Forest Fire in East Nusa Tenggara during 2015-2019: Comparison to Forest Fire in Kalimantan and Sumatera

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Abstract. East Nusa Tenggara is one of the provinces in Indonesia that has big forest fires following some provinces in Kalimantan and Sumatra. However, forest fires in East Nusa Tenggara have less attention in forest fires discussion in Indonesia. This study aims to analyze forest fires in East Nusa Tenggara and their impact on reducing visibility and increasing carbon monoxide (CO) from 2015 to 2019. In this study, hotspot, forest fire area, Oceanic Niño Index, visibility, and CO total column data were used to analyze the forest fires using a statistical comparison method in East Nusa Tenggara, Kalimantan, and Sumatra. The result shows that the number of hotspots in East Nusa Tenggara less than in Kalimantan and Sumatra for the same forest fire area. The forest fires in East Nusa Tenggara do not harm the atmospheric environment significantly. East Nusa Tenggara dominantly consists of savanna areas with no peatland, hence, the forest biomass burning produces less smoke and CO. Furthermore, the forest fire in East Nusa Tenggara has not an impact on decreasing visibility and increasing CO total column, in contrast, visibility in Sumatra and Kalimantan has fallen to 6 km from the annual average, and CO total column rise three times of normal condition during peak fire.

1. Introduction
The forest fire events in Sumatera and Kalimantan are always getting serious attention in many forest fire discussions in Indonesia. Even in the international forest fire studies, fires in Kalimantan are the most discussed with the El Niño event, which is a meteorological factor causing forest fires to become more severe [1]. Forest fire in Sumatra and Kalimantan has increased both in burning duration and burned-area during an El Niño event that causes loss both economically and ecologically for Indonesia and neighbouring countries. However, a forest fire is affected not only by El Niño as a natural factor but also economic factors such as the transmigration program, crude palm oil (CPO) prices, log prices, and the Ministry of Forestry's budget policies [2,3].

One of the reasons why forest fires in Kalimantan and Sumatra become a concern on forest fire assessment is the amount of smoke that causes transboundary pollution. Smoke from forest fires in Sumatra has already polluted the Malacca Peninsula since the 1960s [3]. Smoke is a heterogeneous mixture of various chemical compounds influenced by the type of vegetation and the combustion process condition, such as wet or dry vegetation conditions, softwood or hardwood, smouldering, or flaming stage burnings [4]. Importantly, particulates in smoke in the atmosphere can lead to degrading the quality of visibility. The previous study revealed that the reduction of visibility is associated with PM10 concentration, with a strong correlation between those parameters during the forest fire in Palangka Raya [5]. However, Indonesia has a limited observation in particulate. Thus, the analysis of the reduction...
In visibility is effective enough to detect an increase in particulate concentrations as a result of forest fires owing to the availability of data at airports.

Besides smoke, carbon monoxide (CO) is also addressing as a crucial issue in forest fire. Carbon monoxide is a tasteless, odourless, and colourless toxic gas that leads to a lack of oxygen in the blood drives a fatal impact when someone inhales it [6]. Ideally, the carbon should be released into the atmosphere as CO₂ if the combustion process is complete. However, if the process is identified as incomplete combustion, it will produce carbon monoxide.

Due to the severe impact of forest fires in Sumatra and Kalimantan, it is as if forest fires in Indonesia only occur on both of the two major islands. The recapitulation of forest fires reported by the Ministry of Environment and Forestry shows that many high-intensity forest fires occur in other areas, such as in the East Nusa Tenggara province. The East Nusa Tenggara province has different characteristics from Sumatera and Kalimantan, such as climate conditions and forest biomass. Regarding the research in this area, there are limited publications related to forest fires in the East Nusa Tenggara region [7]. On the contrary, the forest fires in Sumatra and Kalimantan have been studied widely by previous researchers.

