Spatial dispersion of particulate matters to ambient air in Jakarta and Palembang

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Abstract. The minimum requirement of green space area is about 30\% of the urban area. The green space area of Jakarta is around 12\% and Palembang, 20\%. This condition can cause air pollution to increase especially for a certain parameter (PM). The objective of this study is to predict spatial dispersion of PM less than 10 microns (PM\textsubscript{10}) of ambient air in Jakarta and Palembang. Spatial dispersion prediction is done using wind rose diagram from the dominant wind direction. The study has continued with the prediction of PM\textsubscript{10} sources based on the city’s overlaid map with the pollution rose diagram. The PM\textsubscript{10} sources of Jakarta have been predicted from road and soil dust while Palembang are predicted from road dust, soil dust, transportation, industrial emission and smoke from fire. The dominant wind direction of Jakarta and Palembang are east-southeast (dry season) and west-northwest (rainy season) which correlates with the seasonal winds. Key Words: green space area, air pollution, particulate matter, wind rose.

1. Introduction

1.1. Background

Jakarta and Palembang are two cities in Indonesia that have high a population density and activities. Technological developments and urban population growth lead to increasing various sources of air pollution. Various urban activities ranging from offices, shops, markets, services, tourism and others become the sources of air pollution. These sources of air pollution have the potential to release pollutants in the form of solids and gases that are very harmful to human health.

Based on the monitoring results of Meteorological, Climatological and Geophysics Agency (BMKG), Indonesia and other countries in the Pacific region experienced El-Nino climate phenomenon in 2015. El-Nino is a climate deviation that occurs due to the deviation of atmospheric conditions that originated from deviation of sea surface temperature in the middle equatorial pacific ocean. The El-Nino phenomenon is what causes a long dry season to dry rainy season and forest fires on the island of Sumatra. Decreased visibility has occurred in Palembang due to smoke from this forest fire (particulate fraction exposure). In addition, El-Nino phenomenon also clearly affects Jakarta with the decreasing of rain intensity, which only reaches 5 millimeters (mm) from July to August 2015\textsuperscript{[1]}.

The El-Nino phenomenon and forest fires which occurred in 2015 lead to the increasing of air pollution and the decreasing of urban green space. Urban green space is known to help the prevention
of air pollution. The minimum standard of the green space area amounts up to 30% of the urban land. The green space area of Jakarta was 12% [2] and Palembang 20% [3] as of November 2016, which were below the minimum standard. This condition could cause air pollution to increase specifically for certain parameters.

1.2. Purpose
The purpose of this study was to predict spatial dispersion of particulate matters less than 10 microns (PM$_{10}$) in the ambient air of Jakarta and Palembang.

2. Literature Review

2.1. Openair model
Openair is one of the air quality models in the form of a computer programming language. It is developed specially by R-project as part of R-package for air quality data analysis. The advantage of R is that it comes in the form of free software that can be online-downloaded from its official website. It can be applied on various platforms from Windows, Mac, and Linux [4]. Openair model is specifically designed to perform air quality analysis along with the atmospheric conditions. This model also has advantages in terms of missing data manipulation, statistical data analysis, and creation and visualization of high quality graphics [4]. Many functions can be used to analyze air quality data such as theilSen Function for trend analysis, scatterPlot Function for linear regression analysis, and others [4].

2.2. Air pollution
Air as one of the environment component has special characteristics that are high level in terms of mobility. Changes in the quality of air due to its high mobility can cause impacts to the environment from the local, regional, to the global scale. According to Government Regulation No. 41/1999, 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 functions [5]. Air pollution in this case is defined as the presence of pollutants such as dust, gas, and odor in the atmosphere. Pollutants can be emitted either from mobile sources such as motor vehicles or from fixed sources such as factory/industry.

