

IDENTIFICATION OF ASSOCIATION BETWEEN PM₁₀ AND HOTSPOT DISTRIBUTION DURING 2019 PEATFIRE EPISODE IN SOUTH SUMATRA PROVINCE, INDONESIA

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ABSTRACT

Exposure to air pollution from peat fires causes serious environmental issues. Peat fires occurred frequently and emitted particulates in some areas in Indonesia, including South Sumatra Province. Hotspots were commonly found in several areas, notably during the dry season. Objective of this study aims to elaborate the association between wildfire and PM₁₀ spatially and the possibility of wildfire contribution to PM₁₀ concentration during the 2019 dry season (June to October). The PM₁₀ concentration, meteorological data (wind direction and wind speed), and hotspot data had been collected. To address hotspot distribution from peat fire and large scale of wind direction in South Sumatra, the spatial analysis was used meanwhile the meteorological and PM₁₀ concentration were analyzed using RStudio by windrose and CBPF method. The provided PM₁₀ concentration data had violated national ambient air quality standard for 11 days. The detected hotspot area was distributed dominantly in OKI (Ogan Komering Ilir) Regency. The CBPF result and spatial analysis were found that the most probable source was likely coming from South East to East direction. The source was predicted from OKI Regency with a big portion of hotspots area (>50%). The study showed a good probability (0.6) that the prediction of the hotspot in OKI Regency contributed spatially and statistically to PM₁₀ concentration for receptor location in Palembang City.

KEY WORDS : Peat fire, PM₁₀, Hotspot, South Sumatra Province.

INTRODUCTION

Wildfire on peatlands is one of the major issues related to global warming and human health impact on the local to regional scale area (Uda *et al.*, 2019; Wooster *et al.*, 2018). Unmanaged peatlands released C stocks due to drought leading to peat oxidation, permafrost melting and fire. Carbon concentration in the atmosphere is predicted to be converted as peatlands respond to climate change and boosted atmospheric global warming potential because of CO₂ and CH₄ release to the atmosphere (Lundin *et al.*, 2008; Page *et al.*, 2016). Besides, other problems may affect human health directly such as peat fires

that emitted severe pollutants and threaten humans and the ecosystem. A change in the weather pattern, deforestation, and land-use change are some of the drivers for the increased fire occurrence. The fire tipping point occurrence usually is found in the dry season combined with human disturbance and increased accessibility to fire fuel and ignition sources.

The estimated peatland area has been characterized as covering 400 million ha or 3% of the Earth's land surface. Tropical peatlands in East Asia, Southeast Asia, the Caribbean, and Central America, South America, and Southern Africa covered an estimated area of 30 to 45 million ha or

10-12% of global peatlands resource where one of them was Indonesia. The peatlands area in Indonesia was around 14.91 million ha spread out in Sumatra, Kalimantan, and Papua Island. Sumatra island has the biggest portion (43%) of the peatlands area compared with other islands (below 40% coverage area) (Osaki *et al.*, 2016). In 1997, 2002, 2006, 2009, 2013, 2014, and notably in 2015, smoke from Indonesian peat fires resulted in severe haze pollution incidents affecting not only inhabitants of Indonesia but also becoming transboundary pollutant to countries near Indonesia and even countries further afield, such as Thailand and Philippines. Consequently, the effect caused serious health, economic and social impact (Page *et al.*, 2016).

Deforestation and draining of the peatlands during the great wildfire in September-October 2015 related to a strong El Niño primarily in Kalimantan and Sumatra caused the worst sustained outdoor air pollution ever recorded (Putra *et al.*, 2019). One of those impacts was the greatest air quality impact and daily average PM_{10} concentration often reaches 1,000-2,000 $\mu\text{g}/\text{m}^3$. In Palangkaraya, for instance, the maximum PM_{10} measurement reported $>3,000 \mu\text{g}/\text{m}^3$ which was 10 times the threshold standard of considered extremely hazardous for health (Wooster *et al.*, 2018). A similar occurrence of wildfire in South Sumatra as a research study that from 1st to 26th September in 2014, the maximum PM_{10} concentration reached up to 646.9 $\mu\text{g}/\text{m}^3$ with a range of 40-650 $\mu\text{g}/\text{m}^3$. The hotspot was reported more than 50 hotspots in several Regencies in South Sumatra. The trajectory study showed that the

