Identification of Pollutant Sources on PM$_{10}$: Case Study in West Surabaya

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Abstract. The emission of motor vehicles can cause air pollution, the industry, and household activities and is currently a severe problem. Surabaya City, especially West Surabaya, is an area that has heavy traffic because it is a warehouse area, directly adjacent to Gresik Regency, which is an industrial area and other activities such as garbage final processing place and port. Therefore, a study needed to monitor the quality of the PM pollutants in West Surabaya and further estimates are the source location of the pollutants. The results of this study can complement previous research and can be used to make policies in air pollution control in Surabaya city. Sampling for fine and coarse particles using Gent Stacked Filter Unit (Gent SFU) every six days between November-December and meteorological data obtained using Kestrel 5500 Weather Meter. The concentration of PM$_{10}$ was analyzed using the gravimetric method while estimating the pollutant source location using the Conditional Probability Function (CPF). The average concentration of PM$_{10}$ at the time of research of 32.24 µg/m$^3$. The estimated source location of pollutant for PM$_{10}$ is from north, northeast, east, south, and southwest and the potential source of pollutant is possible from industrial activities, traffic, warehousing activities, and natural sources such as dirt dust.

1. Introduction
Air pollution is one of the consequences of high population activity. Air pollution is a serious concern because, in addition to degradable environmental quality also affects human health. Air pollution can cause respiratory diseases and disorders of the cardiovascular system. Air pollution is the inclusion of substances, energy and other components into the ambient air by human activity so the quality of the ambient air down to a certain extent that causes ambient air can not fulfill its function [1]. In air pollution, Particulate Matter (PM) is one of the indicators of air pollution. PM formed from a mixture of solid particles and liquids that exist in the air including dust, smoke and ash. The source of the PM can originate from anthropogenic sources and natural sources. Anthropogenic sources derive from combustion processes such as industries and motor vehicles. Natural sources can come from dust and seawater condensed [2]. For this category, the sources of pollution are divided into pollution due to transportation activities, industry, and from decomposition or burning of waste [3]. The PM is in the atmosphere for an extended period and is distinguished into a coarse particle diameter between 2.5-10 μm and a fine particle with a diameter of fewer than 2.5 μm [4].

The research of Ahmad and Santos [5] mentions that the concentration of PM$_{2.5}$ in the city of Surabaya, does not meet the annual quality standards stipulated by Government Regulation of The Republic of Indonesia number 41 the year 1999, USEPA, and WHO. The concentration of PM$_{2.5}$ in Surabaya, is 15.05 µg/m$^3$. Research conducted in Serpong states the source of pollution comes from motor vehicle diesel (30%), lead industry (12%), power plant (26%), and road dust (17%)[6]. The
research by Mukhtar et al. [6] states that the air of Surabaya contains Zn and Pb with the highest concentration compared to other cities. The average concentration of Zn is 344.78 μg/m³ while the rest of the city is still below 150 μg/m³. Pb concentration in the city of Surabaya reaches 2664 μg/m³. Pb and Zn metals are mainly of industry and traffic [7].

The study by Samet et al. [8] states that the particle size is significantly related to the accumulation of particles of diameter < 2-3 μm in the inner lung of the terminals Bronchiolus and alveoli. Large particles will accumulate in the upper airway. Particulates are measured with TSPs, which are all dissolved particles of more than 30-40 μm. For PM$_{10}$, it can enter aerodynamically through the inhalation size of the < 10. Particulate matter/dust can cause an increase in premature infants' mortality, in addition to disturbing humans, in particular, causing lung diseases such as bronchial asthma, pulmonary obstruction of lung disease (COPD), including chronic bronchitis and emphysema, in addition to causing heart disease. Exposure to particles in the air polluted can trigger chronic asthma in the case of shortness of breath and cough, as well as respiratory irritation in people with sensitive airways [9].

