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FIRE HOTSPOT AND PARTICULATE MATTER ($PM_{2.5}$) DISTRIBUTION PATTERNS IN TROPICAL RAINFOREST ECOSYSTEMS OF BATANGHARI RIVER BASIN IN JULY 2021

POLA DISTRIBUSI TITIK PANAS API DAN PARTICULATE MATTER ($PM_{2.5}$) DI EKOSISTEM HUTAN HUJAN TROPIS DAS BATANGHARI PADA BULAN JULI 2021

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ABSTRACT

Rainforest in the Batanghari River basin is one of the tropical ecosystems that currently is threatened by deforestation, slash and burn swidden farming that lead to the increased numbers of fire hotspots. The fire hotspots are high in midyear during the dry season when a swidden farming activity starts. Then this study aims to assess the distribution of fire hotspots and its impact in the form of $PM_{2.5}$ contents. The study was conducted in the rainforest of the Batanghari River basin in midyear in July 2021. The methods to classify the rainforest covers and to detect fire hotspots and $PM_{2.5}$ contents were based on remote sensing and GIS analysis using Landsat 8 OLI, VIIRS, and MODIS remote sensing imageries. The result showed increasing trends of daily fire hotspot numbers in the rainforest of the Batanghari River basin for one month in July 2021. There were significant differences in the daily average of fire hotspots based on the week (P = 0.006, F = 8.677). The daily average of hotspots in the first week of July 2021 was 1.333 hotspots (95%CI: 0-3.94 hotspots). Whereas in the third and fourth weeks, there were sharp increases in the daily average of hotspots. In the third week, the average of hotspots was 4.333 hotspots (95%CI: 0-9.04 hotspots) and increased almost threefold in the fourth week with 11.000 hotspots (95%CI: 7.61-14.4 hotspots). In the areas where the fire hotspots have occurred, the PM2.5 contents ranged from 30 to 80 µg/m^3.

Keywords: *basin, fire, hotspot, $PM_{2.5}$, tropical rainforest*

ABSTRAK

Hutan hujan di DAS Batanghari merupakan salah satu ekosistem tropis yang saat ini terancam oleh deforestasi dan perladangan berpindah yang menyebabkan meningkatnya jumlah titik api. Titik api tinggi pada pertengahan tahun selama musim kemarau ketika kegiatan perladangan berpindah dimulai. Terkait dengan hal itu, penelitian ini bertujuan untuk menganalisa sebaran titik api dan dampaknya berupa kandungan $PM_{2.5}$. Penelitian dilakukan di hutan hujan DAS Batanghari pada pertengahan tahun pada bulan Juli 2021. Metode untuk mengklasifikasi tutupan hutan hujan dan mendeteksi titik api dan kandungan $PM_{2.5}$ berdasarkan pada penginderaan jauh dan analisis SIG menggunakan citra Landsat 8 OLI, VIIRS, dan MODIS. Hasil penelitian menunjukkan tren peningkatan jumlah titik api harian di hutan hujan DAS Batanghari selama 1 bulan pada Juli 2021. Terdapat perbedaan yang signifikan rata-rata harian titik api berdasarkan minggu (P = 0,006, F = 8,677). Rata-rata harian titik panas pada minggu pertama Juli 2021 adalah 1,333 titik api (95%CI: 0-3,94 titik api). Sedangkan pada minggu ke-3 dan ke-4 terjadi peningkatan tajam rata-rata harian titik panas. Pada minggu ke-3, rata-rata titik panas adalah 4,333 titik api (95%CI: 0-9,04 titik api) dan meningkat hampir 3 kali lipat pada minggu ke-4 dengan nilai 11,000 titik api (95%CI: 7,61-14,4 titik api). Di wilayah yang pernah terjadi titik api, kandungan PM2.5 berkisar antara 30 hingga 80 µg/m^3.