sources possibly came from the southeast direction located Ogan Komering Ilir (OKI) regency. Meanwhile, the monthly concentration of PM_{10} in Palembang city was measured 292.37 $\mu\text{g}/\text{m}^3$ with peak concentration up to 1,369.34 $\mu\text{g}/\text{m}^3$ during wildfire episodes in 2015 (Raharja *et al.*, 2019). Since the peat fire occurred frequently, we need to continuously renew simulation and estimation to identify the relationship between peat fire represented by hotspots and PM_{10} concentration. The estimation can be used for monitoring and evaluation purposes. This study aims to identify provided PM_{10} concentration data during the 2019 peat fire and its association with hotspot using spatial and probability function analysis.

Methods

Study Area

The site area of this study was South Sumatra Province. Sumatra Selatan Province is located in the South of Sumatra Island established in 1950. The province covers an area of approximately 91,592.43 km^2 in 2019 with 13 regionals and 4 cities where Palembang City is the capital city of the province. Based on the Indonesian Ministry of Environment and Forestry data in 2017, South Sumatra province has around 2.1 million hectares of peatland (Figure 1).

The average meteorological aspects of relative humidity, wind speed, and precipitation were 85.9%, 3.9 knots, and 2,915 mm respectively (BPS-Statistic Indonesia, 20219). Peatland is distributed and spread out in many areas in South Sumatra. The

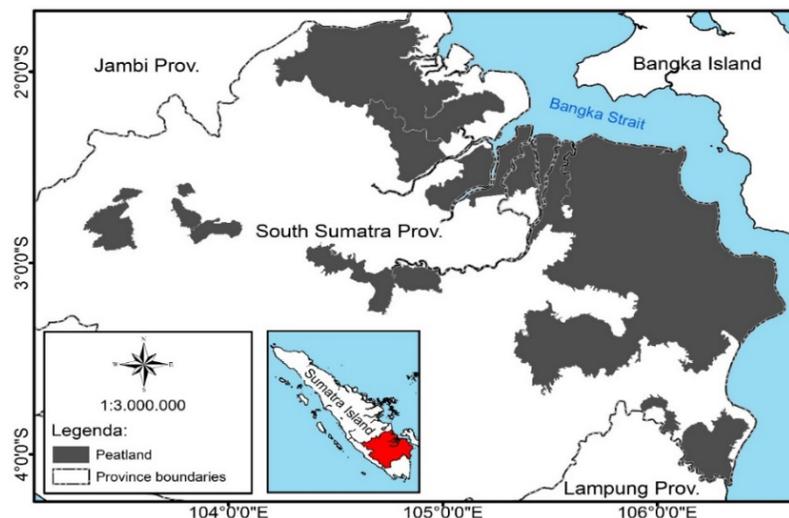


Fig. 1. Peat distribution in South Sumatra Province

distribution is shown in Figure 1. Unfortunately, peat fires had been occurring for many years and found dangerously in the past 10 years of September and October 2015. The peat fires episode has emitted air pollution which had considered dangers to health status (Sitanggang *et al.*, 2018).

Data Collection

Meteorological (wind speed and wind direction), PM₁₀ concentration, and hotspot data were collected from various sources during the wildfire episode (June to October 2019) as the period of this study. Meteorological data (a 30-minute data) for wind speed and wind direction were taken from AWS (Automatic Weather Station) located in Palembang City. To recognize the influenced wind direction to the site area broadly, satellite data was used from European Centre for Medium-Range Weather Forecast (*ecmwf.int*).

Identifying the probability of PM₁₀ concentration influenced the air quality monitoring station in Palembang City, we used an average daily of PM₁₀ pollutant concentration located in Palembang City based on the Ministry of Environment and Forestry website (*iku.menlhk.go.id/aqms/arsip*). The provided data on that website should be further interpreted since it met some conditions and limitations. Firstly, the data would be shown only one parameter that had the highest index compared with others and at least was only displayed every 09.00 a.m and 03.00 p.m for the public. The presented data was a 24-hour average data. Since the data should meet certain conditions, the missed PM₁₀ concentration data was set to be a limitation.

