Analysis of PM$_{10}$ in urban and rural environment in Sumatra Island over the past half-decade

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Abstract. Particulate Matter 10 (PM$_{10}$) is an inhalable particle with a diameter smaller than 10 $\mu$m that disrupt the health of human respiratory. The distribution of PM$_{10}$ varies depending on the region. This study aims to analyze the temporal distribution of PM$_{10}$ in Sumatra Island, Indonesia, as one of the forest fires prone areas that affect neighboring countries, over the past half-decade. Study location was divided into two, Pekanbaru, Medan, Batam, and Palembang represent urban; and Jambi and Aceh represent rural areas, as we want to see the difference of variation of PM$_{10}$ between two different locations of pollution source. In general, the results showed that the average PM$_{10}$ concentration throughout the past half-decade was below the value threshold in all regions. The monthly PM$_{10}$ concentration in rural areas is below the threshold except in Jambi, a monthly concentration above the threshold is in October. While the monthly PM$_{10}$ concentration in urban areas tends to be above the threshold except for Batam and Pekanbaru. The monthly concentration of PM$_{10}$ above the threshold occurs in Medan and Palembang in October. For trends in the rural and urban area, it shows different. Pekanbaru and Palembang which are located in urban area has significant decrease trend of concentration. For diurnal, the hourly average value tends to have different pattern in both urban and rural areas. PM$_{10}$ concentrations in urban areas tend to be low in the morning and high during the day and rise again at night. The frequency of PM$_{10}$ concentration above the threshold which is >10% occurrences is only in Medan and Palembang. Others have less than 10% occurrences of the frequency of PM$_{10}$ concentration below the threshold.

Keyword: PM$_{10}$ concentration, forest fires prone, Sumatra, neighboring countries

1. Introduction

Air is one of the important factors in life. But the increasing of the development of cities and industrial centers, the quality of our air has changed. The air that used to be fresh is now dry and dirty. Until 2018, many of the major cities in the world have experienced poor air quality. PM or particulate matter represents a complex mixture of organic and inorganic substances in the form of solid or liquid suspended in the air. PM has a variation of particle size. It could be large or dark enough to be seen with the naked eye. Others are so small they can only be detected using an electron microscope [1]. Particulate matter was grouped according to particle diameter size, Total Suspended Particulate (TSP) <100 $\mu$m, PM$_{10}$ <10 $\mu$m in diameter, PM$_{2.5}$ <2.5 $\mu$m [2] and PM$_1$ <1 $\mu$m in diameter [3]. The number of particles
in the air is expressed as a measure of concentration (µg/m³). Inhaling particulate pollution can have a detrimental effect on health [4]. In general, air pollution coincides with an increase in human activity, where more human activity can reduce air quality both spatially and temporally [5], related to the number of population and time of occurrence.

Air quality in urban areas is dominated by a large number of vehicles and industrial machinery, for example large cities in Java, in contrast to the air quality in rural areas which are dominated by seasons, for example the regions of Sumatra and Kalimantan where in general dry seasons can cause forest and land fires which increase high air pollution [6]. The physical and chemical composition of airborne particulate matter varies in time and space and is influenced by meteorological factors and their precursors. These physical and chemical properties, then, will govern PM concentration, composition, deposition, removal, and transport [7]. Rapid economic growth consequently will increase emissions and pollutants concentration in Indonesia. Without control and increased awareness, biomass burning and urban air pollution that occur, consecutively, in several wildfire prone provinces [8] [9] and big cities in Indonesia will likely severe in the future. This study aims to analyze the temporal distribution of PM$_{10}$ in Sumatra Island, Indonesia, as one of the forest fires prone areas that affect neighboring countries, over the past half-decade. Until now, there has been no study in comparing variations of PM$_{10}$ in Sumatera regions. Whereas, information of how the temporal distribution of PM$_{10}$, particularly in forest fire prone areas, which also has the potential to spread the smoke to neighboring country, is needed.

2. Material and methods

2.1. Data and location
Data series of PM$_{10}$ concentration from 6 (six) locations of air quality observation which are laid along Sumatera island were collected for this study. Those 6 (six) locations are Pekanbaru, Medan, Palembang, Jambi, Batam, and Aceh. In terms of population density, a number of urban facilities, formal education facilities, public health facilities, it’s categorized that Pekanbaru, Medan, Batam, and Palembang are areas that represent urban. Batam is known as its industrial area, also Medan, Palembang, and Pekanbaru are well-known for their overcrowding and their city development that is still ongoing. While Jambi and Aceh are categorized as an area that represents rural (BPS, 2010).

