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# Forest covers, land fire hotspots, and atmospheric pollutions (CO, $SO_2$) in the lower Batanghari River Basin landscape during dry season (June-August 2021)

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Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia. Jl. Lingar Akademik, Pondok Cina, Beji, Depok 16424, West Java, Indonesia. Tel/fax.: +62-21-786-3436. ♥email: awbio2021b@gmail.com

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**Abstract.** *Wibowo AA, Basukriadi A, Nurdin E. 2021. Forest covers, land fire hotspots, and atmospheric pollutions (CO, $SO_2$) in the lower Batanghari River Basin landscape during dry season (June-August 2021). Biodiversitas 22: 5678-5687.* Land fire is a major threat to the intact forest in Indonesia, including the rainforests of Sumatra. Land fires are caused by several factors, ranging from deforestation, slash and burn to farm, and also weather where land fires occur during dry seasons. Land fires that occur in forests can release significant amounts of atmospheric pollution in the form of CO and $SO_2$ emissions. Since there is a paucity of information about land fire hotspot distribution and atmospheric pollution in Sumatra's forest, this study aims to assess the distribution and impacts of land fires within the lower Batanghari forest landscape on atmospheric pollution during the dry season from June to August 2021. The study was conducted in 15 sampling locations covering three districts in the lower Batanghari landscape. The method uses a coupled ground-based and remote sensing measurement. For ground-based measurement, the CO and $SO_2$ emissions were determined based on in-situ observation of burned biomass in the field and calculation using Seiler and Crutzen equation. While the land fire hotspots were detected using combinations of VIIRS (Visible Infrared Imaging Radiometer Suite) and MODIS (Moderate-resolution Imaging Spectroradiometer) remote sensing sensors. The result shows that 65.85% of the land fires that happened in the lower Batanghari landscape occurred within forests. In West Tanjung Jabung District, 70.37% of land fires were observed within forests, in East Tanjung Jabung was 60% and 55.55% for Muaro Jambi District. The weekly land fires, CO, and $SO_2$ emissions were high in June as the onset of dry season. In West Tanjung Jabung, this district has the highest weekly land fires, CO, and $SO_2$ emissions. The ranges of CO and $SO_2$ emissions when land fires occur were 200-350 ppbv and 1.5-2.75 ug/$m^3$. The Principal Component Analysis confirms that the frequency of land fires was positively correlated with CO rather than $SO_2$ emissions. This concludes the magnitude of land fires in forests that have the potential to release significant atmospheric pollutants.

**Keywords:** Air pollutant, CO, forest, land fires, $SO_2$

## INTRODUCTION

Land fire hotspots are described as occurrences of fire in natural landscapes and ecosystems (Coogan et al. 2019). In Southeast Asia (Huijnen et al. 2016), occurrences of land fires were related to the massive land-use conversions from intact tropical rainforest to the plantation either for oil palm or rubber plantation (Carlson et al. 2018; Schoneveld et al. 2019). Land fire has been involved in the land-use conversions and replanting of plantations. Land-use conversions from rainforest to plantation involved land clearing using the slash and burn methods that cause a land fire. The aggregate annual 2000-2015 land-use conversions rate across all plantations was 3.3%/year. Land-use conversions increased from 0.74%/year in 2001 to a maximum of 6.5%/year in 2012 before falling to 4.0%/year in 2015 with similar temporal dynamics for forest and primary land-use conversions. The frequency of land fire hotspots is positively correlated with the weather. More land fire hotspots are occurring during the dry seasons from June to September. Dry seasons characterized by high temperatures and low rainfall have made vegetations in the forest, including trees, bushes, and grasses become drier and vulnerable to fire. Dry seasons have increased the availability of combustion materials in forests (Adrianto et al. 2020; Budiningsih 2017).

Land conversion has converted 14.4 mha of old-growth rainforest in Indonesia into plantations (Gaveau et al. 2016). Higher land-use conversion rates were correlated with smaller remaining rainforest areas. In Sumatra, the plantations had a higher aggregate land-use conversion rate equals 7.5%/year. From 2000 to 2015, rainforest loss in plantations in Sumatra equals 5,451 $km^2$. This land-use conversion using the slash and burn method has led to land fire hotspots in plantations nearby rainforests. Active land fire hotspot rates from 2002 to 2015 averaged 0.078 fire detections per square kilometer per year. Land fire hotspot rates in all plantations were lower from 2007 to 2013 compared with the 2002-2006 and current 2014-2015 periods. As of September 2019, the number of land fire hotspots in Indonesia was 2,583 with coverage of land and forest fires equal 328,724 Ha. In Sumatra Island, there are 3 provinces that have the most land fire hotspot numbers and forest fire events. Those provinces include South Sumatra, Jambi, and Riau. Land fire hotspots are a cause of major national and international concern because of the large air pollutant emissions associated with these land fires (Misra et al. 2021) and the negative impact of air pollutant emissions on human health, transport, tourism, economic activity in the Southeast Asian region.