Kata kunci: *api, DAS, PM2.5, hutan hujan tropis, titik panas*

INTRODUCTION

Fire hotspots are described as occurrences of forest fire in natural landscapes and ecosystems. In Southeast Asia, occurrences of forest fire were related to the massive land-use conversions from intact tropical rainforest to the plantation either for oil palm or rubber plantation [1, 2]. 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 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 high of 6.5%/year in 2012 before falling to 4.0%/year in 2015. Peat and primary land-use conversions experienced similar temporal dynamics. In Indonesia, 14.4 million hectares of old-growth rainforest have been converted to plantations [3]. Higher rates of land-use conversion were associated with smaller remaining rainforest areas. As a result, while Kalimantan plantations had a lower aggregate land-use conversion rate (4.1%/year) than Sumatra plantations (7.5%/year), total 2000–2015 rainforest loss in plantations was greater in Kalimantan (18,439 km^2) than Sumatra (7.5%/year) (5,451 km^2). This slash-and-burn land conversion has resulted in fire hotspots in plantations near rainforests. From 2002 to 2015, active fire hotspot rates averaged 0.078 fire detections per square kilometer per year. Fire hotspot rates were lower in all plantations from 2007 to 2013, compared to 2002–2006 and the current 2014–2015 periods.

As of September 2019, the number of fire hot spots in Indonesia was 2,583, with coverage of land and forest fires equaling 328,724 ha. In Sumatra Island, three provinces have the most fire hotspot numbers and forest fire events. Those provinces include South Sumatra, Jambi, and Riau.

Because of the large Greenhouse Gases (GHG) emissions associated with these fires [4] and the negative impact of resulting aerosol emissions on human health, transportation, tourism, and economic activity in the Southeast Asian region, fire hotspots are a major source of national and international concern. Fire hotspots can produce a higher proportion of fine particles known as $PM_{2.5}$. These particles, which are 30 times smaller than human hair, are more easily absorbed and have a negative impact on human health. Air pollution in Southeast Asia is caused by vehicles in major cities, but it is caused by fires in places like South Sumatra and Riau. During the last forest fire in Palangkaraya, Central Kalimantan, a fire hotspot was responsible for the rising of $PM_{2.5}$. Normally, the $PM_{2.5}$ level was 19 µg/m^3 in conditions without the presence of a forest fire. Whereas, during a forest fire, the $PM_{2.5}$ level increased to 129 µg/m^3 [5]. Patterns of high $PM_{2.5}$ levels were inconsistent with provinces that frequently have massive numbers of fire hotspots.

Batanghari River basin is located in Jambi Province that has experienced forest fires. Jambi alone has a rainforest ecosystem sizing of 2,179,440 ha. Despite the size of the rainforest and the importance of the river basin, whereas information on the distribution of fire hotspots along with $PM_{2.5}$ resulting from fire hotspots mainly in the rainforest of the Batanghari River basin is still limited. Then this study aims to assess the distribution of fire hotspots along with $PM_{2.5}$ contents resulted from fire hotspots to contribute to the conservation efforts of this basin and at the same time reduce the impacts of $PM_{2.5}$ to the population living nearby the basin. The study was conducted in July since July is the onset of the dry season when the rainforest becomes vulnerable to fire in dry season because of its drought condition.

METHODS

Descriptions of the study area. The study area was located in the Batanghari River basin located between 1˚0'0''– 3˚0'0'' S and 101˚0'0'' – 104˚0'0'' E (Figure 1). 81% of this basin is located in Jambi, and the rest about 19% is in West Sumatra Provinces. In record, it is the second largest river basin in Indonesia, covering an area of 4.4 million hectares or 44,555 km^2. This basin is surrounded by several mountains and a strait. 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 basin covers 14 districts including Batanghari, Kota Jambi, Merangin, Bungo, Tebo, Sarolangun, Muaro Jambi, Tanjung Jabung Timur, Kerinci, Kota Sungai Penuh, Dharmasraya, Sijunjung, Solok, Solok Selatan Districts. The basin encompasses a large river basin area dominated by forests, plantations, and agricultural land use. In this basin, there has been a rapid conversion of land use from forest to agriculture. This basin's average temperature is 23 ºC, with the lowest temperature of 22 ºC in January and the highest temperature of 24 ºC in June. The average annual rainfall is 2,383 mm, with December having the highest average monthly rainfall of 344 mm and August having the lowest average monthly rainfall of 90 mm.