Hourly and monthly observation data of PM$_{10}$ concentration from each location were taken over the last five years, from 2014 to 2018, aim to see the current conditions of the PM$_{10}$. The data series were taken from the BMKG (Meteorology/Climatology Station) station which is located in those six areas (Picture 1).

![Figure 1. Site locations of the PM$_{10}$ monitoring concentration](image)
2.2. Analysis methods

Time series data of $\text{PM}_{10}$ concentration for each study location were analyzed using trend analysis to find out how the trend of $\text{PM}_{10}$ concentration in the long term. The trend is an up or down movement (tendency) which is obtained from the average change over time. Its changes average can increase and also can decrease. In some researches, linear trends helped to study the extreme precipitation events (Zhang et al, 2001) and changes in air temperature (Easterling et al, 1997). The statistical significance of the trends was assessed by the Mann-Kendall test. The Mann–Kendall (MK) test is a nonparametric test used to analyze the null hypothesis of no change in the mean of a series (no trend) against the alternative hypothesis of an increase or decrease overtime (existence of a trend) [10].

Times series data are averaged per month to see whether $\text{PM}_{10}$ concentrations in the study areas exceed the monthly threshold value. Indonesian government regulation already specified the threshold value for $\text{PM}_{10}$ per day which is 150 µgram/m$^3$. $\text{PM}_{10}$ concentration considered normal if the concentration value is equal or less than 150 µgram/m$^2$ per day, which in this paper we assumed that equal or less than 150 µgram/m$^3$ is also categorized as normal for a monthly period. Besides the monthly average, the data series are also averaged per hour. Hourly average for 24 hours in the last 5 (five) years period can be used to find out at what time the concentration value has increased and also decreased in each location.

3. Results and discussions

The monthly average of $\text{PM}_{10}$ concentration in urban and rural areas in Sumatra Island shows different results. In general, almost every month in both urban and rural areas, the concentration value is below the threshold (150 µgram/m$^3$) (Figure 2). In Jambi, the monthly average of the $\text{PM}_{10}$ concentration reached above the threshold in October, reaching 164.2 µgram/m$^3$. In the other months, the monthly average of the concentration is below the threshold, with a year-round average concentration of 54.5 µgram/m$^3$. The high monthly average concentration in October in Jambi was influenced by El Nino which was happened in 2015. It caused a lot of forest fires in 2015 so that it became high on the average during the study period.

Even though it is a rural area, Jambi has a high concentration of $\text{PM}_{10}$ in the dry season. It was influenced by Jambi as one of the prone areas to forest fires. The average $\text{PM}_{10}$ concentrations in 2015 in Jambi were 485.1 µgram/m$^3$. While the annual average in other years was below the threshold. The average concentration throughout the year in Aceh is 23.5 µgram/m$^3$, and the highest $\text{PM}_{10}$ concentration occurred in March, which is 33.8 µgram/m$^3$. March happens to be dry season in Aceh. Rainy and dry season in Aceh is not influenced by El Nino in general. NASA recorded that Jambi had 3702 hotspots in 2015 and Aceh only had 100 hotspots. The high number of hotspot in Jambi in 2015 effected the increase of $\text{PM}_{10}$ concentration. As result, the monthly concentration in October was above the threshold in the study period.

![Figure 2](image-url)  
**Figure 2.** Monthly average of $\text{PM}_{10}$ concentrations in rural areas (left) dan urban areas (right)
The monthly average of PM$_{10}$ concentration in Medan and Palembang in October exceeded the threshold. The monthly average of PM$_{10}$ concentration was below the threshold throughout the year, except for October in Medan and Palembang. The average value of PM$_{10}$ concentration in 2015 in Medan is 252.2 µgram/m$^3$ and in Palembang is 346.2 µgram/m$^3$. The monthly average of PM$_{10}$ concentration in Batam and Pekanbaru is below the threshold. The maximum PM$_{10}$ concentration occurred in Batam in October, which is 37.2 µgram/m$^3$ and Pekanbaru is in September which is 108.7 µgram/m$^3$. Comparing to the rural area, concentration of PM$_{10}$ in urban area in rainy season (Oct- Mar) was different. PM$_{10}$ concentration in urban area was slightly higher than in rural in the rainy season. Figure 3 shows hourly concentration of the PM$_{10}$ in both rural and urban locations have different variation, but it has the same pattern in general.