A land fire hotspot in forests can release pollutants (Ribeiro-Kumara et al. 2020) include heavy metals (As, Cd, Cu, Cr, Hg, Pb, Zn), greenhouses gases (carbon dioxide/$CO_2$, methane/$CH_4$, nitrogen protoxide/$N_2O$) (Jones et al. 2019), ammonia ($NH_3$), and air pollutants. Under the group of air pollutants, there are nitrogen oxides (NO, $NO_2$, $N_2O$) (Butterbach-Bahl et al. 2013), sulphur oxides ($SO_2$, $SO_3$), non-methane Volatile Organic Compounds (VOC), carbon monoxide (CO), and particulate matter with diameter less than 10 µ ($PM_{10}$) (Trozzi et al. 2002). The emissions of those air pollutants can play a significant role in atmospheric chemistry and contribute to climate change (Sannigrahia et al. 2020, Vasquez 2021). Several air pollutants generated from land fires that need to be concerned are CO and $SO_2$. Land forest fires contribute to the to the emissions of CO ranging from 225 ± 109 mg/g to 277 ± 21 mg/g caused by the land forest fire in China (Guo et al. 2020). The removal of trees and forests from the ecosystem will cause a release and accumulations formaldehyde, phenol, sulfide hydrogen ($H_2S$), nitrogen oxides ($NO_x$), ammonia ($NH_3$), carbon monoxide (CO), hydrogen fluoride (HF), and common particulate matter (PM) (Krupnova et al. 2020).

In contrast to greenhouse gas emissions, the content of atmospheric pollutants such as CO and $SO_2$ is poorly quantified in the literature due to difficulties in estimating their temporal and spatial distribution, particularly in Indonesia. At the same time, there is still a paucity of information about the relationship between forests, land fires, and atmospheric pollutions, mainly in the lower Batanghari River Basin forest landscape. On the contrary, most of the land fire studies were assessed in the upper and central parts of the Batanghari River Basin. Information about the land forest fires and their release of atmospheric pollution, mainly in the lower Batanghari River landscape, is very important and required immediately. This is considering that the lower Batanghari River landscape has intact lowland rainforest with its vast biodiversity that needs to be conserved (Susanti et al. 2020; Tamin et al. 2019). While at the same time, the landscape is threatened due to deforestation, land-use conversion, plantation expansion, slash and burn practices that have all led to the increase in land fires (Vadrevu et al. 2019). Then, considering this situation, this study aims to assess the distribution and impacts of land fires within the lower Batanghari forest landscape on atmospheric pollution.

## MATERIALS AND METHODS

### Study area

The study area was located in the lower parts of the Batanghari River Basin in the east of Sumatra Island of Jambi Province, Indonesia (Figure 1) and these lower parts cover several districts. This basin is formed because of the Batanghari River streams with a length of 800 km. It is the second-largest river basin in Indonesia, covering 4.4 million Ha or 44,555 km$^2$. The landscape of this basin is characterized by several mountains and a strait. The basin represents a large river basin area dominated by forests, plantations, and agricultural land-uses. An intensive conversion of land-use from forest to agriculture was encountered in this basin. The mountain ranges are located in the western parts of the basin with the highest peak is observed in Mount Kerinci with an altitude of 3,800 m. The central and east parts of the basin were dominated by rainforest, lowland, and peatlands with an altitude of 100 m. The average temperature of this basin is 23°C, with the lowest temperature of 22°C observed in January and the hottest temperature of 24°C observed in June. The average annual rainfall is 2,383 mm with the highest average monthly rainfall of 344 mm in December and the lowest average monthly rainfall of 90 mm observed in August. Overall, the basin covers 14 districts including Batanghari, Kota Jambi, Merangin, Bungo, Tebo, Sarolangun, Muaro Jambi, East Tanjung Jabung, Kerinci, Kota Sungai Penuh, Dharmasraya, Sijunjung, Solok, Solok Selatan Districts. While the lower Batanghari River Basin located in the east is covering East Tanjung Jabung, West Tanjung Jabung, and Muaro Jambi Districts. The lower parts were at an elevation of 0 m since it is located near the coasts between 0.7337°-2.1561°S and 102.6572°-104.4650°E. There are several important ecosystems in the lower parts of the basin since the basin has high diversity including forests and peatland that are now threatened by deforestation.

West Tanjung Jabung District in the lower parts of the Batanghari River Basin has a topography that varies from an altitude of 0 meters above sea level in the east to an altitude above 500 meters above sea level, to the west. The morphology of the land is changing towards the west in the Bukit Tiga Puluh National Park (TNBT) area, which borders the Tebo District and Riau Province. For the parts of West Tanjung Jabung with elevation ranging from 0-25 meters above sea level, the soil structure is mostly peat soil and is influenced by tides and tidal waves. West Tanjung Jabung has a wet tropical climate with small variations depending on relative humidity. The highlands of West Tanjung Jabung have a max temperature of 27°C and the lowlands have a temperature of 32°C, while the average rainfall per year is 241.48 mm with a monthly rainfall range of 100-300 mm/month (Table 1). In West Tanjung Jabung, the total size of the landscape that is covered by forests is 238,871 Ha. Production forests (permanent/ limited), peatland reserves, Pantai Timur forest reserves, and the Bukit Tiga Puluh National Park (TNBT) are among the forest types. The size of the permanent production forest is 171,165 Ha, and 44,082 Ha for a limited production forest. Since West Tanjung Jabung was located near the east coast of Sumatra, this district had a peatland cover that was protected with a size of 14,746 Ha. At the same time, the protected terrestrial forests included TNBT, which was 8,791 Ha in size, and Pantai Timur Forest Reserve, which was 87 Ha in size (Tanjabbarkab 2016).