Air pollution in the provincial capital became a severe problem. The pollution comes from the emission of motor vehicles, power plants, industrial and household activities. The pollution material can be either gas or dust [7]. Surabaya is the provincial capital of East Java and became the second most populous city after Jakarta. Surabaya city, especially in the west part of Surabaya is a warehousing area which is widely traversed by vehicles transporting goods. In this area, there is the final processing place (TPA) garbage City of Surabaya and Terminal Teluk Lamong. Besides, the West Surabaya area is also a border with Gresik Regency, which is an industrial area. There are activities in warehousing such as traffic, emissions from TPA, Teluk Lamong Terminal, and industrial areas in the western part of the Surabaya and Gresik Regency are feared to affect people's health in the area. Based on the explanation, the study needed to monitor the quality of the PM pollutants in West Surabaya. Further estimates are the source location of the polluters by using the Conditional Probability Function (CPF). The results of this study can complement previous research and can be used to make policies in air pollution control in Surabaya city.

2. Materials and Methods

2.1. Sampling Site

Surabaya City is the capital of East Java province, with a total area of approximately 326.36 km². The sampling was conducted at Surabaya Barat, known to be industrial and warehousing area. The west of Surabaya is a strategic area that potentially developed continuously to support the development of the city in the future. The western part of the city of Surabaya is a supporter of economic growth seen from his accessibilities. It located adjacent to Tanjung Perak Harbor and Teluk Lamong Port and Sidoarjo-Gresik-Surabaya toll road. In the West Surabaya there are warehouse and Margomulyo industrial and final processing place (TPA) garbage Benowo [10].

![Figure 1. Sampling Site.](image-url)
2.2. Sampling
Data analysis in the study included concentrations of PM$_{10}$ and estimated location of pollutants. Sampling carried out every six (6) days for 24 hours from November-Desember 2019, according to the EPA sampling schedule. The Osowilangun Terminal chosen to be the sampling location of the wind direction analysis conducted in September to early October 2019 (Figure 1). The primary data retrieval method in this study conducted using the Gent Stacked Filter Unit (Gen SFU) tool which has installed polycarbonate filter and placed on the roof of the building with a height of 3 m from the ground level. The Gen SFU is a dichotomous sampler collect air particulates with a size of 2.5 to 10 μm and less than 2.5 μm and composed of two parts, the first part is the container containing the filter and the second part is the vacuum pump system with the timer and flow rate. In the outermost part of the container is the impactor system inlet cut off, causing only dust measuring less than 10 μm which can enter while dust measuring more than 10 μm will fall. The air that enters through the filter container is set at 18 L/min rate. In addition, meteorological data such as wind direction, wind speed, humidity, and the temperature measured using Kestrel 5500 Weather Meter.

2.3. Analysis of Samples
Concentrations of PM$_{10}$ analyzed by gravimetric methods. PM$_{10}$ concentration is derived from the summation of concentrations in PM$_{2.5}$ and PM$_{2.5-10}$ (Eq.3). The concentration of PM$_{2.5}$ resulting from a reduction in the sample weight (mg) on the fine filter and a clear filter and then divided by the volume of air (m$^3$) (Eq.1). Concentrations of PM$_{2.5-10}$ obtained from heavy summation on rough filters (coarse filter) divided by the volume of air (Eq.2). The weighed filter conditioned first in the space with temperature 18-25°C and humidity below 55% so the water content in PM is stable. The results of the analysis then compared with the PM$_{10}$ quality standards

$$\text{PM}_{2.5}(\mu g/m^3) = \frac{\text{dust weight on the filter (mg)}}{\text{air volume (m}^3\text{)}} \times 1000 \quad (1)$$

$$\text{PM}_{2.5-10}(\mu g/m^3) = \frac{\text{dust weight on the filter (mg)/air volume (m}^3\text{)}}{\times 1000 \quad (2)}$$

$$\text{PM}_{10}(\mu g/m^3) = \text{PM}_{2.5} (\mu g/m^3) + \text{PM}_{2.5-10} (\mu g/m^3) \quad (3)$$