This paper aims to study the characteristics of forest fires in East Nusa Tenggara Province and compare them to forest fires in Kalimantan and Sumatra, which have different biota and climate characteristics. East Nusa Tenggara comprises savanna land about 22% of the land area with a semi-arid climate which affects the nature of its dry land [8, 9, 10]. On the other hand, Kalimantan and Sumatra do not have savanna with monsoonal rainfall types influence the majority of those regions [11]. Based on the peatland map of Indonesia, Kalimantan and Sumatra consist of peatlands as their dominant land. Additionally, many hotspots have been also observed on these peatlands [12].

2. Data and Method

This study focuses on the forest fire events in the South Sumatra, South Kalimantan, Central Kalimantan, and East Nusa Tenggara provinces due to the high intensity of its forest fires. The number of hotspots, Oceanic Niño Index (ONI), forest burned area, visibility, and CO total column were used in this research. In detail, the number of hotspots was identified by the SNPP and Modis satellite with Aqua and Terra sensors provided by LAPAN (http://modis-catalog.lapan.go.id/monitoring/hotspot/index). A confidence level of more than 80% is selected to determine this hotspot. To investigate the meteorological factors that affect the forest fire, El Niño events identify using the ONI that are available at https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php. Furthermore, the annual forest burned area reported by the Ministry of Environment and Forestry was used to identify the forest fire in each region of the study area. This data could be downloaded on the site (http://sipongi.menlhk.go.id/hotspot/exp_kebakaran).

The impact of forest fires was known by visibility reduction and increasing CO content in the atmosphere. Thus, this study also utilized the visibility data obtained from Ogimet station (https://www.ogimet.com/gsynres.phtml.en) at airports shown in Figure 1. The increase in CO content in the area covers both the province and its surrounding area, as shown in figure 1. This data obtained from the MOPITT data (https://giovanni.gsfc.nasa.gov/giovanni/) in the form of total column concentration, namely the number of molecules per 1 cm² area between the surface and the top of the atmosphere. Besides, this study also used other supporting data, such as the provincial administration.

In order to determine the intensity of forest fires in each province, this study arranged a sequence of forest fire areas in each province and the percentage of forest fire area to its provincial area. This rank sequence showed how high the intensity of forest fire in East Nusa Tenggara province. Furthermore, the correlation equation between the number of the hotspot and burned areas were used to analyze the relationship between both of them in each province [13].

The visible particulates are the essential emissions from forest fires seen as smoke and CO gas. Visibility parameters were used to determine the amount of particulate because there was a strong correlation between particulate matter and visibility during a severe forest fire [5, 14] and the wide availability of visibility data. The change in daily visibility was calculated as the value of the visibility deviation by the annual mean in the year when a major fire occurs. Meanwhile, the changes in CO gas
content could be seen from the change of the monthly average of a total column in the covered area, as shown in Figure 1.

Finally, all of the parameters studied above compared among fire seasons in East Nusa Tenggara, Sumatra, and Kalimantan, represented by the provinces of South Sumatra, Central Kalimantan, and South Kalimantan provinces.

A. South Sumatra:
1. Talang Betutu, Palembang (2°54’ S, 104°42’ E)

B. Central Kalimantan and South Kalimantan:
2. Muara Teweh (1°1’ S, 114°56’ E)
3. Pangkalan Bun (2°42’ S, 111°40’ E)
4. Palangka Raya (2°13’ S, 113°56’ E)
5. Banjarmasin (3°27’ S, 114°45’ E)
6. Kota Baru (3° 18’ S, 116° 45’ E)

C. East Nusa Tenggara
7. Ruteng (8° 36’ S, 120° 29’ E)
8. Maumere (8° 38’ S, 122° 14’ E)
9. Larantuka (8° 16’ S, 123° 0’ E)
10. Alor (8° 8’ S, 124° 36’ E)
11. Waingapu (9° 40’ S, 120° 18’ E)
12. Sabu (10° 29’ S, 121° 51’ E)
13. Rote (10° 46’ S, 123° 4’ E)
14. El Tari (10° 10’ S, 123° 40’ E)