Hotspot data was taken from the National Oceanographic and Atmospheric Administration (NOAA). Hotspot distribution would show fire intensity around the study area. The 2019 hotspot data was downloaded in Fire Information for Resource Management System (*firms.modaps.eosdis.nasa.gov*) with 1 and 0.3-kilometer resolution.

Data Analysis

Data analysis was done by applying ArcGIS version 9.3 and RStudio version 1.1.456 Software. Hotspot and wind direction data by satellite-based were further analyzed and visualized by ArcGIS. PM₁₀ concentration was analyzed by R Studio for its descriptive data to identify the characteristic data during the research period. 30-minute wind speed and wind direction data during June-October 2019

were analyzed using the wind rose method in RStudio Software. The wind rose chart represents information regarding the frequency distribution of wind direction and its visualization (Varma *et al.*, 2013).

Identification of relationship (based on its probability) between PM₁₀ concentration and hotspot by finding the most probable sources for its pollution source from various directions called CBPF (Conditional Bivariate Probability Function). CBPF model is a statistical analysis with improvement from Conditional Probability Function (CPF) using wind speed in certain wind direction sectors. The CPF method is an effective way to estimate a particular source and the bivariate polar plots give additional information to address how dispersion occurs (Varma *et al.*, 2013). The CBPF approach presents better results compared to CPF with the application of wind direction sectors alone. The equation of CBPF can be defined as (Jerieviæ *et al.*, 2019; Masiol *et al.*, 2019; Uria-Tellaetxe *et al.*, 2014):

$$CBPF = \frac{m_{\Delta\theta, \Delta u} C_{\geq x}}{n_{\Delta\theta, \Delta u}} \quad .. (1)$$

where $m_{\Delta\theta, \Delta u}$ is the number of occurrences from wind sector $\Delta\theta$ (set at $\Delta\theta$: 45°) with wind speed interval Δu having concentration (C) greater than the threshold value. The provided PM₁₀ concentration (C) applies > 75th percentile as the threshold criterion. The high percentiles are represented by x notation. $n_{\Delta\theta, \Delta u}$ is the total number of occurrences from wind sector $\Delta\theta$ in a determined wind direction-speed interval. Wind speed less than 1 ms⁻¹ were excluded from the analysis because it categorizes as calm wind and has the isotropic behavior of the wind vane for such condition (Raharja and Meisda Dyni, 2019); (Sitanggang *et al.*, 2018).

RESULT AND DISCUSSION

Meteorological and Pollutant Analysis

In this research, surface wind measurement from AWS was also provided to identify the probability of PM₁₀ and hotspot relationship. The wind speed value was around 1.61 to 19.31 m/s with an average of 4.09 ± 2.67 m/s (n = 3,095). The wind direction was caused by the monsoon season. The frequency of counts by wind direction was further plotted using the wind rose plot that can be seen in Figure 2. The highest frequency was by wind direction 2 to 4

m/s. The wind direction tendency from June to October 2019 was coming from East (dominantly) to South East with various wind speed range. Furthermore, based on satellite data was found wind direction on large scale from the southeast into North-West. The PM₁₀ concentration had a range of 18.32 to 631.94 µg/m³ (n=43 data) during the research period with displayed data 09.00 a.m. There were 11 days far from Indonesia Air Quality Standard (150 µg/m³). The highest concentration from the provided data was detected in 631.94 µg/m³ on 23/09/19 followed by 555.61 µg/m³ on 02/10/19 and 436.02 µg/m³ in 19/09/19. All of these data had violated Indonesia Ambient Air Quality Standard (150 µg/m³).