2.4. Conditional Probability Function (CPF)
Estimation of the source location of these polluters using Conditional Probability Function (CPF). CPF serves to estimate the source of pollutants based on data from the PMF results, direction, and wind speeds. Estimation of local pollutant sources done by combining polluted source factor data formed from PMF with directional meteorological data and wind speeds. Data used only that has a wind speed of more than 1 m/s. The data then sort from high concentrations to low concentrations. The data used is 25% data that has the highest concentration. The CPF method divides 25% of the data with total data (Eq.4). The processing of such data done with Microsoft Excel. The result of the CPF is a radar plot graph that uses 16 points of the wind as a predictor of the direction of the pollutant source. Sources have most likely been in the direction that has a considerable CPF value.

$$\Delta \theta = \frac{M_{\Delta \theta}}{n_{\Delta \theta}} \quad (4)$$

3. Results and Discussion

3.1. PM$_{10}$ concentrations
The focus of the discussion here is PM$_{10}$ because it adjusts to the tools owned by the government and sources of pollution in the research location. The daily average concentrations PM$_{10}$ at location study amounted to 32.24 μg/m$^3$ or 31.81 μg/Nm$^3$. The concentration is following the research by Ahmad and Santoso [5] which states the annual concentration range in Surabaya for PM$_{10}$ is 18.35 μg/m$^2$-50.65 μg/m$^3$. Based on the Government Regulation of The Republic of Indonesia No. 41 the year 1999 quality standards of PM$_{10}$ is 150 μg/Nm$^3$. According to WHO, quality standards of PM$_{10}$ amounted to 50 μg/m$^3$.  

3
From the observation results, concentrations of PM$_{10}$ in West Surabaya still meet the quality standard of daily PM based on Government Regulation of The Republic of Indonesia No. 41 the year 1999 and WHO.

The PM$_{10}$ daily concentration has the lowest concentration of 20.68 μg/m$^3$ on December 31, 2019. PM$_{10}$ highest daily concentration of 43.86 μg/m$^3$ on December 2, 2019 (Table 1). On November 14, 2019, the PM$_{10}$ concentration on that date amounted to 40.49 μg/m$^3$, an increase from the previous week of 28.71 μg/m$^3$. The concentration lowering can be seen on December 8, 2019, PM$_{10}$ concentration decreased to 21.83 μg/m$^3$ from the previous week of 43.86 μg/m$^3$ (Figure 2). The increase or decrease in the concentration can be caused by several things, such as activities around and meteorological conditions.

Meteorological conditions are a major factor that can affect the daily concentration of pollutants [11]. On the date of the weather in the research location is sunny especially during October-December 2019 because it is still in the dry season, besides the wind speed is also relatively quiet at the range of 0.5-2.1 m/s. When the high wind speed of particulate can be spread so that the concentration decreases while the speed of wind relatively calm particulate can not spread and causes high concentrations of particulate. But according to Cheng and Li [12] high wind speed can also make PM$_{10}$ concentration to be high because re-suspension of particulate matter under well dispersed conditions.

The average concentration in November-December is higher because the month of October-December 2019 is still in the dry season, when the dry season evaporation will be higher so that the particulate concentration obtained higher because there is no water grain trapped in the particulate. Meanwhile, during the rainy season, particulate will be trapped in a grain of rainwater so that the concentration becomes lower [5]. According to the daily rainfall data from BMKG of Perak meteorological station, I Surabaya, in October to December 2019 rainfall in the city of Surabaya is still low. The average rainfall in November-December 2019 are 0.6 mm and 2.5 mm.

Activities around the research site can also influence concentrations PM$_{10}$. In West Surabaya, there are many goods transporting vehicles from warehousing area, but also many public transportations such as the bus or private vehicle. High traffic activities can affect concentrations of PM$_{10}$, PM$_{10}$ concentration when heavy traffic has the highest concentration in comparison with traffic at medium and low [13]. Aside from activities and weather, the concentration of PM$_{10}$ can also be influenced by wind direction and wind speed (Figures 3 and 4). From the research results of Cheng and Li [12], the emission of traffic and also meteorological conditions can affect the PM$_{10}$ level especially in the highway toll. From the observation, the dominant wind direction of the month is northeast and southwest. From this direction, there are some industrial activities, and also traffic is quite substantial.