2.3. Particulate matter 10 (PM10)
Particulate Matter 10 is a particulate with a size less than 10 microns (μm). As PM10 includes particles that have aerodynamic diameters less than or equal to 10 μm, it is approximately equal to one-seventh of the diameter of human hair [6]. It is categorized as Respirable Particulate Matter (RPM) which can enter human lungs easily. The exposure of PM10 can be quite far in distance which is varies less than 1 km to 10 km which causes the long last age in the air. Some elements found in PM10 are Silicate, Calcium, and Titanium [7]. The sources of PM10 vary from vehicle exhaust emissions, dust roads, industry emission, agriculture, construction, building demolition, to airborne dust from burning fossil fuels and potentially cause eye irritation, decreased visibility, respiratory.

2.4. Wind factor
Wind is the air that moves due to differences in air pressure with the direction of the flow from a high to a low pressure site or from a low to a high temperature area [8]. Strong wind speeds cause pollutants to fly to all the directions and exposure areas that do not have pollutant sources while weak wind speeds cause emitted pollutants to be accumulated and exposure the area around the pollution site. Wind direction is also influenced by climatic condition, the seasonal wind. In tropical regions such as Indonesia, the direction of the wind during the dry season tends to be dominated from the east to the southeast (east monsoon) and in the rainy season tends to be dominated from the west to
northwest (west monsoon). Generally, wind direction is divided by 8 sections (45°) which are north, south, east, west, northeast, northwest, southeast and south west.

3. Methodology
Spatial dispersion prediction was needed to identify potential sources of air pollution in Jakarta and Palembang. The analysis was undertaken based on the rise of wind and pollution diagrams using the air quality model (openair). The El-Nino phenomenon and the mass transportation development project by 2015 indicated an increase in air pollutant sources rather than other urban activity in which occurred in Jakarta and Palembang.

3.1. Data collection
The research emphasized on the ambient air in Jakarta and Palembang. Secondary data used in this research was acquired from the Meteorological, Climatological, and Geophysics Agency (BMKG), which is the meteorology station BMKG Kemayoran for Jakarta and the climatology station BMKG Kenten for Palembang. The secondary data required was PM$_{10}$ the concentration data per hour and meteorology data (the speed and direction of wind per hour). The PM$_{10}$ exposure in ambient water was measured by the sampling and analysis method using an instrument called Particulate Monitor. Particulate Monitor used in meteorology station BMKG Kemayoran was Beta Attenuation Monitor/BAM and in climatology station BMKG Kenten is Thermo.

3.2. Pre-analyze data
The data of PM$_{10}$ concentrations are verified using 50% of the World Health Organization (WHO) standard. If there was no PM$_{10}$ concentration for at least 12 hours in a day, the entire data concentrated on that day was deleted because it was considered invalid [9]. Meanwhile, both wind, speed and the direction was not verified like the PM$_{10}$ concentration. The data of wind was not verified because it represented existing meteorological phenomenon as a base/support condition as a space where pollutants are present at ambient air. The data of PM$_{10}$ per hour concentrated as the result of the verification then was synchronized with the speed and direction of wind data to visualize the wind rose and pollution rose diagram using an open air model.

3.3. Analyze data
Spatial dispersion analysis was done by making a wind rose and a pollution rose diagrams using WindRose Function (wind rose) and PolarPlot Function (pollution rose) in openair Model. These diagrams illustrated how pollutant concentration, wind direction and wind speed vary over a period of time. The analysis was conducted based on the dry and rainy season annually from 2015 until 2016. Dry season occurred in June, July, August, September, October and November while the rainy season occurred in December, January, February, March, April, and May.

The wind rose diagram was used to see the dominant wind direction and the maximum speed of wind, while the pollution rose diagram was used to identify the source and area of PM$_{10}$ pollutant dispersion. The dominant wind direction indicated the direction of PM$_{10}$ pollutant distribution from its pollutant sources to the final prediction of polluted distribution area. The maximum wind speed indicated how far pollutants have the potential to transport from its source to the receptors. After wind the rose diagram was made, the analysis was continued with the pollution rose diagram. A pollution rose diagram was the development of a wind rose diagram in the form of reflection. For identifying possible sources, a pollution rose diagram was overlaid with a spatial map of Jakarta and Palembang respectively in order to see the potential sources based on the designated urban area.
4. Results and discussion