Batanghari land-use and rainforest classification and mapping. The rainforest ecosystem in the Batanghari River basin was classified using Geographical Information System (GIS) methods with ArcView 3.2 [6]. The method is started with the retrieval of the 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 land-uses classes, including forest, swidden farming, plantation, paddy field, bush, open field, settlement, and water body [7]. The result is a thematic layer in the form of shapefiles (shp) of the Batanghari River basin rainforest and land-uses.

Fire hotspot data distribution and mapping. Fire hotspot data for one month in July 2021 were obtained from Terra/Aqua Satellite using the combinations of Visible Infrared Imaging Radiometer Suite (VIIRS) and Moderate-resolution Imaging Spectroradiometer (MODIS) remote sensing sensors [8, 9]. The VIIRS sensor

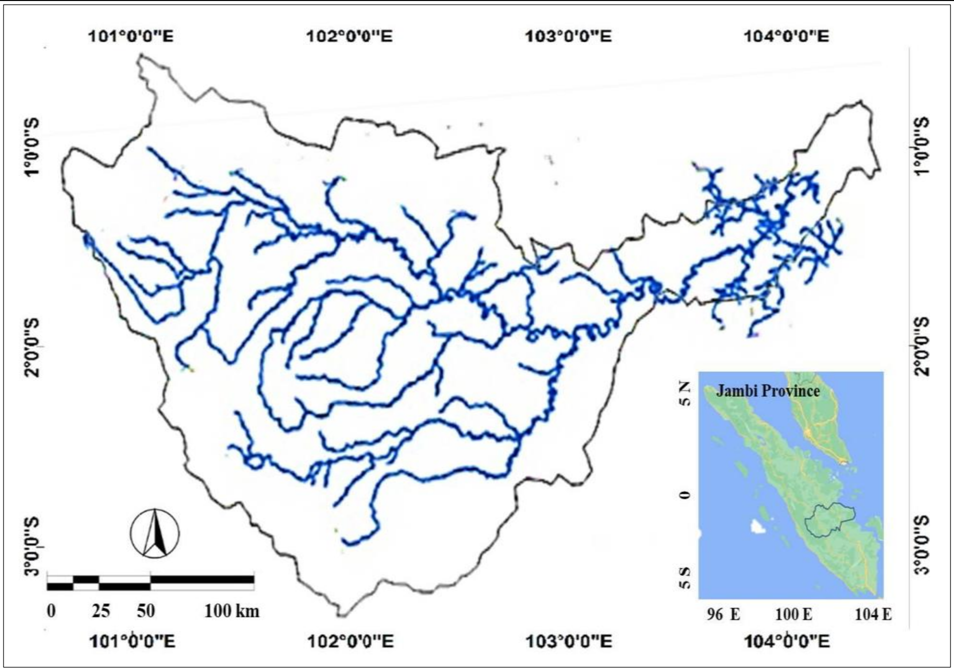

Figure 1. Batanghari River basin in Jambi Province, Sumatra

had a 375 m per pixel resolution, and MODIS was 1000 m per pixel. The use of two different sensors aims to obtain more fire hotspot data. The VIIRS was used to cover and detect fire hotspots in small areas and MODIS to cover fire hotspots in large areas [10, 11]. The fire hotspot data were then classified as points using GIS methods with ArcView 3.2. The result was a thematic layer in the form of shapefiles of fire hotspot distributions sharing the same coordinate and projection with Batanghari River basin land-uses layers.