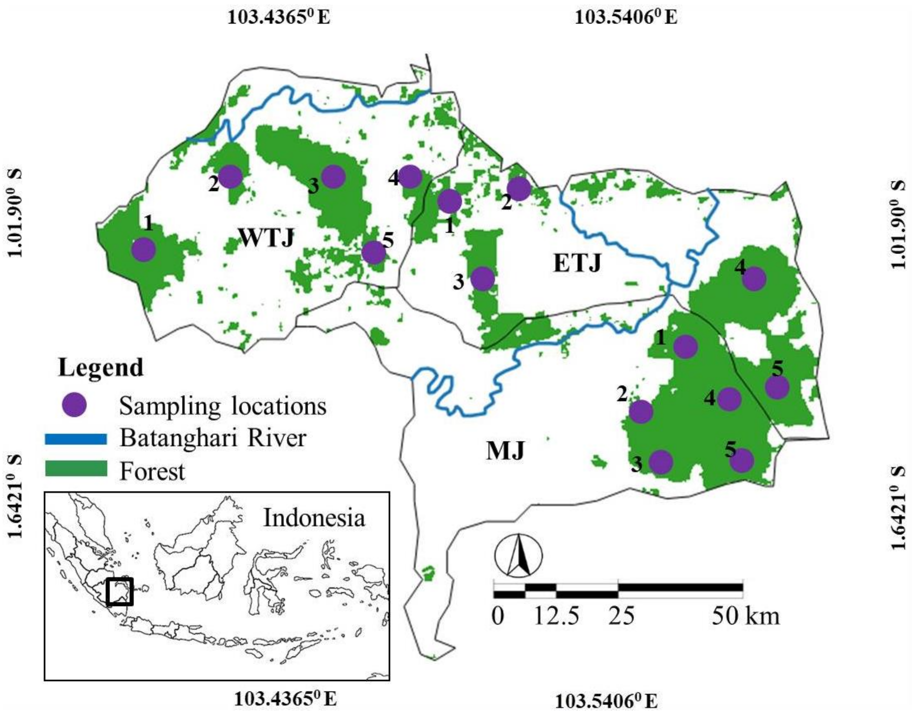



**Figure 1.** Study area, forests, and 15 sampling locations in West Tanjung Jabung (WTJ), East Tanjung Jabung (ETJ), and Muaro Jambi (MJ) Districts in the lower Batanghari River Basin landscape.

**Table 1.** Landscape characteristics of West Tanjung Jabung (WTJ), East Tanjung Jabung (ETJ), and Muaro Jambi (MJ) Districts in lower Batanghari River Basin

| Districts | Area ($km^2$) | Elevation (m) | | Temperature (°C) | | Monthly rainfall (mm/month) | Forest size (Ha) |
|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | | |
| WTJ | 5,009 | 0 | 500 | 27 | 32 | 100-300 | 238,871 |
| ETJ | 5,445 | 0 | 10 | 25 | 27 | 179-279 | 203,921 |
| MJ | 5,246 | 0 | 35 | 24 | 33 | 156-451 | 162,700 |

The East Tanjung Jabung District is located in the eastern part of the West Tanjung Jabung District. The landscape of this district is characterized by a vast lowland rainforest. The forests in East Tanjung Jabung include national parks, wildlife reserves, peatland reserves, community forests, and production forests. In this district, the size of Berbak National Park is 116,605 Ha, peatland reserve is 24,288 Ha, Pantai Timur mangrove reserve is 3,932 Ha, and 2,678 Ha for the community forest. At the same time, the forest that can be utilized includes a permanent production forest with the size of 55,083 Ha and 1,355 Ha for the forest that can be converted (Tanjabtimkab 2019). Muaro Jambi is the neighboring district of East Tanjung Jabung, located in the southern parts of East Tanjung Jabung. The prominent forest covers in the Muaro Jambi are observed within the Berbak National Park, which has a size of 162,700 Ha. The Berbak National Park is shared by East Tanjung Jabung and Muaro Jambi. The northern parts of the national park are located in East Tanjung Jabung and the southern parts are in Muaro Jambi. Muaro Jambi has a temperature range of 24°C to 33 °C and a monthly rainfall range of 156-451 mm/month (Table 1). The coordinates of 15 sampling locations in West Tanjung Jabung, East Tanjung Jabung, and Muaro Jambi Districts are available in Table 2.