4.1. Jakarta

Figure 1 illustrates the wind rose and pollution rose diagram of Jakarta during the dry season while figure 2 illustrates the wind rose and pollution rose diagram of Jakarta during the rainy season. These two seasons produced differences in both dominant wind direction and dispersion area of PM$_{10}$. In the dry season, the dominant wind direction came from the east (Kelapa Gading) with the exposure area on the eastern and southern boundaries towards the pollution rose center (Tanjung Priok, Kemayoran and Cempaka Putih). In the rainy season, the dominant wind direction came from the northwest (Grogol Petamburan and Taman Sari) with the exposure area on the eastern boundary (Kemayoran and Kelapa Gading). In both seasons, the east boundary (Kemayoran) was the dominant area of PM$_{10}$ exposure.

**Figure 1.** Wind rose and pollution rose diagram of Jakarta (dry season).

**Figure 2.** Wind rose and pollution rose diagram of Jakarta (rainy season).
The potential source of PM$_{10}$ based on the designation area came from the inhabited area. The PM$_{10}$ sources in both seasons were allegedly derived from road dust and soil dust. Based on maximum wind speed, PM$_{10}$ had the potential to transport further in the dry season (61.2 kilometers) than in the rainy season (50.4 kilometers) in 1 hour.

Meanwhile, figure 3 illustrates the windrose and pollution rose diagram of Jakarta yearly from 2015 to 2016. The dominant wind direction of Jakarta came from the northwest with a maximum wind speed range of 6 – 17 meters/second and the frequency of 10 – 12%. The northwest boundary as the dominant PM$_{10}$ sources was located around Grogol Petamburan, Tambora and Taman Sari. These areas were located in the area of West Jakarta and well known as an inhabited area. The potential sources of PM$_{10}$ was also identified and suspected to come from road dust and soil dust.

4.2. Palembang

A wind rose and a pollution rose diagram for each season of Palembang can be seen in figure 4 (dry season) and figure 5 (rainy season). In the dry season, the dominant wind direction came from the southeast and east (Kalidoni and Plaju) while in the rainy season, the dominant wind direction came from the west and northwest (Alang-Alang Lebar). In the dry season, PM$_{10}$ exposure area was located in the southeastern boundary (Kalidoni) while during the rainy season, the PM$_{10}$ exposure area was located in the southern boundary (Bukit Kecil). Based on the maximum wind speed, PM$_{10}$ was estimated to transport further in the dry season (93.6 kilometers) than in the rainy season (50.4 kilometers) in 1 hour.

Kalidoni and Plaju as potential PM$_{10}$ sources of Palembang during dry season and Alang-Alang Lebar as potential PM$_{10}$ sources of Palembang during rainy season had primary functions as residential, commercial, service and industry areas. The potential PM$_{10}$ sources originated from road dust, soil dust, vehicle transportation and industry emission. To be informed that during the dry season of 2015, there a forest fire occurred in Palembang which caused a new source of PM$_{10}$ exposure (smoke of forest fire).
Figure 4. Wind rose and pollution rose diagram of Palembang (dry season).

Figure 5. Wind rose and pollution rose diagram of Palembang (rainy season).

The wind rose and pollution rose diagram of Palembang can be seen in figure 6. The dominant wind direction of Palembang came from the southeast with a frequency between 15 – 20% and maximum wind speed that occurred between 6 - 26 meters/sec. It can be seen that the southeastern boundary (Kalidoni and Plaju) was the dominant source of PM$_{10}$ of Palembang during 2015 to 2016. Kalidoni and Plaju were designated as residential, commercial, services and industry area. The potential PM$_{10}$ sources of Palembang generally came from road dust, soil dust, transportation vehicle and industrial emission.
4.3. Comparison between Jakarta and Palembang

During the dry season, the dominant wind direction of Jakarta and Palembang tended to be different which was from the east for Jakarta and the southeast for Palembang. Both dominant wind directions were fit with the direction of seasonal wind (east monsoon) that tended to come from the east-southeast for dry season. The east monsoon originated from Australia to Asia and tended to contain little moisture because it passed through the narrow gaps and deserts in Australia (Gibson, Great Australia, and Victoria). Based on a pollution rose diagram, potential PM$_{10}$ sources of Jakarta came from road dust and soil dust while Palembang came from industrial emission, transportation vehicle, smoke of fire, soil and road dust.