$PM_{2.5}$ distribution and mapping. The $PM_{2.5}$ distribution and mapping analysis was followed current methods [12, 13]. The sources of $PM_{2.5}$ were Aerosol Optical Depth (AOD) data produced by MODIS. The result is a thematic layer in the form of shapefiles of $PM_{2.5}$ distributions sharing the same coordinate and projection with fire hotspots and Batanghari River basin land-uses layers. The $PM_{2.5}$ was denoted as $\mu g/m^3$.

Data and statistical analysis. The ANOVA test was used to analyze the differences in daily average of fire hotspots based on the week. The significant level to test the difference was $P < 0.05$. The fire hotspot data were calculated to obtain average values with 95% Confidence Intervals (CI).

RESULTS AND DISCUSSION

Rainforest and land-use patterns. Figure 2 described the rainforest and land-use patterns based on the Landsat 8 OLI image classifications. The western parts of the basin were the mountainous landscape dominated by rain forest covers. This dense rainforest cover was parts of Kerinci Seblat National Park. Several natural ecosystems in this national park consisted of slope forest, lowland forest, and upper montane forest. The areas still had lowland forests, which were under serious threats caused by illegal logging and land clearance. The logging activities that led to the land conversion agreed with the land-uses classifications. Areas near the rainforest and national park consisted of non-forest land-uses consisting of paddy fields, swidden farms, and massive plantations.

In contrast, the rainforest cover areas were decreasing in the central parts of the basin. In this part, the land-uses were dominated by massive plantations followed by swidden farms and paddy fields. In eastern parts of the basin, the rainforests were becoming more fragmented. The land-uses were still dominated by plantations, swidden farms, and bush in these parts. The most eastern parts were more fragmented since the land-uses here were dominated by paddy fields, settlements, swidden farms, bush and small remnants of rainforest covers.

Batanghari basin has experienced rapid land cover change due to the expansion of agricultural plantations, including oil palm and rubber. Land-use conversions have threatened the upper parts or western parts of the basin. During period of 1990-2013 there was a significant conversion of the rainforest at the upper stream of Batanghari. The results of this rainforest conversion were a bare land and open field that has been planted partly by oil palm and partly becoming bush [14]. The problems of this rainforest conversion are the use of slash and burn methods that cause a significant increase in fire hotspot numbers [15].

