Potential impact of particulate matter less than 10 micron (PM$_{10}$) to ambient air quality of Jakarta and Palembang

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Abstract. Particulate is a main urban air pollutant affects the environment and human wellbeing. The purpose of this study is to analyze the impact of particulate matter less than 10 micron (PM$_{10}$) to ambient air quality of Jakarta and Palembang. The analysis is done with calendarPlot Function of openair model, which is based on the calculation of Pollutant Standards Index (PSI) or better known as Air Quality Index (AQI). The AQI category of “moderate” dominates Jakarta’s calendar from 2015 to 2016, which indicates the impact of PM$_{10}$ is the visibility reduction. There was one day with category “unhealthy” that indicates the impact of dust exposure everywhere in Jakarta during 2015. Similar to Jakarta, the AQI category “moderate” also dominates Palembang’s calendar during 2015. However, the AQI category “hazardous” happened for few days in September and October 2015 during forest fires, which indicates the more harmful impacts of PM$_{10}$, such as reduced visibility, dust exposure everywhere, increased sensitivity in patients with asthma and bronchitis to respiratory illness in all exposed populations. During 2016, AQI category of Jakarta mostly “moderate”, while in Palembang was “good”. Dominant AQI category from 2015 to 2016 shows higher PM$_{10}$ concentration occurred in Jakarta compared to Palembang.

Keywords: ambient, air quality, particulate, potential impact

1. Introduction
Particulate matter (PM) is a major urban air pollutants that has significant impacts on the environment and human wellbeing. It has high potential to be accumulated in the human respiratory system. The smaller the particulate size, the more likely it is to settle and be inhaled by the human respiratory system. In general, there are two particulate matter types: PM less than 10 micron (PM$_{10}$) and PM less than 2.5 micron (PM$_{2.5}$). The PM$_{10}$ is inhalable and has the potential to enter the human respiratory system. It can also cause the decrease of visibility, smoke, haze, and smog. However, very limited cities in Indonesia monitor the PM$_{10}$, and only in recent years have been monitored.

Indonesia is one of the countries in the world with the deadliest air pollution levels [1]. World Health Organization (WHO) has stated that every year there are about 3.2 million cases of death caused by air pollution in the world. A total of 3.3 million people worldwide died in 2010 because of inhaling small dust flying in the air and it is estimated that this number will double by 2050 [2].

Jakarta and Palembang are two metropolitan cities in Indonesia that have various sources of air pollution. Types of pollutants emitted ranging from PM, carbon monoxide (CO), carbon dioxide (CO$_2$), nitrogen dioxide (NO$_2$), and others. Currently Jakarta and Palembang are undertaking mass transportation development projects namely Mass Rapid Transit (MRT) and Light Rail Transit (LRT)
for Jakarta and LRT for Palembang which indicate the increasing particulate concentration especially \( \text{PM}_{10} \) in ambient air of both cities.

Monitoring ambient air quality towards \( \text{PM}_{10} \) can be done by analyzing the status of urban ambient air quality. Status of urban ambient air quality in Indonesia is often represented by the Air Quality Index (AQI). The AQI describes ambient air quality at a particular location and time based on impacts on human health, aesthetic values and other living things. The AQI is presented in the form of color categories that are simply used to inform public about ambient air quality at a particular location and time. The purpose of this study is to analyze the impact of \( \text{PM}_{10} \) to ambient air quality of Jakarta and Palembang according to AQI from 2015 to 2016 using openair model.

1.1 Literature Review

1.1.1 Openair Model

Openair model is a part of R package in the form of computer programming language developed specially by R-project for data analysis. The advantage of R is that this model comes in the form of free software that can be applied on various platforms from Windows, Mac, and Linux which are available internationally. This model is specifically designed to perform air quality analysis functions along with the atmospheric conditions. Some air quality analysis functions that can be used such as theilSen, windRose, timeVariation, and calendarPlot [3]. Several studies have been conducted using this model such as Munir’s research on temporal variation of ozone [4] and Habeebullah’s research about characterizing and temporal variability of nitrogen dioxide [5].

1.1.2 Air Pollution

Air as one of the environment component has a special characteristic that is in terms of high level of mobility. Changes in air quality due to high mobility can impact the environmental from local, regional to global scale. Air pollution is the entry or inclusion of substances, energies, and/or other components into the ambient air by human activities, so that ambient air quality drops to some degree which causes ambient air unable to fulfill its function [6]. Air pollution is characterized by the presence of pollutants in the atmosphere in certain concentrations which disturbs the dynamic balance of the atmosphere and has an effect on humans and the environment [7].

1.1.3 Air Quality Index (AQI)

Air Quality Index (AQI) is a tool, introduced by Environmental Protection agency (EPA) in USA to measure the levels of pollution due to major air pollutants [8]. AQI is a non-unit number that describes ambient air quality conditions at a particular location and time based on impacts on human health, aesthetic values, and other living things. In this case, AQI is presented as an air quality report for the public to simply explain how clean or contaminated air quality is and also how it affects human health. Procedure related to the calculation, reporting and information of Indonesia’s AQI are regulated by government [9]. For example, a study of ambient air of Vapi City, India by Sarella found the overall AQI category was “moderate” [10].

