Identification of Pollutant Sources of $PM_{2,5}$ and PM_{10} in Waru, Sidoarjo, East Java

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Abstract— **Air pollution have a very detrimental effect, not only for humans but also impact on the ecosystem of animals and plants. In this study, we will examine air pollution in March 2019 around Waru, Sidoarjo, East Java through research on air particulate concentrations with the size of $PM_{2.5}$ and PM_{10}. This study aims to determine the estimation of the origin of pollution around the Waru, Sidoarjo, East Java so that can be used as a scientific reference as a step to make the right decisions and policies in overcoming the effects of pollution. The data processing method in this study is with use the Conditional Probability Function (CPF) method to find out the estimated source the origin of pollution is based on meteorological data (speed and wind direction). The highest measurement results obtained at $PM_{2.5}$ concentration was 24.13 µg/m^3 still fulfilling the daily quality standards set by Goverment Regulations No. 41/1999 and WHO, whereas at PM_{10} concentration was 66.53 µg/m^3 still met the daily quality standards has been established Goverment Regulations No. 41/1999 but has exceeded the quality standards set by WHO. While the results of the analysis of the CPF Method are obtained from the original source pollutants for $PM_{2.5}$ come from vehicle activities on the highway, while the source of pollutants for PM_{10} comes from industrial activities.**

Keywords— **Air Particles, $PM_{2.5}$, PM_{10}, and CPF**

I. INTRODUCTION

POLLUTION of the air environment is pollution which knows no administrative boundaries of the territory. Air pollution in an area does not only come from local pollutants but can also come from transportation across provinces and countries [1]. According to Government Regulation of The Republic of Indonesia No. 41/1999, air pollution is the entry or inclusion of substances, energy, and / or other components into ambient air by human activities, so that ambient air quality drops to a certain level which causes ambient air to not fulfill its function. Particulate matter (PM) is one of 12 air pollutant parameters contained in Government Regulation of The Republic of Indonesia No. 41/1999, of course this PM has the most harmful impact on human health because of its ability to enter the deepest respiratory system [2].

According to the Environmental Protection Agency (EPA) particulate matter (PM) are particles that float in the air for long periods of time or particles found in the air, including dust, dirt, soot and smoke. These particles originate from a variety of sources, such as power plants, industrial processes, and diesel trucks, and they are formed in the atmosphere by transformation of gaseous emissions. Their chemical and physical compositions depending of location, time of year, and weather. PM is the term used for a mixture of solid particles and liquid droplets suspended in the air. These particles originate from a variety of sources, such as power plants, industrial processes, and diesel trucks, and they are formed in the atmosphere by transformation of gaseous emissions. Their chemical and physical compositions depending of location, time of year, and weather. The Environmental Protection Agency (EPA) groups dust particles according to their size into 2 categories, namely dust particles $\leq$ 10 micrometers (PM_{10}) and dust particles $\leq$ 2.5 micrometers ($PM_{2.5}$)[3].

PM_{10} are formed by mechanical disruption (e.g. crushing, grinding, abrasion of surfaces); evaporation of sprays, and suspension of dust. PM_{10} is composed of aluminium silicate and other oxides of crustal elements, and major sources including fugitive dust from roads, industry, agriculture, construction and demolition, and fly ash from fossil fuel combustion. The lifetime of PM_{10} is from minutes to hours, and its travel distance varies from < 1 km to 10 km. $PM_{2,5}$ are formed from gas and condensation of high-temperature vapors during combustion, and they are composed of various combinations of sulfate compounds, nitrate compounds, carbon compounds, ammonium, hydrogen ion, organic compounds, metals (Pb, Cd, V, Ni, Cu, Zn, Mn, and Fe), and particle bound water. The major sources of $PM_{2.5}$ are fossil fuel combustion, vegetation burning, and the smelting and processing of metals. Their lifetime is from days to weeks and travel distance ranges from 100s to >1000s km [4].