**Sampling locations**

Several sampling locations were located in the East Tanjung Jabung, West Tanjung Jabung, and Muaro Jambi Districts. In each district, 5 sampling locations were placed within the forest patches (Figure 1). In each sampling location, several sampling activities were conducted. Those activities include surveying the forest, confirming the presence of land fire hotspots as detected by remote sensing, and sampling the CO and $SO_2$ for a period of June-August 2021.

**Table 2.** The coordinates of 15 sampling locations in West Tanjung Jabung (WTJ), East Tanjung Jabung (ETJ), and Muaro Jambi (MJ) Districts in lower Batanghari River Basin

| Districts | Sampling locations | Coordinate | |
|---|---|---|---|
| | | Longitude (East) | Latitude (South) |
| WTJ | 1 | 102.8219° | 1.1476° |
| | 2 | 103.0050° | 0.9792° |
| | 3 | 103.2525° | 0.9893° |
| | 4 | 103.4773° | 1.0754° |
| | 5 | 103.3236° | 1.1751° |
| ETJ | 1 | 103.5042° | 1.0885° |
| | 2 | 103.7448° | 1.0133° |
| | 3 | 103.6042° | 1.1729° |
| | 4 | 104.2626° | 1.3045° |
| | 5 | 104.3144° | 1.5214° |
| MJ | 1 | 104.0857° | 1.4126° |
| | 2 | 104.0549° | 1.5472° |
| | 3 | 104.0376° | 1.6865° |
| | 4 | 104.2043° | 1.5065° |
| | 5 | 104.2410° | 1.6555° |

## Methods

*Measuring CO and $SO_2$*

The method for measuring CO and $SO_2$ followed Gustina (2021) and Olivia et al. (2020). Measurement of CO and $SO_2$ involved measurement activity in each sampling location and calculation in the laboratory. Measurement is based on the amount of burning material recorded from the land forest fire field data. In each sampling location that has a fire hotspot and has been burnt, individual trees and shrubs were measured for their Diameter at Breast Height and Diameter at Base according to their state, whether alive or dead. The diameter was measured using a tape meter. The measurement results were then used to estimate the amount of biomass burnt. Then the first step is to calculate the amount of material burned. The method steps include estimation of the biomass burnt, estimation of the total carbon emitted, and calculation of the emissions of CO and $SO_2$ compounds.

Estimation of the biomass (M) burnt follows a Seiler and Crutzen (1980) equation as follows:

$$M = a \times b \times A \times B \times \rho CO \text{ or } \rho SO_2$$

Where:

a: the fraction of biomass above the surface,

b: the burning efficiency of the vegetation which exists above the ground,

A: the area burnt as measured in each sampling location and denoted as $m^2$,

B: the mean biomass quantity per area unit denoted as kg/ $m^2$,

$\rho CO$: the carbon in dry matter denoted as ton C/ton dry matter,

$\rho SO_2$: The level of sulfur at dry matter denoted as ton S/ton dry matter

The next step is the calculation of pollutant emissions (E) for CO and $SO_2$ as follows (Gustina 2021):

$$E_{CO} = M_{CO} \times EF_{CO} \times 18/12$$
$$E_{SO2} = M_{SO2} \times EF_{SO2} \times 64/32$$

Where:

$EF_{CO}$: emission factor for CO equals 0.0068

$E_{SO2}$: emission factor for $SO_2$ equals 0.00043

*Forest landscape classification and mapping*

The forest landscape and cover in the lower the Batanghari River Basin within East Tanjung Jabung, West Tanjung Jabung, and Muaro Jambi Districts were classified using Geographical Information System (GIS) methods with ArcView 3.2 (Thoha and Triani 2021). The method is started with the retrieval of Batanghari River Basin boundary and Landsat 8 Operational Land Imager (OLI) images of this basin with a spatial resolution of 30 m per pixel. The Landsat 8 OLI imagery of the basin was then classified into several districts and forest covers (Utami et al. 2017). The result is a thematic layer in the form of shapefiles (shps) of districts located in the lower Batanghari River Basin with their forest covers.

*Land fire hotspot classification and mapping*

Land fire hotspot data from June, July, and August 2021 were obtained from Terra/Aqua satellite using the combinations of VIIRS (Visible Infrared Imaging Radiometer Suite) and MODIS (Moderate-resolution Imaging Spectroradiometer) remote sensing sensors (Kumari and Pandey 2019; Lin et al. 2020). The VIIRS (Csiszar et al. 2014) sensor has a resolution of 375 m per pixel and MODIS is 1000 m per pixel. The use of 2 different sensors aims to obtain more land fire hotspot data. The VIIRS was used to cover and detect land fire hotspots in small areas and MODIS to cover fire hotspots in large areas (Gustiandi et al. 2020; Indradjad et al. 2019). The land fire hotspot data is then classified as points by using GIS methods with ArcView 3.2. The result is a thematic layer in the form of shp files of fire hotspot distributions sharing the same coordinate and projection with lower Batanghari River Basin, forest cover, and administrative district layers. The presence of land fire hotspots as detected by remote sensing were confirmed in the field.