The dominant wind direction during the rainy season of Jakarta and Palembang was also different. The dominant wind direction of Jakarta came from the northwest, while Palembang came from the west. Both these wind directions were dominant and fit with the direction of the seasonal wind (west monsoon) for rainy season. The west monsoon wind blew from Asia to Australia. This wind contained much water vapour because it passed through many dump areas such as the Pacific Ocean, Indian Ocean and South China Sea. According to the pollution rose diagram, the potential PM$_{10}$ sources of Jakarta was only dominated by soil dust and road dust while Palembang was dominated by many such as soil dust, road dust, industrial emission and transportation vehicle.
Table 1. Recapitulation of the wind rose and pollution rose diagram of Jakarta and Palembang.

|          | Jakarta                          | Palembang                                      |
|----------|----------------------------------|-----------------------------------------------|
|          | Dominant Wind Direction (Max. Wind Speed) | Potential Sources               | Dominant Wind Direction (Max. Wind Speed) | Potential Sources               |
| 2015 – 2016 |                                    | Road dust, soil dust                          | Southeast (6 - 26 m/s)                      | Road dust, soil dust, transportation vehicle, industry emission, smoke of fire |
| Dry Season | East (6 - 17 m/s)                | Road dust, soil dust                          | West (6 - 14 m/s)                           | Road dust, soil dust, transportation vehicle, industry emission               |
| Rainy Season | Northwest (6 - 14 m/s)         | Road dust, soil dust                          | West (6 - 14 m/s)                           | Road dust, soil dust, transportation vehicle, industry emission               |
| Yearly    | Northwest (6 - 17 m/s)          | Road dust, soil dust                          | Southeast (6 - 26 m/s)                      | Road dust, soil dust, transportation vehicle, industry emission, smoke of fire |

Recapitulation of a wind rose and a pollution rose diagram of Jakarta and Palembang can be seen in table 1. However by conducting the analysis annually, it was determined that the dominant wind direction of Jakarta was more influenced by the rainy season (west monsoon) with dominant wind directions from the northwest while Palembang was more influenced by the dry season (east monsoon) with dominant wind direction that came from the southeast. This difference also indicated that the El-Nino phenomenon in 2015 tended to have more impact in Palembang than in Jakarta. It is fair to know that Palembang is located on Sumatra Island as the site of the massive forest fire caused by El-Nino's phenomenon. While Palembang experienced fog smoke, Jakarta might only experience dust exposure (increasing of PM$_{10}$ concentration). The dominant PM$_{10}$ sources came from road and soil dust for Jakarta; while from industrial emissions, smoke which came from forest fires, transportation vehicles, soil and road dust in Palembang. Basically, road dust and soil dust were the dominant sources of PM$_{10}$ for Jakarta and Palembang.

5. Conclusion & suggestion

Jakarta’s most dominant wind direction was the east during dry season and the northwest during rainy season with predicted PM$_{10}$ sources from road and soil dusts. The dominant wind direction for Palembang was southeast during dry season and west during rainy season with predicted PM$_{10}$ sources from road dust, soil dust, transportation vehicle, industrial emission and smoke of forest fires. The dominant wind direction in Jakarta and Palembang corresponded to the seasonal winds, which was east-southeast during dry season and west-northwest during rainy season. The dominant PM$_{10}$ sources of both the cities were predicted from road and soil dusts. Therefore, urban green areas with selected type of vegetation are needed to reduce the air pollution. It is advisable to conduct further research using particles matters of 2.5 microns (PM2.5) data in view of their potentially more harmful to human health.

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