Increased mass PM concentration at the time of monitoring in an area due to increased PM pollutant activity activities both natural and artificial sources of emissions. However, the increase in PM mass concentration is not only due to an increase in PM pollutant activity activities, but also strongly influenced by weather factors (temperature and humidity) and meteorology (speed and wind direction). The monitoring of PM parameter mass concentration is part of the control which aims to ensure that the mass concentration of PM does not exceed the value of the ambient air quality standard. Based on the Appendix Government Regulation of the Republic of Indonesia No. 41/1999 concerning ambient air quality standards nationally that for $PM_{2.5}$ quality standards of 65 µg/m^3 (24 hours) and 15 µg/m^3 (annual), while for PM_{10} is 150 µg/m^3 (24 Hours). WHO publications provide quality standard values for mass concentrations for PM_{10} of 50 µg/m^3 (24 hours) and 20 µg/m^3 (annual) while $PM_{2.5}$ is 25 µg/ m^3 (24 hours) and 10 µg/m^3 (annual) [5].

This study was carried out in Waru. There are many industrial centers in Waru, starting from the metal industry and footwear / sandals industries in Wadung Asri village, Berbek industrial area, Kepuhkiriman and Wedoro. Berbek Village, which administratively entered the Waru sub-district, also became part of the Industry Rungkut (SIER) area, which became known as the Berbek Industrial Zone. Waru is also known as the center of the buffer industry from Surabaya, and many important industries were previously centered in this sub-district city. The number of industries in the Waru area is feared to make metal pollutant concentration large and have a negative impact on public health.

Increasing industrial development activities have consequences, namely increasing the waste produced by the industry, including air pollutants that can change the quality of ambient air [6]. Industrial activities are complex activities and involve various processes. The use of fuel, the incineration process or the burning of raw materials with high temperatures is generally found in industrial activities [7]. Emissions from industry are believed to be one of the main contributors of pollutant sources to airborne particulates [8]. Therefore, this study is needed to estimate the location of PM pollutant sources.

II. METHOD

A. Sampling

Sampling using the Gent stacked filter unit sampler (GSFU Sampler) at a height of 5 meters above building that is located around Waru District, Sidoarjo, East Java. Sampling is done for one month in March 2019. Sampling is done during 24 hours with a flow rate of around 15-18 L/min [9]. The Gent stacked filter sampler unit consists from two filters, namely type filter polycarbonate with a diameter of 47 mm which has a pore size of 0.4µm which is called a fine filter which is will be used for determination of $PM_{2,5}$, and pore-sized filters 8µm is called a coarse filter, which is used for determination of $PM_{2,5\text{-}10}$. Before and after sampling, filters conditioned in a clean room to weigh at least 24 hours. Clean room equipped with dehumidifier and Air Conditioner for controlling room air humidity at humidity level of 40-60% with a temperature of 18-25 °C [10]. For Wind speed and direction were assessed using a Kestrel 5500 with same elevation level with gent stack.

B. Determination of PM concentration

The particulate matter mass of each of the coarse and fine fractions was determined by gravimetric. Mass concentrations were obtained by dividing the gravimetric mass by the volume of air that passed through the filter to obtain the concentration of $PM_{2.5}$ and $PM_{2.5–10}$ (µg/m^3). From the fine filter, data $PM_{2.5}$ is obtained. Equation (1) is used to get concentration $PM_{2.5}$. From coarse filters obtained coarse PM coarse data (2.5-10µm). Equation (2) is used forget a PM coarse concentration. $PM_{2,5}$ and PM coarse is used to get PM_{10} use Equation (3).

$$PM_{2,5}(\mu g/m^3) = \frac{\text{Dust weight on filters fine } (\mu g)}{\text{Air volume } (m^3)} \times 1000 \quad (1)$$

$$\text{PM Coarse } (\mu g/m^3) = \frac{\text{Dust weight on filters fine } (\mu g)}{\text{Air volume } (m^3)} \times 1000 \quad (2)$$

$$PM_{10}\ (\mu g/m^3) = PM_{2,5}\ (\mu g/m^3) + \text{PM Coarse } (\mu g/m^3) \quad (3)$$