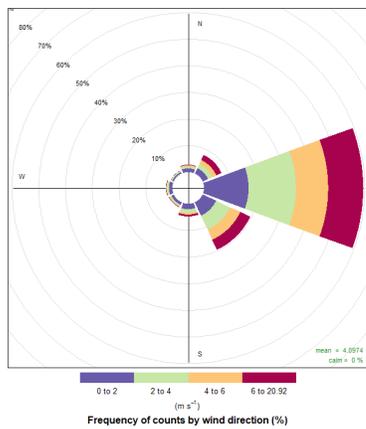


Fig. 2. Windrose Plot During June-October 2019

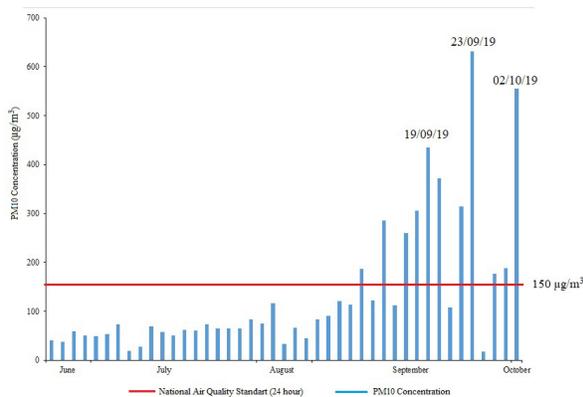


Fig. 3. PM₁₀ Concentration during June-October 2019

Hotspots Distribution

During June to October period was detected 7,611 hotspots in the South Sumatra peat area. Figure 4 provides spatial information of hotspot distribution around the study area. Of 1,043 hotspots had an 80% confidence interval in Ogan Komering Ilir (OKI) regency. The largest recorded fire was dominantly distributed in OKI Regency. About 57% of wildfire

area burned (equivalent to 91,214.37 Ha) was detected using ArcGIS software, followed by Banyuasin (21,4%) and Musi Banyuasin (13,4%) Regency.

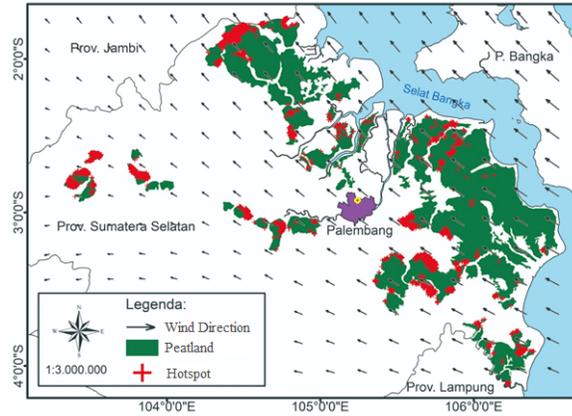


Fig. 4. CBPF Plot combined with hotspot area During June-October 2019

Hotspots and PM10 Relationship

The Association between the presence of hotspot and PM₁₀ was further analyzed based on trajectory analysis using CBPF method. Figure 4 gives information about the hotspot and spatially according to CBPF results. From the plot, a potential source of PM₁₀ was identified using a conditional probability function coupled with wind speed information. The ability to identify a source at a specific receptor location will depend on the prevailing meteorology (Uria-Tellaetxe et al., 2014). In this case, wind speed and wind direction data were applied to support the identification of hotspot and PM₁₀ pollutant association. The considered receptor location was only one site (BMKG-PLB) since its monitoring purpose is for ambient local air quality monitoring rather than another available local station monitoring of AQMS is for local road-side monitoring.

To understand better in PM₁₀ impact due to peat fire in South Sumatra based on monitoring station in Palembang city, the CBPF diagram (Figure 5) was plotted to show hotspot distribution (Figure 4). It shows that the South-East and East direction became the most likely sources detected. The probability coming from South-East and East was 0.6 with a range wind speed of 10-15 m/s. There were fewer wind conditions from North-East (See Figure 5). It makes clear information that a specific source can be detected. The OKI Regency had a big