*NDVI analysis*

The method used to measure the Normalized Difference Vegetation Index (NDVI) of the lower Batanghari landscape followed Philiani et al. (2016), Kawamuna et al. (2017), and Sukojo and Arindi (2019). The NDVI is described as a simple graphical indicator that can be used to analyze remote sensing measurements, often from a space satellite platform, assessing whether or not the target being observed contains live green vegetation. The NDVI was measured by analyzing the wavelengths of a satellite image retrieved from Landsat 8 containing vegetation images and in this study, forest covers. This measurement is possible since the cell structure of leaves in the vegetation strongly reflects near-infrared light wavelengths ranging from 0.7 to 1.1 µm. The calculation of NDVI for each pixel of vegetation was as follows:

NDVI = near-invisible red wavelength-red wavelength / near-invisible red wavelength + red wavelength

The NDVI was denoted as a range from 0 (no vegetation) to 1(high vegetation density). The NDVI values were then overlayed and mapped into lower Batanghari landscape layers using GIS. The forest covers were then categorized and classified using NDVI as follows: (i) if 0 < NDVI < 0.5 then NDVI is low; (ii) -if 0.6 < NDVI < 1.0 then NDVI is high.

### Data analysis

The land fire hotspots, CO, and $SO_2$ concentrations were presented as average and visualized as a graphic. The data were grouped based on districts include East Tanjung Jabung, West Tanjung Jabung, and Muaro Jambi and the period from June to August 2021. Principal Component Analysis (PCA) was used to test correlation significance between land fire hotspots, CO, and $SO_2$ concentrations. A statistical analysis tool known as R Version 3.6.1 has been used to perform PCA. Recently, PCA has been used widely in forestry (Erzsébet and Cristea 2013; Yahya and Roslan 2015) and land forest fire (Carlucci et al. 2019; Saghri et al. 2011) researches. This happens since PCA has an advantage in classifying a huge of information into manageable meaningful quantities in comparison to other correlation analysis methods. Cluster analysis is concerned with the classification and there is no prior knowledge about which element belongs to which cluster. In this regard, PCA was run to explore the intensity of change in basic attributes of land fire hotspots, CO (ppbv), and $SO_2$ (ug/m$^3$) over the time period of June-August 2021. This technique was run on a data matrix of land fire hotspot indicators calculated as a three month weekly average, producing a central value separately for each of three months. This land fire hotspot value was compared with the corresponding value of CO and $SO_2$ variables at the beginning of each time interval of June-August 2021.

## RESULTS AND DISCUSSION

### Land fire hotspot distributions

Land fires were observed whether in forests and non-forest areas in Batanghari River Basin landscape. The non-forest areas here are defined as settlements, paddy fields, and open fields. The result shows that 65.85% of land fires that happened in the Batanghari River Basin landscape was occurred within forests (Figure 2). In West Tanjung Jabung District, 70.37% of land fires were observed within forests, in East Tanjung Jabung was 60% and 55.55% for Muaro Jambi District. Figure 3 shows the distributions of weekly land fires based on the districts and the period. For all districts, the fire hotspots decreased from June to August 2021. June was the month with the highest fire hotspots and then the hotspots have decreasing trends. Based on the district, the West Tanjung Jabung district always has the highest weekly land fires that exceed other districts. The highest weekly land fire average, equaling five fires/week was observed in the West Tanjung Jabung in June 2021. Districts that have fewer weekly land fires are East Tanjung Jabung and Muaro Jambi. Figure 6 shows the distributions and exact locations of land fires across the forest covers in the lower Batanghari River Basin landscape in 3 districts. In the West Tanjung Jabung district, it is observed that most of the land fires occur in the forests. In East Tanjung Jabung, land fires also occurred in forest areas. While in Muaro Jambi, land fires occurred in the forest areas that are in the vicinity of Berbak National Park. Figure 7 shows the distribution of land fire hotspots related to the NDVI values of the Batanghari River Basin landscape. It is also clear that land fires occurred in areas where the NDVI values were also high, with values equaling 0.6-1.0. High NDVI values indicate that the areas where land fires are present contain forest covers.

### CO and $SO_2$ distributions

Air pollution variables measured in this study are CO and $SO_2$. As can be seen in Figure 4, CO was observed increasing from June to July 2021 and decreasing in August 2021. This trend was observed for CO in all districts. The CO was observed within a range of 200-350 ppbv in June and July. In August, it was between 200 and 250 ppbv. All districts were observed to have a similar level of CO. The $SO_2$ was observed to be high from June to July and then decline in August. East Tanjung Jabung, followed by West Tanjung Jabung, were districts that had high $SO_2$. The range of $SO_2$ in those districts was 1.5-2.75 ug/m$^3$. Whereas, a lower $SO_2$ range equaling 0.25-0.75 ug/m$^3$ was observed in Muaro Jambi District (Figure 5).

### Correlations of land fire hotspots, CO, and $SO_2$

Figure 8 shows land fire hotspots have a significant positive correlation with CO. It indicates that the increase in weekly land fire frequency will be followed by an increase in CO. In contrast, $SO_2$ tends to be more independent and is not related to the presence of land fires. Land fire hotspots, CO, and $SO_2$ were observed to be high, especially in June and July. On the contrary, land fire hotspots, CO, and $SO_2$ were observed less in August.