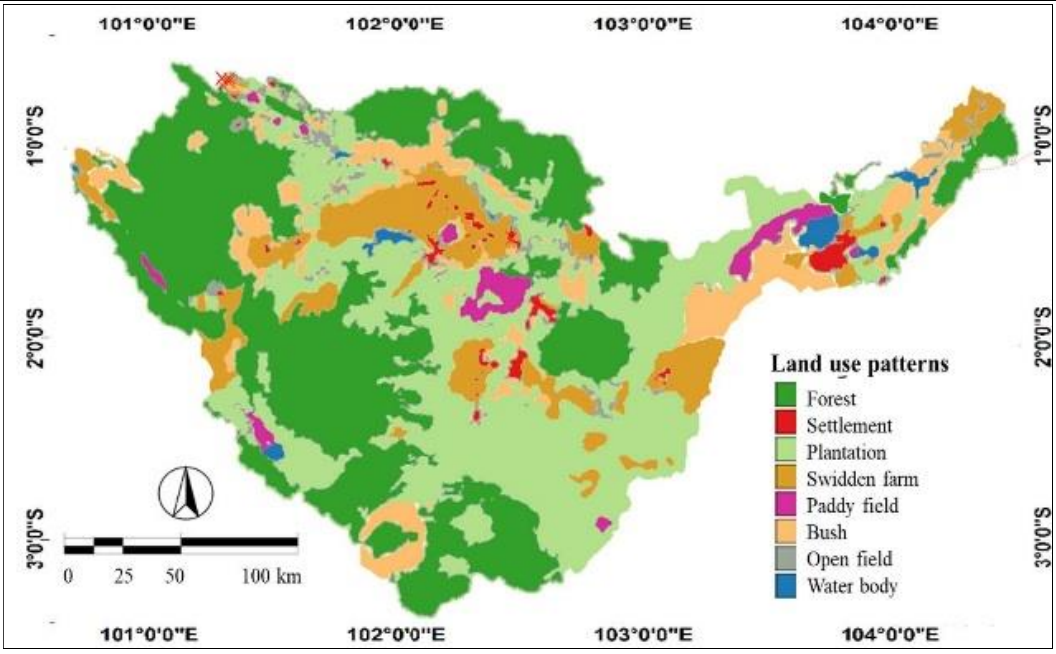

Figure 2. Rainforest and land-use patterns of Batanghari River basin

Fire hotspots in the rainforest ecosystem. The daily fire hotspot numbers in the rainforest of the Batanghari River basin were increasing from the first week (1st day) of July 2021 and reaching their peak in the third and fourth weeks or 28th day (Figure 3). There are significant differences in the daily average of fire hotspots based on the week (P = 0.006, F = 8.677). The daily average of hotspots in the first week of July 2021 was 1.333 hotspots (95%CI: 0-3.94 hotspots). In the second week, the daily average declined to 0.333 hotspots (95%CI: 0-0.986 hotspots). Whereas in the third and fourth weeks, there were sharp increases in the daily average of hotspots. In the third week, the average of hotspots was 4.333 (95%CI: 0-9.04 hotspots) and increased almost three times in the fourth week. In this week, the daily average of hotspots in the rainforest was 11.000 hotspots (95%CI: 7.61-14.4 hotspots) (Figure 4).

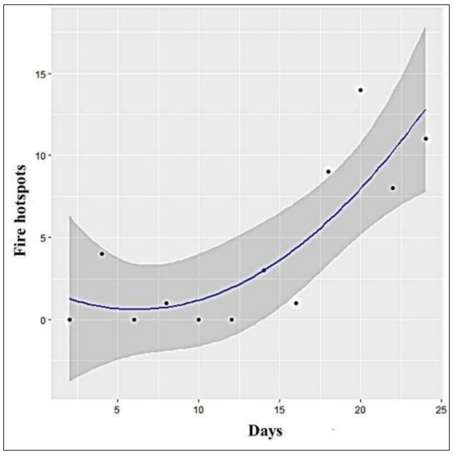

Figure 3. Increasing trends (95%CI is shaded areas) of daily fire hotspots for 30 days in July 2021 in the rainforest of the Batanghari River basin

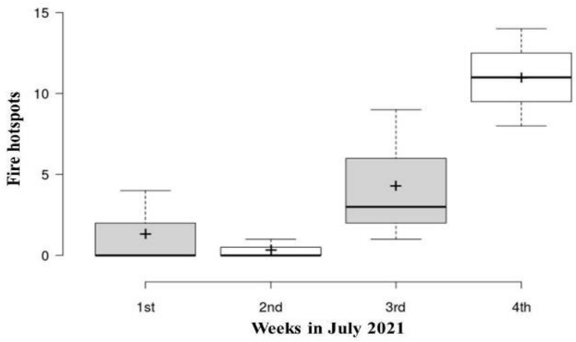

Figure 4. Daily average of fire hotspots in first, second, third, and fourth weeks of July 2021 in the rainforest of Batanghari River basin

This trend was associated with the slash and burn activities of the farmer. Farmers in Jambi Province typically begin slashing in March and burn in July and August. The burning process begins with a broadcast burn and is followed by a pile-and-burn. According to the farmers, the reasons for using fire were as follows burning can create space, burning can produce ash that can be used as fertilizer, burning can improve soil structure allowing for the faster establishment of seedlings, burning can reduce weed/tree competition, and burning can also reduce the occurrence of pests/diseases [16].