![Figure 2. PM$_{10}$ daily concentration.](image-url)
Table 1. Daily Concentration of PM$_{10}$.

| Time       | PM$_{10}$ (µg/m$^3$) | PM$_{10}$ (µg/Nm$^3$) |
|------------|-----------------------|------------------------|
| 11/2/2019  | 28.05                 | 28.02                  |
| 11/8/2019  | 28.71                 | 28.17                  |
| 11/14/2019 | 40.49                 | 39.96                  |
| 11/20/2019 | 36.07                 | 35.44                  |
| 11/26/2019 | 39.02                 | 38.62                  |
| 12/2/2019  | 43.86                 | 43.23                  |
| 12/8/2019  | 21.83                 | 21.41                  |
| 12/14/2019 | 30.40                 | 30.00                  |
| 12/20/2019 | 30.24                 | 29.73                  |
| 12/26/2019 | 35.25                 | 34.86                  |
| 12/31/2019 | 20.68                 | 20.51                  |
| Mean       | 32.24                 | 31.81                  |
| Min        | 20.68                 | 20.51                  |
| Max        | 43.86                 | 43.23                  |
| Median     | 30.40                 | 30.00                  |
| St.dev     | 7.43                  | 7.33                   |

Figure 3. Wind Direction on November.

Figure 4. Wind Direction on December.
3.2. Conditional Probably Function (CPF)

The following is the result of the CPF method to estimate the source of the PM$_{10}$ based particulate concentrations, wind direction, and wind speed. Based on the results of the analysis of the CPF, the PM$_{10}$ sources based on CPF analysis, it also comes from north with possible values of 0.4, from northeast, east, south and southwest with possible values of 0.3 (Figure 5).

The potential pollutant sources in PM$_{10}$ come from the northwest, north, east, and south. There is a toll road from the northwest that connects the city of Surabaya with Gresik Regency and a toll road construction. There is a large salt pond from the northwest. Surabaya city has land for salt ponds of 623 Ha and processed by salt farmers. The process of processing salt is done by supplying the seawater to the plots of land to undergo further the evaporation process [14]. In the north, there is Tambak Osowilangun Street, as well as warehousing and residential areas. In the east, there is vacant land and construction industry, and in the south, there are warehousing area and some industries. PM$_{10}$ in West Surabaya can be made possible from the traffic activities of private vehicles, public transport or freight vehicles, construction activities, and industrial activities. Industrial activities are activities involving various processes, such as the use of fuels, incineration processes, or raw material burning activities with high temperatures [15].

Pollutants around the location caused by traffic activities in the warehouse area from the north and south that many pass through freight vehicles and also many loading and unloading activities, besides concentrations of PM$_{10}$ caused by the traffic activity on Tambak Osowilangun Street located in the east to the north of the research site. The road connects Surabaya and Gresik so that the traffic crowded due to various types of vehicles, from private vehicles to public transportation to cargo trucks. Other traffic activities that can contribute to PM$_{10}$ are traffic on toll roads from the south to the northwest connecting the city of Surabaya with Gresik regency. The high concentration of particulate caused by road construction and vehicle activity in the port of Lamong Bay from the northeast.

Figure 5. CPF for PM$_{10}$.

4. Conclusion

The daily average concentrations PM$_{10}$ at location study amounted to 32.24 μg/m$^3$ or 31.81 μg/Nm$^3$ still meet the quality standards of both Government Regulation of The Republic of Indonesia No. 41/1999 and WHO. Based on the estimated location’s results, the potential source of polluters in West Surabaya is possible from industrial activities, traffic, warehousing activities, and natural sources such as dirt dust and sea salt[17].
Indonesia No.41 Year 1999 and WHO amounted 150 μg/Nm$^3$ and 50 μg/m$^3$ but need monitoring and evaluation periodically of the PM parameters in the ambient air as a control for air quality.

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