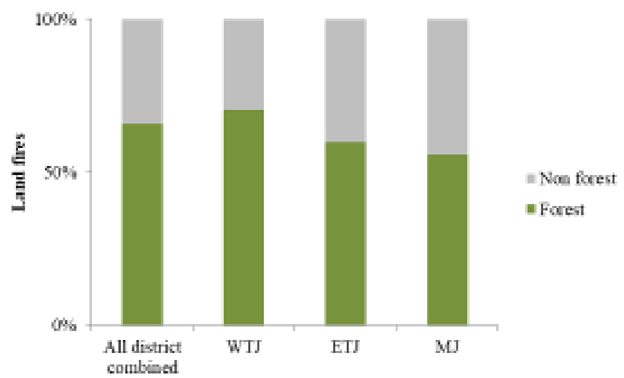



**Figure 2.** Land fire (%) comparisons between forest and non forest in all combined districts, West Tanjung Jabung (WTJ), East Tanjung Jabung (ETJ), and Muaro Jambi (MJ) of lower Batanghari River Basin forest landscape.

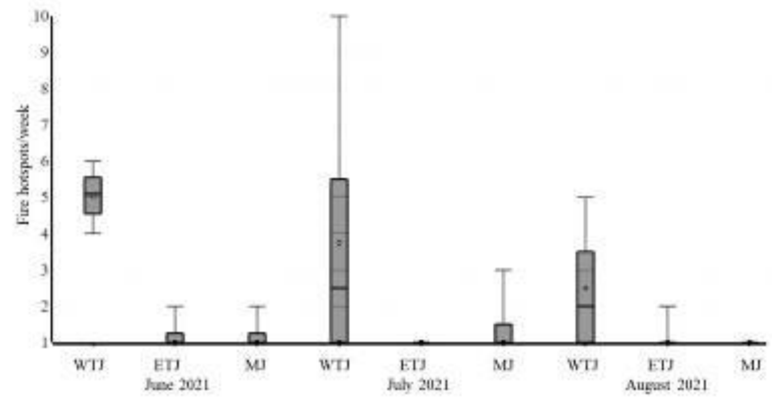



**Figure 3.** Averages of land fire hotspots/week in West Tanjung Jabung (WTJ), East Tanjung Jabung (ETJ), and Muaro Jambi (MJ) of lower Batanghari River Basin forest landscape from June to August 2021

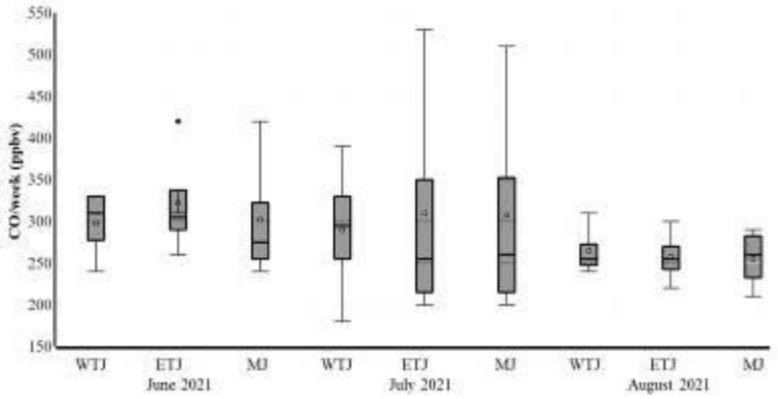



**Figure 4**. Averages of CO/week (ppbv) in West Tanjung Jabung (WTJ), East Tanjung Jabung (ETJ), and Muaro Jambi (MJ) of lower Batanghari River Basin forest landscape from June to August 2021

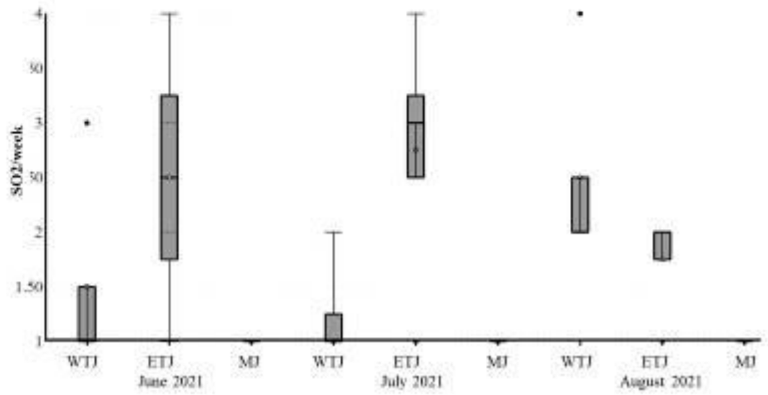



**Figure 5**. Averages of $SO_2$/week (ug/m$^3$) in West Tanjung Jabung (WTJ), East Tanjung Jabung (ETJ), and Muaro Jambi (MJ) of lower Batanghari River Basin forest landscape from June to August 2021