Besides the increasing trends of daily hotspots in July, which were influenced by anthropogenic activities, another factor was the climate. Even though anthropogenic ignition was dominant in the majority of fire hotspot occurrences, variations in the ease of ignition and the conditions affecting fire after the ignition was primarily governed by the presence, amount, and connectivity of fuel combined with its moisture content and fuel moisture, which are associated with climate variability [17, 18]. A recent study has shown a statistically significant relationship between summer droughts and fire occurrences in environments [19].

In forests in India, most of the fire hotspots were found in the midyear period in March and April. The percentage increase in maximum temperature, wind velocity, and solar radiation observed in March were 36, 39, and 62%, respectively, and a 60% decrease in relative humidity observed in the same month is the major cause of fire hotspots from March onwards [20]. A recent study in Sumatra confirmed the similar effects of climate and drought season on fire hotspots. Previous extreme fires in North Sumatra in 2005 and South Sumatra in 2006 could be explained in part by an increased drought occurrence due to El Nino events. The two distinct seasonal fire activities in N. and S. Sumatra were closely related to the two distinct dry season types, which included 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 explains the increasing trends of fire hotspots in the rainforest of Batanghari following dry seasons starting from July.

Several fire hotspots were detected in the rainforest ecosystem in the Kerinci Seblat National Park. The occurrences of these hotspots were related to the deforestation activity that has been reported happens for the long term inside the national park. From 2005 to 2014, several areas of the national park have been threatened by deforestation. Those areas included Sipurak, Bungo, and Ipuh. For example, the mean annual forest loss in Sipurak was 1037 ha year (0.93%), in Bungo was 739 ha/year (0.67%) and 693 ha/year or 0.61% in Ipuh areas [21].

The deforestation causing the fire hotspots was driven by agricultural activities near the rainforest. This activity was the conversion of rainforest into a plantation that used the slash and burn method because it was the low-cost method. In the vicinity of rainforests, fires are typically lit for agricultural purposes during the regular dry season. A recent study [3] found that 52% of the total fire hotspots covering areas of 84,717 ha were within concessions that are land allocated to companies for plantation development. While the other 60% of fire hotspots covering concession areas sizing of 50,248 ha was also occupied by communities [22, 23].

Besides inside and nearby rainforests, fire hotspots were also detected in other land-uses outside the rainforests. In fact, fire hotspots occurrences were not always caused by agricultural activities and land-use conversion from rainforests to plantations. In Indonesia and similar to other countries, fire hotspots are not systematically or specifically related to plantations since fire hotspots can occur in ecosystems that do not have plantations. There were several areas in Indonesia without massive plantations that were still threatened by fire hotspots. Those areas included East Java, West Nusa Tenggara, and West Java. Recent studies have found that the distribution of hotspots in November 2015 was only 44% of hotspots related to the rainforests and plantations. This explains the occurrences of fire hotspots in land-uses other rainforests in the Batanghari River basin.

$PM_{2.5}$ content distributions. Figure 5 showed the distributions of $PM_{2.5}$ related to the fire hotspots and rainforest boundaries. It was clear that the presences and the patterns of fire hotspots were followed by the presences and high $PM_{2.5}$ contents. The central and southern parts of the basin had large numbers of fire hotspots. This condition was followed by increasing $PM_{2.5}$ contents, as seen in southern parts of the basin with $PM_{2.5}$ values of more than 80 μg/m^3. The $PM_{2.5}$ values decreased in central parts of the basin with values ranging from 30 to 60 μg/m^3. Lower $PM_{2.5}$ values were observed in western parts of the basin with the value can be as low as10 μg/m^3. The western parts where the $PM_{2.5}$ value was very low were dominated by the rainforest covers.