portion (>50%) of hotspot area compared with others and had a good probability value (0.6) coming from South East and East Direction, which was estimated from OKI Regency. The data supported the estimation that PM_{10} concentration if the receptor location in Palembang City was influenced by the hotspot area in OKI Regency. The result had a similarity with the previous study in 2014 using the HYSPLIT model that OKI Regency was predicted to be a major source to contribute PM_{10} concentration in Palembang City (Raharja *et al.*, 2019). Wildfire can be a major contributor to atmospheric gaseous and particulate pollutants (Lazaridis *et al.*, 2008). The primary pollutants emitted from wildfires consist of greenhouse gases (CO_2 , CH_4), NMVOC (Non-methane volatile organic compound), NO_x , and aerosol (Urbanski *et al.*, 2008). PM_{10} is also one of the major contributors to the atmosphere due to wildfire. The particulate itself is a complex mixture of solids and aerosols composed of small droplets of liquid, dry solid fragments, and solid cores with liquid coatings. The pollutant presents in the fire chemical mixture contain a complex mixture of aerosols suspended in the air (Oliveira *et al.*, 2020).

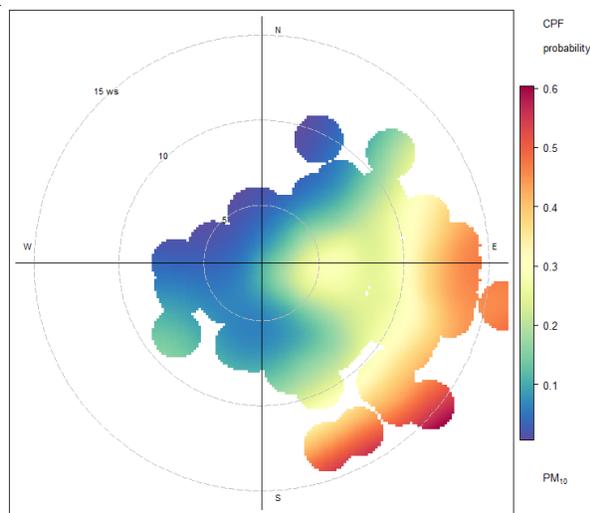


Fig. 5. CBPF Plot during June-October 2019

National Ambient Air Quality Standard had been violated in several days during the peat fire. This became a big problem and treated the population in Palembang city. It needed to be managed since Palembang city is the capital city of South Sumatra Province and the urban city had the 6th biggest population in Indonesia. Furthermore, it also caused a serious impact on another Regency located North-

West and West direction toward OKI Regency.

The high concentration because of smoke could affect visibility and other serious aspects such as economic, human health, and social problems. Air pollution can threaten visibility impairment. Based on online news of Tempo and Detik presented information that on 23/09/2020 (the highest concentration from provided data), visibility was reduced only up to 600 m (dropped 200 m) so that the Sultan Mahmud Badaruddin II Palembang Airport management delayed 18 flights due to an increased thickening haze (Detik, 2019; TEMPO, 2019).

Further research related to emission and chemical substances from peatland needs to be conducted to specify in more detail the sources. Besides, further and continuous simulation becomes essential to identify transboundary pollutants (inter-province, island, and country) to know the pollution behavior caused by a peat fire.

CONCLUSION

Peat fire Episode was identified regarding the hotspot, and its probability to contribute PM_{10} at the receptor location in Palembang City. Distribution hotspots were found in a large area (>50%) in OKI (Ogan Komering Ilir) Regency compared to other hotspots areas while PM_{10} concentration was identified 11 days violation of national ambient air quality standard based on provided data of BMKG-PLB. Further identification using spatial analysis and CBPF method was used to obtain spatial relationship and the most probable source contributing to PM_{10} concentration. The Southeast to East direction was likely PM_{10} coming from toward receptor site with a good probability of 0.6. The direction was identified coming from OKI Regency that also had a big portion of the hotspot area. This became a serious problem to human health, ecosystem, economic and social impact to Palembang City and other places located North-West and West direction toward OKI Regency.