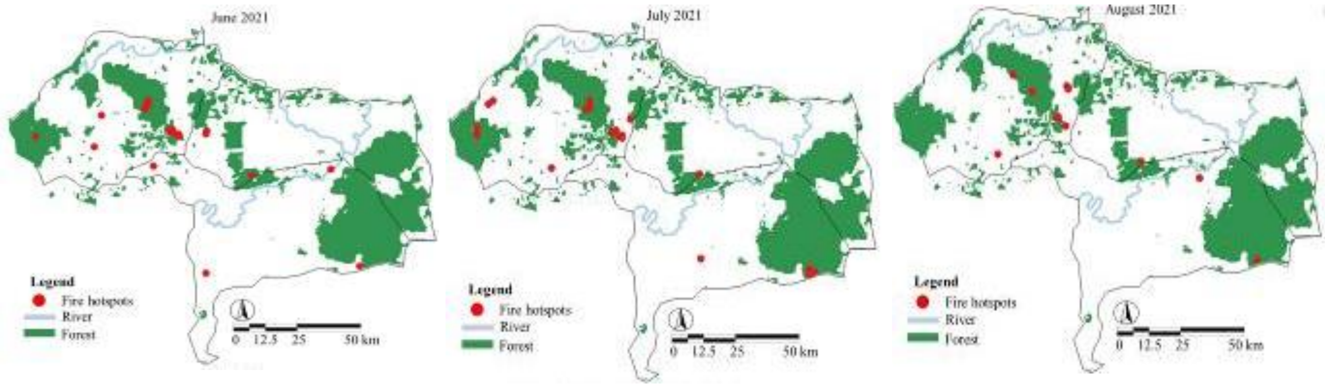



**Figure 6.** Map depicting the distribution of land fire hotspots and forest covers in the lower Batanghari River Basin landscape from June to August 2021. A. June 2021, B. July 2021, C. August 2021

## Discussion

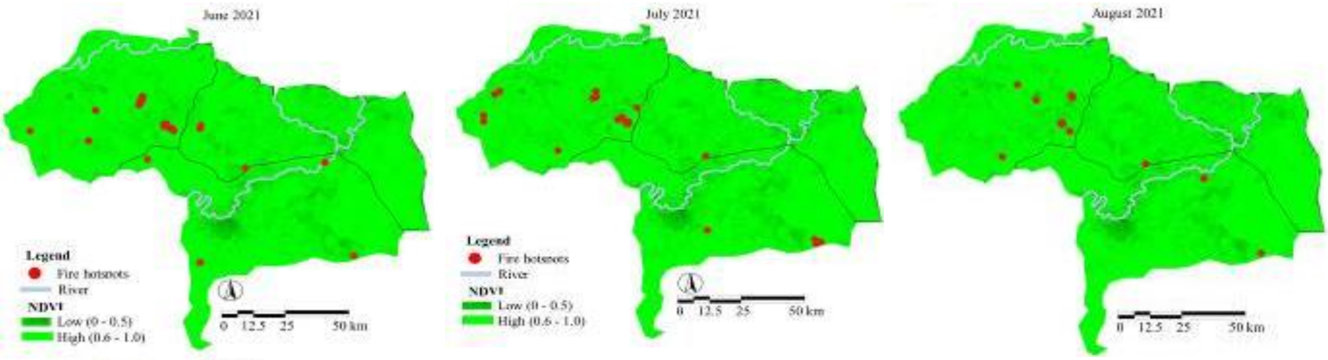
The result of this study confirms that atmospheric pollution, especially CO, is associated with land fires resulting from burning forest biomass. This association was in agreement with previous studies. Wiggins et al. (2021) recorded that land fires in the Boreal forest can release 828-1,103 Tg of $CO_2$, 88-128 Tg of CO, and 2.9-4.7 Tg of $CH_4$. This represents 13.8% of global fire CO emissions. In this study, the land fire in Batanghari in June released CO with a range of 200-350 ppbv. This amount is similar to the CO released during massive land fires in the Western US in 2007 and 2012 (Mallia et al. 2014), Saddleworth Moor (Graham et al. 2020) in 2018, and in California in 2020. Land fire is also releasing $SO_2$ to the atmosphere (Liu et al. 2017). In Batanghari, the recorded $SO_2$ was comparable to the $SO_2$ recorded in the past wildfire in Jambi Province in the past massive land fire events in 1997 (Prasetyo et al. 2016).

In the lower Batanghari, land fires increased with the onset of the dry season from June to July 2021, when rainfall was also decreasing. Figure 8 shows land fire and CO were high, especially in June and July. As a comparison, (Abatzoglou and Williams 2016), significant declines in summer precipitation throughout parts of the northwestern United States hastened increases in fire-season fuel aridity, consistent with observed increases in the number of consecutive dry days across the region. Similar patterns of how the season affects precipitation and land fires were also observed here in Indonesia. A large number of fire activities that occurred in El Nino years, namely 2002, 2006, and 2009 in Kapuas District, happen when rainfall decreases. As a result, land fire hotspots increase drastically in June-August almost every year in Southeast Asia (Thoha et al. 2019).