C. Statistical Analysis

To identify possible source of PM based on the wind speed and direction, we use conditional probability function method (CPF). The CPF method is to divide the number of events in a particular wind direction by contributing the greatest mass concentration of factors with wind speed and direction above 1 m/s to the total mass concentration factor in wind direction and speed greater than 1 m/s. The CPF estimates the probability that a given source Contribution from a given wind direction will exceed a predetermined threshold criterion. The same daily contribution was as signed to each hour of a given day to match to the hourly wind data [9]. The results of the CPF analysis are formed in later radar plots overlay into the location map of the sampling point. The CPF is defined as :

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

Where

$M_{\Delta\theta}$: the number of occurrence from wind sector $\Delta\theta$ that exceeded the threshold criterion

$n_{\Delta\theta}$: the total number of data from the same wind sector

III. RESULTS AND DISCUSSION

A. Particulate Mass Concentrations

All samples used in this analysis were sampled for one month with a total sample of 10 filters for PM Fine and PM coarse (Table 1). Table 2 shows the average PM concentrations, standard deviation and median values of fine particulate mass (FPM) and coarse particulate mass (CPM) collected at around Waru, Sidoarjo, Jawa Timur. The results of $PM_{2.5}$ measurements based on time series around Waru are shown in Figure 2. Whereas, the results of PM_{10} measurements based on time series around Waru are shown in Figure 1.

Table 1.
Concentration of $PM_{2,5}$ dan PM_{10} at around Waru (Time Series).

Date	$PM_{2,5}$(µg/m^3)	PM_{10} (µg/m^3)	Temperature (ºC)
14/03/2019	20,91	66,53	27
16/03/2019	17,54	34,65	30
17/03/2019	6,00	21,74	27
19/03/2019	16,01	32,21	30
20/03/2019	4,81	30,83	28
21/03/2019	20,65	44,03	30
23/03/2019	13,46	32,73	28
24/03/2019	21,95	53,05	27
26/03/2019	17,94	44,19	28
28/03/2019	24,13	55,03	28

Table 2.
Concentration of PM2,5 dan PM10 at around Waru.
(Mean, Maximum, Minimum, Median, Standar Deviasi)

Parameter	Mean	Max	Min	Median	STD
$PM_{2,5}$ (µg/m^3)	16,34	24,13	4,81	17,74	6,53
PM_{10} (µg/m^3)	41,50	66,53	21,74	39,34	13,63

The results of the analysis of $PM_{2.5}$ concentrations in Waru, Sidoarjo, East Java (Figure 2) were 16.34 ± 6.53 µg/m^3, with the highest concentration values of 24.13 µg/m^3 and the lowest concentration was 4.81 µg/m^3. Although this concentration has not exceeded the daily $PM_{2.5}$ threshold value in Indonesia namely 65 μg/m^3 and the daily quality standard $PM_{2.5}$ at WHO is 25 μg/m^3, but in the time series graph $PM_{2.5}$ concentration has increased $PM_{2.5}$ concentration, such as during sampling on 28 March 2019, $PM_{2.5}$ concentration was the maximum concentration in March of 24.13 μg/m^3, meaning that the concentration was almost close to the WHO daily PM $_{2.5}$ quality standard of 25 μg/m^3, on 28 March, 2019 the weather at the sampling location was very bright (temperature = 30^{o}C, wind speed = 1.2 mps (slightly quiet)).

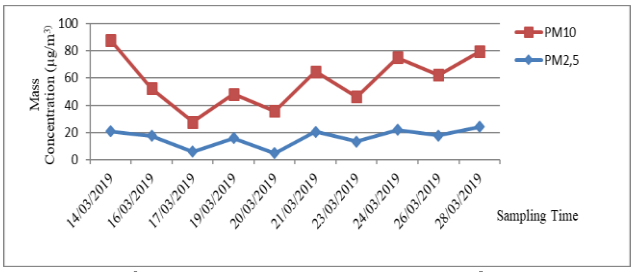

Figure 1. $PM_{2,5}$ dan PM_{10} mass concentration in Waru, Sidoarjo, Jawa Timur.