Figure 1. Study Area

3. Result and Discussion
3.1. The Impact of weather on the forest fires
Table 1 shows the forest fire area in Indonesia during 2015 and 2019 based on the report by the Ministry of Environment and Forestry of the Republic of Indonesia. The most severe forest fire occurred in 2015 and 2019 with the fire-affected areas of about 26,114.11 km$^2$ and 15,920.10 km$^2$, respectively. Those conditions identified as abnormally dry years typically associated with the El Niño periods. As shown in Figure 2, the ONI in 2015 was more than two which is categorized as a strong El Niño event, while 2019’s condition was corresponding with weak El Niño that affected the prolonged dry season in Indonesia. On the contrary, when the ONI reached the negative value from 2016 to 2018, the burned-area was just below 5,000 km$^2$. As the result, the El Niño periods played an essential role in the forest fire activities in Indonesia. This condition is consistent with the previous study reported by Cahyono et al. [2] that the El Niño phenomena is a climate factor that leads to an extensive dry season and has a strong control in increasing the forest fires both its magnitude and duration.

| Year | Forest Fire Area |
|------|------------------|
| 2014 | 444.11 km$^2$   |
| 2015 | 26,114.11 km$^2$|
| 2016 | 4,383.63 km$^2$  |
| 2017 | 1,654.84 km$^2$  |
| 2018 | 5,292.67 km$^2$  |
| 2019 | 15,920.10 km$^2$ |
To identify the distribution of forest fire during the severe events as the impact of the El Niño period in 2015 and 2019, analysis of the distribution of affected area in each province and its percentage compared with the provincial area was carried out based on the data from Ministry of Environment and Forestry as shown in Figure 3. Interestingly, East Nusa Tenggara has an adequate large forest fire area both its burned area and the percentage to the provincial area especially in 2019. It can be seen that around 2.8% of the provincial area is affected by a forest fire which is the third-highest during that period.

Figure 2. Oceanic Niño Index (ONI) indices during 2015 – 2019

Figure 3. The forest fire area (x 1000 km²) and percentage of forest fire to provincial area in 2015 and 2019.
Additionally, the South Sumatera was the most affected area, both in burned-area and its percentage to the provincial area. It is also important to note that Central Kalimantan has the second-highest forest fire area of about 5.84 and 3.40 in 2015 and 2019, respectively. However, it was not followed by the percentage of the forest fire to the provincial area, Central Kalimantan placed in the third rank in 2015. Based on those results, therefore, the South Sumatera, Central Kalimantan, and South Kalimantan are used as representative of the forest fire phenomena in Sumatera and Kalimantan Island to compare with the East Nusa Tenggara in further analysis.

![Figure 4](image)

**Figure 4.** The percentage of forest fire area to provincial area

During the El Niño periods of 2015 and 2019, Sumatera has the highest proportion of forest fires. Interestingly, a similar condition occurred in the normal period when the ONI showed the value between -1 and 1 in 2018 as depicted in Figure 2, in approximately 3% of the provincial area was affected by the forest fire. On the other hand, when the weak La Niña took place in 2016 and 2017, the most affected-area of the forest fire can be found in East Nusa Tenggara. This comparison revealed that East Nusa Tenggara has a high forest fire through the dry season even though without triggered by any global phenomena such as El Niño events. Furthermore, when the La Niña occurred, the forest fire still could be found in this area.

### 3.2. The hotspot observation to the forest fire

The hotspot is one of the tools to detect a forest fire event. However, every hotspot cannot be identified as a forest fire, and vice versa. This statement is in agreement with the previous research that the area of a forest fire cannot be estimated by the number of the hotspot [15]. On the other hand, more recent studies were conducted to analyze the relationship between hotspot observation and forest fire as well as their impacts [14, 16, 17, 18]. For example, Tansey [19] has found a correlation between the number of hotspots and burned-area and showed that it was estimated that one hotspot is associated with approximately 15–16 ha of burned-area.