In forests in India, most of the fire hotspots were found in the midyear period between the months of March and April. The percentage increase observed in the month of March of maximum temperature, wind velocity, and solar radiation were 36, 39, and 62%, and a 60% decrease in relative humidity that was observed in the same month is the major cause of fire hotspots in the month of March onwards (Ahmad and Goparaju 2019). The similar effects of the climate and drought season on fire hotspots were also confirmed in a recent study in Sumatra. Previous extreme fire occurrences in North Sumatra in 2005 and in South Sumatra in 2006 could be partially explained by an enhanced drought occurrence due to El Niño events. The two different seasonal fire activities in N. and S. Sumatra were closely associated with the two different dry season types, including a winter and summer dry season in N. Sumatra, and a summer dry season type in S. Sumatra. This strong influence of the drought season on hotspot numbers (Lu et al. 2018) explains the increasing trends of land fires in the lower Batanghari River Basin following dry seasons that started in June.

In the lower Batanghari landscape in this study, some fire hotspots were detected in the vicinity of an intact and protected forest that includes the national park. The presence of fires near intact forests was associated with encroachment, land-use conversion, and the slash-and-burn method for agricultural purposes. In this study, a land fire was detected in the Berbak National Park located within the Muaro Jambi District. A recent study has reported several occurrences of land fires in this park. In 1997/1998, large numbers of fires in Berbak occurred 1997/1998. Less fire is found during the period of 2000-2018 (Mora et al. 2019).

Encroachment and the slash-and-burn method are two agricultural activities that are still considered the easiest alternatives for farmers. Various activities that were often carried out by communities around the forest used fire, which could not be separated from their connection with livelihoods or additional activities. In Jambi Province, farmers generally start slashing in March and burning in the months of July and August. Burning takes place, starting with a broadcast burn, followed by pile-and-burn. The reasons for using fire, as mentioned by the farmers, were that burning could create space, burning can produce ash that can be used as fertilizer, burning can improve soil structure, enabling the faster establishment of seedlings especially herbaceous plants, burning can reduce weed/tree competition, and burning can also reduce the occurrence of pests and diseases (Njeri et al. 2017; Purnomo et al. 2021).




**A** **B** **C**

**Figure 7**. Map of the distribution of land fire hotspots and NDVI in the lower Batanghari River Basin landscape from June to August 2021. A. June 2021, B. July 2021, C. August 2021

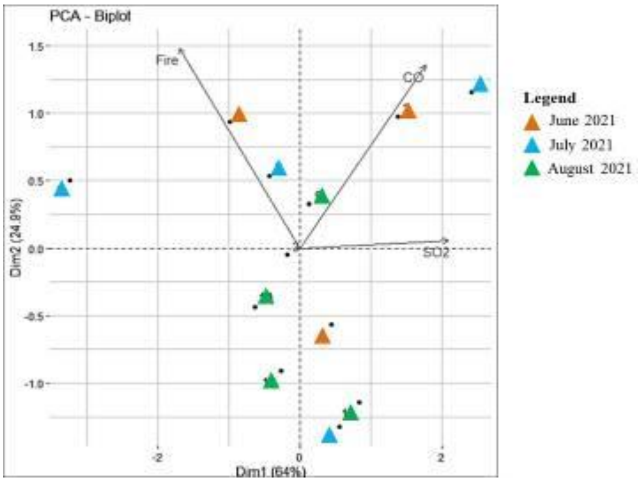



**Figure 8.** Principal Component Analysis (PCA) of land fire hotspots (Fire), CO (ppbv), and $SO_2$ ($ug/m^3$) in the lower Batanghari River Basin landscape from June to August 2021.

One of the greater concerns and consequences regarding land fires, followed by the presence of atmospheric pollutants, falls into the following issues. First, is regarding the potential for transboundary effects in the form of transboundary haze that can reach the neighboring countries, especially during the dry season. Referring to land fire hotspot occurrences in recent years, the transboundary haze caused by forest fires in Indonesia and, in particular, Jambi Province has affected air quality in neighboring Singapore and Malaysia for many years (Forsyth 2014). Previous studies have shown that land fires with their atmospheric pollutants have impacted the health conditions of nearby communities (Kadir 2021). The impacts are increased upper respiratory tract infection (URTI) and pneumonia cases. The data from InfoDatin (2015) shows the increase in land fire hotspots in June as the onset of the dry season was followed by an increase in URTI cases. While the number of land fire hotspots was declining at the end of the dry season from September to October, the URTI cases also decreased. Perwita and Sukana (2015) had confirmed that the prevalence of pneumonia cases in Batanghari before the dry season and the presence of land fires were 0.22. While the prevalence increased almost fivefold to 1.1.7 after the dry seasons and the land fire was present.

To conclude, land fire hotspots in the lower Batanghari River Basin reached their peak in June and July 2021, and then showed declining trends in August 2021. West Tanjung Jabung is the district that has the highest land fire hotspot. Land fire hotspots occur in the lower Batanghari River Basin and have been linked to atmospheric pollutants.

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