The associations of fire hotspots with $PM_{2.5}$ contents were in agreement with previous studies. Fire hotspots in particulate one area could affect air quality in their surrounding areas. This is possible since fire produces a haze that contains aerosol with $PM_{2.5}$. The haze itself was originated from burning biomass. Since the fire hotspots were occurred in the rainforest, then the burning biomass was originated from vegetation or tree parts that ranging from tree trunks, branches, and leaves. While at the ground layer, the grasses, bushes, and dry litter could be potential biomass. Haze and contained $PM_{2.5}$, generated by biomass burning, caused air pollution and dispersal of pollutants including $PM_{2.5}$ that affects local air quality as well as the air quality of distant places [24].

CONCLUSION

The patterns of fire hotspots in rainforests in the Batanghari River basin in July 2021 were showing increasing trends. The fire hotspots at the end of July 2021 were higher, almost tenfold compared to the hotspots detected at the beginning of July 2021. The areas in Batanghari where the fire hotspots occurred had high PM2.5 contents and showed correlations of fire hotspots with this pollutant.

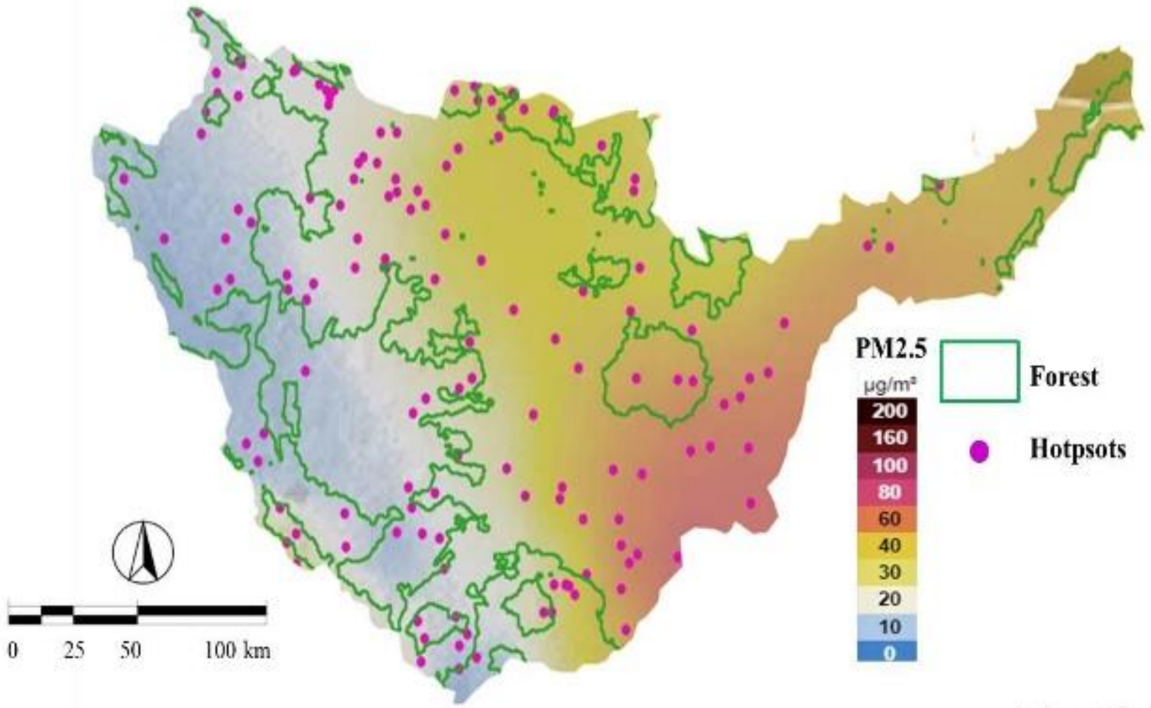

Figure 5. Fire hotspots (purple dots), rainforest boundaries (green rectangles), and $PM_{2.5}$ contents (µg/m^3) in Batanghari River basin in July 2021

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