia: Environment, Subsistence and Exploitation (Japan: Kyoto University Press)