The linear correlation between forest fires and the number of hotspots observed by SNPP and MODIS satellites with TERRA and Aqua sensors is shown in Table 2. In detail, \( m \) is a gradient of the linear equation of the number of observed hotspots per-1 km of the forest fire area and \( r \) states as the correlation coefficient. It can be seen that South Sumatra has the highest correlation coefficient, while East Nusa Tenggara showed the lowest value according to all satellites. Regarding the type of satellites, SNPP gave the best performance in detecting the hotspot as a forest fire showed by the highest correlation in all provinces. Based on the criteria of strong and weak correlations (13,20), it can be said that the relationship between the number of hotspots and the area of forest fires has a strong to very strong correlation range, except for the Aqua satellite in observing forest fires in East Nusa Tenggara.

The gradient value (\( m \)) in the equation states the number of hotspots of each forest fire covering an area of about 1000 ha during a year. Importantly, the forest fire activities in East Nusa Tenggara showed a smaller number of the hotspot in the same burned-area. Actually, the forest fire in East Nusa Tenggara can be classified as savanna fire, due to the savanna is covering 22% of the provincial area (10). While
the savanna land has a low density of biomass and dryness lead to a sufficient combustion process in the flaming phase. Hence, the burning process took place rapidly. For an affected-area in a forest fire event, the hotspot has only been detected once by the satellite, or it has not been detected yet, but the fires have extinguished.

| Province                  | Terra |          |          | Aqua |          |          | SNPP |          |
|---------------------------|-------|----------|----------|------|----------|----------|------|----------|
|                           | m     | r        | m        | r    | m        | r        |
| East Nusa Tenggara       | 1.06  | 0.82     | 3.08     | 0.67 | 8.59     | 0.90     |
| South Sumatera           | 10.15 | 0.95     | 11.35    | 0.98 | 15.63    | 0.96     |
| Central Kalimantan       | 6.27  | 0.89     | 9.09     | 0.97 | 12.88    | 0.97     |
| South Kalimantan         | 5.80  | 0.79     | 9.35     | 0.87 | 10.49    | 0.88     |

On the contrary, Kalimantan and Sumatra Islands have a huge amount of peatland and are comprised of tropical forests causing the combustion process to occur in the smouldering phase which is taken place a long time for that process [21]. This is due to the high density of biomass, wetter biomass condition, and the combustion also occurs in the subsurface soil which is the area of the peatland. The forest fire that occurs in the same area can be detected by satellites many times, while the calculation of the hotspot number does not consider the adjacent location is counted as one location. Therefore, the number of hotspots in Kalimantan and Sumatera was higher than in East Nusa Tenggara for the same area.

According to those conditions, the burned-area cannot be estimated by the number of hotspots as reported by Prasasti et al. [15] if fires occur in some different forests such as tropical forest, savanna, or peat fire. The number of hotspots detected can be used to estimate the fire area if the fire occurred on the same forest land type as reported by Tansey [19]. To estimate the affected area of the forest fires from the number of detected hotspots should consider types the burned-area which determines the speed and duration of the biomass combustion process, as well as the type of sensors in the satellite.
The monthly hotspot distribution shows the different patterns of forest fire events (Figure 5). Interestingly, the forest fire events in East Nusa Tenggara occur relatively longer, from 4 to 6 months. This might be due to the climate condition identified as semi-arid with around 8–9 months of the dry season [9], and also the land use is dominated by savanna. On the contrary, South Kalimantan, Central Kalimantan, and South Sumatra are affected by monsoonal rainfall with the peak of the dry season is June–Augustus [11]. Therefore, it triggers the forest fire events that occur during 2–4 months in El Niño periods and reach a peak in August to September.