Figure 3. Hourly PM$_{10}$ concentration in rural areas (left) and urban areas (right)

Trend in rural locations shows different results (Figure 4). The significance of the trends in both location tested by Mann-Kendall shows that the trends is not significant. The decrease of the trends of the concentration in rural location means that the concentration during the period of the research in the rural decrease. The increase of the trends of the concentration in rural location means that the concentration during the period of the research in the rural increase. Slope value for Aceh is -0.001 means that the trend is decreasing and tested by Mann-Kendall test, p-value for Aceh is 0.546, more than the significant level (%) 5 means that the trend is not significant (p-value > 0.05). Meanwhile Jambi has uptrend with p-value > 0.05, indicates that the trend is not significant. The upward trend in Jambi can be happened because of the increase of the fire forest fires happened in Jambi, considering that Jambi is categorized as forest fire prone area in Indonesia.

Figure 4. Trends of concentration in rural areas, Jambi (left) and Aceh (right)

The same with rural areas, urban areas also shows different results (Picture 5). Trends of concentration in Pekanbaru and Pelambang tend to decrease, meanwhile in Batam and Medan tend to increase. Slope value shows -0.06 and -0.07 for Pekanbaru and Palembang respectively. The significance of the trends in both location tested by Mann-Kendall shows that the trend is significantly decrease. As for Medan and Batam, the slope value are 0.02 and 0.01 resepectively. It shows that the trend for both location are increased. P-value for those locations is more that the significant level (%) 5, means that the trends in those locations are not increase significantly. This potential of increasing concentration of PM$_{10}$ needs
to be concerned. As there are different results between the trends of concentration in urban and rural area, both locations should prepare for the worst condition in the future. The decrease of the PM$_{10}$ concentration in some locations can indicates that the pollution source in these areas also decrease. But it also can mean that the particle which is under 10 µm in diameter turns into smaller particle, namely PM$_{2.5}$. Therefore, further study about PM$_{2.5}$ concentration in Sumatera regions needs to be done.

Figure 5. Trends of concentration in urban areas, (a) Pekanbaru, (b) Palembang, (c) Batam, and (d) Medan

The frequency of PM$_{10}$ concentration above the threshold which is >10% occurrences is only in Medan and Palembang (Table 1). Others have less than 10% occurrences of frequency of PM$_{10}$ concentration below the threshold. 1459 events and 1874 events of PM$_{10}$ concentration above the threshold happened in Palembang in 2014 and 2015 sequentially. 2014 and 2015 are years when the PM$_{10}$ concentration events above the threshold occurred most often than in the other years. PM$_{10}$ concentration events above the threshold happened in 2016 until 2018 are less than 55 events in each year. Meanwhile in Medan, the most often events of PM$_{10}$ concentrations above the threshold happened in 2015, which is 1356 events. Event of PM$_{10}$ concentration above the threshold in other years are less than 40 events each years.

Table 1. Frequency of events >150 µgram/m$^3$ in PM$_{10}$ locations (in %)

| Locations  | Pekanbaru | Medan | Batam | Palembang | Jambi | Aceh |
|------------|-----------|-------|-------|-----------|-------|------|
| >150 µgram/m$^3$ event (%) | 9.3 | 12.2 | 0.5 | 13.3 | 8.4 | 0.1 |

4. Conclusions

The results showed that the average PM$_{10}$ concentration throughout the past half-decade was below the value threshold in all regions. The monthly PM$_{10}$ concentration in rural areas is below the threshold except in Jambi, a monthly concentration above the threshold is in October. High concentration of PM$_{10}$ in rural area was caused by forest fire happened during dry season, as we know that Jambi is forest fire prones area. The trend is non-significantly decreasing in Aceh and increasing in Jambi for rural locations.
While the monthly PM$_{10}$ concentration in urban areas tends to be above the threshold except for Batam and Pekanbaru. The monthly concentration of PM$_{10}$ above the threshold occurs in Medan and Palembang in October. For trends in the urban area, tends to increase in Medan and Batam, but the trends are not significant. And as for Pekanbaru and Palembang, the trends tend to decrease significantly. The decreasing trend of PM$_{10}$ in these areas, indicates that the concentration of PM$_{10}$ contained in the air is reduced. Nevertheless, we still need to beware since the reduction of PM$_{10}$ can also means that the particles are getting smaller, namely PM$_{2.5}$, which is more harmful for human health. For diurnal, the hourly average value tends to have different pattern in both urban and rural areas. PM$_{10}$ concentrations in urban areas tend to be low in the morning and high during the day and rise again at night. The frequency of PM$_{10}$ concentration above the threshold which is $>10\%$ occurrences is only in Medan and Palembang. Others have less than 10\% occurrences of the frequency of PM$_{10}$ concentration below the threshold.

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