1.1.4 Particulate Matter 10 (PM\(_{10}\))

Particulate Matter 10 (PM\(_{10}\)) consists of some elements such as silicate, calcium, and titanium [11]. As PM\(_{10}\) includes particles that have aerodynamic diameters less than or equal to 10 micrometers (\(\mu\)m), it is approximately equal to one-seventh the diameter of human hair [12]. The exposure of PM\(_{10}\) can be quite far in distance which is varying from less than 1 km to 10 km. The PM\(_{10}\) also has a long last age which remains in the air for a long time. A case study by Bigi about long-term trend and variability of PM\(_{10}\) concentration in the Po Valley is done in 2014 [13].

The sources of PM\(_{10}\) varies from vehicle emissions, dust roads, industry emission, agriculture, construction, building demolition, to airborne dust from burning fossil fuels and potentially cause eye irritation, decreased visibility, respiratory. The concentration of PM\(_{10}\) that is inhaled into the respiratory tract is 73.7% and has the potential to cause inflammation and irritation [14].
2. Research Method

2.1 Data Collection
Secondary data used in this research, specifically hourly data of PM$_{10}$ concentration of Jakarta and Palembang from 2015 to 2016. The hourly PM$_{10}$ concentration was collected from Indonesia’s BMKG which is exactly from meteorology station Kemayoran for Jakarta and climatology station Kenten for Palembang. The PM$_{10}$ exposure in ambient air is measured by the sampling and analysis method using an instrument called Particulate Monitor. The type of Particulate Monitor used in meteorology station Kemayoran is Beta Attenuation Monitor (BAM) and in climatology station Kenten is Thermo. These instruments run continuously and directly measuring PM$_{10}$ concentration every hour.

2.2 Pre-analysis Data
The hourly PM$_{10}$ concentration is validated using the standard of World Health Organization (WHO). If there is no PM$_{10}$ concentration for at least 12 hours (50%) in a day, the entire concentration data on that day is deleted because it is considered invalid [15]. The validated hourly PM$_{10}$ concentration is averaged using Microsoft Excel into the daily PM$_{10}$ concentration for both Jakarta and Palembang. Then, the daily PM$_{10}$ concentration data is processed and synchronized with AQI number to analyze the color index and the AQI category each day in a calendar. The color and category of AQI in this daily calendar will be used to estimate the impact of PM$_{10}$ exposure.

2.3 Data Analysis
The daily PM$_{10}$ concentration is processed into a color index representing ambient air quality status using calendarPlot function in the openair model. This function is often used to visualize data by showing daily pollutant concentration (diurnal) on calendar format. This function will convert the daily average concentration to a color index or a symbol with a range of AQI number and certain pollution level categories. The final result of this function analysis is an image of calendar with the AQI color to estimate the impact of PM$_{10}$ exposure based on the range of its AQI number and category.

3. Results and Discussion
The average daily PM$_{10}$ concentration is interpolated with the AQI number to identify its daily AQI category on the calendar. This interpolation is intended to obtain information for the AQI category, its index color, its symbol and the potential impact. Recapitulation of the interpolation between PM$_{10}$ concentration and AQI can be seen in Table 1.

| PM$_{10}$ Concentration ($\mu g/m^3$) | AQI Number | AQI Category | Index Color | Symbol | Potential Impact |
|------------------------------------|------------|--------------|-------------|--------|-----------------|
| 0 – 50                             | 0 – 50     | Good         | Green       | □      | No effects      |
| 51 – 150                           | 51 – 100   | Moderate     | Blue        | =      | Decreased visibility |
| 151 – 350                          | 101 – 199  | Unhealthy    | Yellow      | /      | Decreased visibility and dust exposure everywhere |
| 251 – 420                          | 200 – 299  | Very Unhealthy | Red       | ×      | Increased sensitivity in patients with asthma and bronchitis |
| 421 – more                         | 300 – more | Hazardous    | Black       | •      | Dangerous levels for all exposed populations |
3.1 Jakarta
The worst AQI category in Jakarta was “unhealthy” which was only occurred on February 20th, 2015 with PM$_{10}$ concentration 150.6 μg/m$^3$ (symbol “/” and index color “yellow”). The impact of this PM$_{10}$ concentration includes the decrease of visibility, along with dust exposure everywhere. The “good” days are recorded in 30 days during 2015 and 27 days during 2016 meanwhile the rest are “moderate”.