3.3. The hotspot observation to the forest fire

The forest fires generate a huge amount of smoke which significantly affects to degrade the visibility. Thus, this visibility reduction can lead to transportation disruptions especially flights. The analysis of the visibility changes is carried out by calculating the deviation visibility to its annual mean. Figure 6 shows the visibility deviation in the El Niño periods of 2015 and 2019 in several airports located in study area as depicted in Figure 1. The visibility is considerably decreasing due to the air pollution mainly particulates and certain meteorological factors such as relative humidity, temperature, and wind speed [22, 23, 24]. Based on the hotspot distribution as shown in Figure 5, it can be seen that the degradation of visibility in South Sumatra, Central and South Kalimantan is associated with the forest fires. On the other hand, East Nusa Tenggara has less quality of the visibility when there were no detected hotspots in around January–April. The tendency of visibility degradation in this area is not caused by the pollutant from the forest fire activities. Instead, meteorological factors might play a crucial role in this case [24].
Figure 6 Decreasing of visibility during El Niño events observed at some Airports: (a) South Sumatra, South and Central Kalimantan and (b) East Nusa Tenggara provinces

Figure 7 depicts the monthly mean of CO total column in South Sumatra, Central and South Kalimantan, East Nusa Tenggara, and its surrounding areas. The study of increases in CO gas in the atmosphere as an impact of forest fires has been widely conducted [25, 26]. The CO is a compound that resulted from incomplete combustion in carbon elements of fuel, including biomass. Hence, the CO is an interesting component to analyze due to its characteristics which are colourless and odourless gas but highly toxic.

The concentration of CO in East Nusa Tenggara was lower than in Sumatra and Kalimantan throughout this study period. Generally, the air quality in East Nusa Tenggara was better than other remaining areas. Those concentrations were just below $3 \times 10^{18}$ molecule/cm$^2$ or less than two times by normal condition during the El Niño events. In contrast, the CO concentration in Sumatra and Kalimantan reached a peak of approximately $6 \times 10^{18}$ molecule/cm$^2$ (three times of normal condition) in 2015. This high increase over Kalimantan and Sumatra is due to the amount of burned biomass and incomplete combustion process. On the other hand, complete combustion can generate CO$₂$ gas if there is sufficient oxygen. The supply of oxygen is available both in dry and low-density biomass, such as savanna, while wet and dense biomass, especially in the soil such as roots and peat lead to an insufficient supply of oxygen. As the result, biomass combustion in savanna over East Nusa Tenggara is more complete than the biomass of forest and peatland in Kalimantan and Sumatra, hence, produce less concentration of CO [4].
Further analysis shows that East Nusa Tenggara geographically comprises islands surrounded by ocean give advantages due to the sea breeze covering the islands of East Nusa Tenggara Province. As a result of research Grossi [27], show that sea breeze can lead reduction pollutant, although sometimes sea breezes can cause air pollutant subsidence [28] that leads to rising its concentration on surface levels but does not change column total concentrations. Besides the savanna fires emit relatively less amount of smoke and CO, sea breezes also restore the air quality rapidly in East Nusa Tenggara, hence the fires may not have a bad impact on the atmospheric environment. As the result, it is understandable that forest fire in East Nusa Tenggara has a sufficient number, however, got less attention due to the limited number of detected hotspots and give an insignificant impact on the atmosphere environment. Meanwhile, the carbon cycle of burned savanna land will regenerate rapidly by reabsorbing CO$_2$ in the atmosphere. Therefore, this condition is able to equalize the emission from the previous forest fires [29] and the savanna ecosystem was not seriously damaged by the fire [30].

4. Conclusion
Forest fire in East Nusa Tenggara occurred every year both in normal condition and during El Niño periods with longer duration than in Sumatera and Kalimantan. This might be due to the climate condition as semi-arid and its forest is dominated by savanna. It triggers the forest fire activities to occur in a flaming phase that generates a complete combustion process rapidly. As the result, fewer hotspots are detected in the same burned area and produce less amount of smoke that reduces the visibility and low emission of CO. In addition, East Nusa Tenggara consists of many islands surrounded by ocean that drive the water to remove the pollutant rapidly. Therefore, the forest fires in East Nusa Tenggara are harmless to the atmosphere environment.

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