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REFERENCES

- BPS-Statistics Indonesia, 2019. South Sumatera in Number 2019.
- Detik, 2019. Pagi Ini Jarak Pandang Rendah Terjadi di Sejumlah Bandara Akibat Kabut Asap. *Novel Dhwinuari Antony*. Sep. 23, 2019.
- Jerièeviaè, A., Gašparac, G., Mikulec, M. M., Kumar, P. and Prtenjak, M. T. 2019. Identification of diverse air pollution sources in a complex urban area of Croatia. *Journal of Environmental Management*. 243(July 2018), 67-77. doi: 10.1016/j.jenvman.2019.04.024
- Lazaridis, M., Latos, M., Aleksandropoulou, V., Hov, O., Papayannis, A. and Tørseth, K. 2008. Contribution of forest fire emissions to atmospheric pollution in Greece. *Air Quality, Atmosphere and Health*. 1(3): 143-158. doi: 10.1007/s11869-008-0020-0
- Lundin, L. and Moors, E. 2008. *Restoration of peatlands and greenhouse gas balances* (Issue January).
- Masiol, M., Squizzato, S., Cheng, M. D., Rich, D. Q. and Hopke, P. K. 2019. Differential probability functions for investigating long-term changes in local and regional air pollution sources. *Aerosol and Air Quality Research*. 19(4) : 724-736. doi: 10.4209/aaqr.2018.09.0327
- Oliveira, M., Delerue-Matos, C., Pereira, M. C. and Morais, S. 2020. Environmental particulate matter levels during 2017 large forest fires and megafires in the center region of Portugal: A public health concern? *International Journal of Environmental Research and Public Health*. 17(3) : 10-13. doi: 10.3390/ijerph17031032
- Osaki, M. and Tsuji, N. 2016. Tropical peatland ecosystems. *Tropical Peatland Ecosystems*. 1-651. doi: 10.1007/978-4-431-55681-7
- Page, S. E. and Hooijer, A. 2016. In the line of fire: the peatlands of Southeast Asia. *Philosophical Transactions of the Royal Society B: Biological Sciences*. 371(1696) : 20150176. doi: 10.1098/rstb.2015.0176
- Putra, R., Sutriyono, E., Kadir, S., Iskandar, I. and Lestari, D. O. 2019. *Dynamical Link of Peat Fires in South Sumatra and the Climate Modes in the Indo-Pacific Region*. 51(1).
- Raharja, A.B. and F. Meisda, Dyni. 2019. Particulate Matter 10 (PM10) Concentration Analysis During SMOG Disaster in Palembang (Case Study 26th September 2014). *Pros. SNSA 2015*, vol. 10.
- Sitanggang, I. S., Asti, A. D. and Agmalaro, M. A. 2018. Haze in urban areas from peatland fires in Sumatra based on simulation using HYSPLIT. *IOP Conference Series: Earth and Environmental Science*. 203(1). doi: 10.1088/1755-1315/203/1/012004
- TEMPO. 2019. Palembang Sees Flight Delays Due to Thickening Haze. *En.tempo.co*, Sep. 23, 2019.
- Uda, S. K., Hein, L. and Atmoko, D. 2019. Assessing the health impacts of peatland fires: a case study for Central Kalimantan, Indonesia. *Environmental Science and Pollution Research*. 26(30) : 31315-31327. doi: 10.1007/s11356-019-06264-x
- Urbanski, S. P., Hao, W. M. and Baker, S. 2008. Chapter 4 Chemical Composition of Wildland Fire Emissions. *Developments in Environmental Science*. 8(08) : 79-107. doi: 10.1016/S1474-8177(08)00004-1
- Uria-Tellaetxe, I. and Carslaw, D. C. 2014. Conditional bivariate probability function for source identification. *Environmental Modelling and Software*. 59 : 1-9. doi: 10.1016/j.envsoft.2014.05.002
- Varma, S. A. K. 2013. *Evolution of Wind Rose Diagrams for RTPP, KADAPA, A. P., India Abstract*:2(13), 150-154.
- Wooster, M. J., Gaveau, D. L. A., Salim, M. A., Zhang, T., Xu, W., Green, D. C., Huijnen, V., Murdiyarso, D., Gunawan, D., Borchard, N., Schirrmann, M., Main, B. and Sepriando, A. 2018. New tropical peatland gas and particulate emissions factors indicate 2015 Indonesian fires released far more particulate matter (but Less Methane) than current inventories imply. *Remote Sensing*. 10(4) : 1-31. doi: 10.3390/rs10040495