Generally, the status of ambient air quality of Jakarta from 2015 to 2016 was “moderate”. It is concluded by its index color which was dominated by “blue” or symbol “=” from 2015 to 2016 (Figure 1). Index color “blue” means AQI category is “moderate” with the impact of PM$_{10}$ exposure is the decrease of visibility. The upper limit PM$_{10}$ concentration of the AQI category “moderate” is 150 μg/m$^3$ which is the standard value of ambient air quality standard in Indonesia for PM$_{10}$. Therefore, the index color in AQI is only limited to “green” and “blue” to classify as a good ambient air quality.
3.2 Palembang

Figure 2 shows the calendar with AQI category for PM$_{10}$ in Palembang for 2015 and 2016. There were few days with the worst AQI category from “unhealthy” to “hazardous” in 2015 (42 “unhealthy” days, 11 “very unhealthy” days, 10 “hazardous” days). The highest concentration 606.0μg/m$^3$ occurred on September 28th, 2015 with the impact such as visibility reduction, dust exposure everywhere, increased sensitivity in patients with asthma and bronchitis to respiratory illness in all exposed populations. Those were expected to be the result of forest fires on Sumatra Island during El-Nino phenomenon.

Based on domination of AQI category and index color, air quality status of Palembang during 2015 was quite good with AQI category “moderate” or symbol “=” and some “blue” (index color “blue”). The impact was limited to the decrease of visibility. In 2016, the air quality status of Palembang was getting better which was dominated by the index color “green” (symbol “””) and some “blue” (symbol “=”). Overall, the “good” days were recorded in 56 days during 2015 and dominated in 192 days during 2016. The status of ambient air quality of Palembang from 2015 to 2016 was getting better from “hazardous” to “good”.

3.3 Comparison between Jakarta and Palembang

| Year | Jakarta | Palembang |
|------|---------|-----------|
|      | Index Color (AQI Category) | PM$_{10}$ Concentration (µg/m$^3$) | Index Color (AQI Category) | PM$_{10}$ Concentration (µg/m$^3$) |
| 2015 | Yellow (Unhealthy) | 150.6 | Black (Hazardous) | 606.0 |
| 2016 | Blue (Moderate) | 134.9 | Blue (Moderate) | 76.4 |

Table 2. Highest PM$_{10}$ concentration alongside its Index Color and AQI category

During 2015 when Indonesia experiences El-Nino phenomenon, the highest average daily PM$_{10}$ concentration of Jakarta reached 150.6 µg/m$^3$ while Palembang reached 606.0µg/m$^3$ (Table 2). Both of these concentrations have passed the permitted ambient air quality standard that is below 150µg/m$^3$. The gap between these two concentrations have resulted a significant difference of AQI category and its index color. The highest concentration in Jakarta has the symbol “” or index color “yellow” with AQI category “unhealthy” while in Palembang has the symbol “” or index color “black” with AQI category “hazardous”. This condition indicates that higher PM$_{10}$ exposure occurs in Palembang with more harmful impact than in Jakarta. If the impact in ambient air of Jakarta is limited to the decrease of visibility and dust exposure everywhere, the impact on Palembang City’s ambient air is more dangerous such as decreased visibility, dust exposure everywhere, increased sensitivity in patients with asthma and bronchitis to respiratory illness in all exposed populations.

| Year | Dominant Index Color |
|------|----------------------|
| 2015 | Blue (=)             |
| 2016 | Blue (=)             |

Table 3. Comparison of Dominant AQI index color

During 2016, the highest average daily PM$_{10}$ concentration in both Jakarta 134.9 µg/m$^3$ and Palembang 76.4µg/m$^3$ has the same symbol “=” or index color “blue” with AQI category “moderate”. The impact of pollution that occurs is similar which the decreased of visibility. However when analyzed based on the highest PM$_{10}$ concentration during 2016, PM$_{10}$ exposure tends to be higher in Jakarta compared to Palembang.

Table 3 shows comparison of index color on AQI calendar which respectively dominates Jakarta and Palembang from 2015 to 2016. During 2015, the dominant index color of Jakarta and Palembang were “blue” or symbol “=” with the AQI category “moderate” which indicates PM$_{10}$ exposure and impacts that happens to be the same. As the result, the impact of pollution of PM$_{10}$ that occurs in both city was only limited to the decrease of visibility. While during 2016, dominant index color was found differently
in Jakarta (“blue” or symbol “=”) and Palembang (“green” or symbol “□”). The differences indicate that the exposure of PM$_{10}$ was higher in the city of Jakarta compared to Palembang during 2016. Overall based on the dominant index color for the entire year 2015 until 2016, higher concentration of PM$_{10}$ occurred in Jakarta than in Palembang.

4. Conclusion
The highest PM$_{10}$ concentration in Jakarta and Palembang has exceeded the ambient air quality standard (150 $\mu$g/m$^3$). Based on daily analysis of Indonesia’s AQI, the worst impact of PM$_{10}$ in Jakarta is visibility reduction and dust exposure everywhere. Whereas in Palembang tends to have higher daily PM$_{10}$ concentration that more harmful impacts such as the decrease of visibility, dust exposure everywhere, increased sensitivity in patients with asthma and bronchitis as well as respiratory illness in all exposed populations. However dominant AQI category from 2015 to 2016 shows higher PM$_{10}$ concentration occurred in Jakarta compared to Palembang. It is needed to continue monitor PM$_{10}$ to reduce the negative impacts with air pollution mitigation program.

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