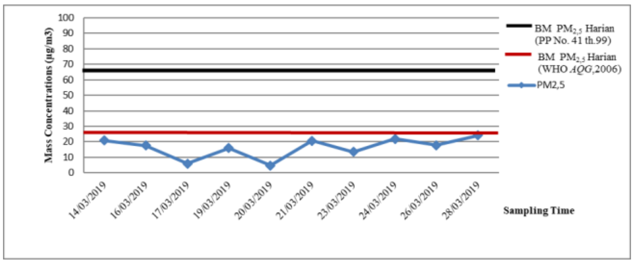

Figure 2. $PM_{2.5}$ mass concentration in Waru sub-district, Sidoarjo, Jawa Timur.

Then there was a decrease in concentration on 17 and 20 March 2019, a decrease in the concentration of PM $_{2.5}$ occurred because during sampling there was rain (temperature = 27^{o}c, wind speed = 0.6 mps (relatively calm)) so that the concentration of particulates in the air be low because particulates in the air will be caught by raindrops (Figure 3). This is supported by the research of [10] that PM concentrations are strongly influenced by weather conditions at the sampling location. There is a relationship between the season and the amount of concentration, where the higher the evaporation the greater the concentration obtained due to the absence of grains of water trapped in particulates.

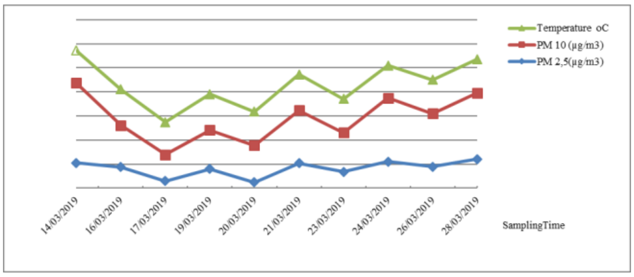

Figure 3. Correlation PM and temperature.

For the analysis of PM_{10} Waru, Sidoarjo, East Java concentration is 41.50 ± 13.63 μg/m^3, with the highest concentration value 66.53 μg/m^3 and the lowest concentration is 21.74 μg/m^3 (Figure 4). For PM_{10} concentrations this has not exceeded the daily $PM_{2.5}$ threshold value in Indonesia, which is 150 μg/m^3, but has passed the daily quality standard PM_{10} at WHO which is 50 μg/m^3, the highest concentration occurred on 14 March, 2019, at 66.53 μg/m^3, on that date the weather at the sampling location is very bright with temperatures = 30^{o}C and wind speed = 1.3 mps (slightly quiet). While the low PM_{10} concentration also occurred on the same date as the concentration decline at $PM_{2.5}$, namely on the 17 and 20 March 2019.

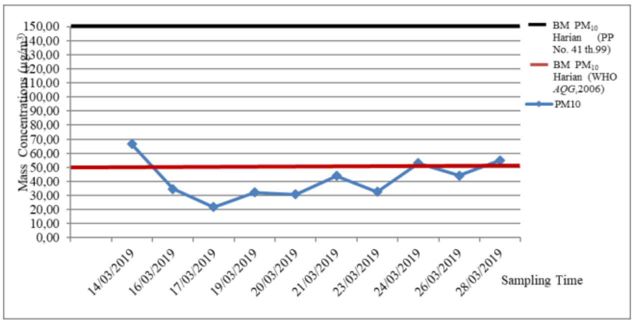

Figure 4. PM_{10} mass concentration in Waru, Sidoarjo, Jawa Timur.

The results of the study of particulate matter concentration in the form of a graph of the results of the relationship between particulate concentration. PM and temperature in March 2019 can be seen in Graph 3. Based on the results of research that the maximum PM Particulate Metter occurs at increased temperatures, while the minimum particulate matter occurs at decreased temperatures.

In addition, if you see the ratio between PM $_{2.5}$ and PM $_{10}$ gives a value the mean is 0.65 which indicates that $PM_{2.5}$ contributes 0.65 of the total mass of PM_{10} and identifies that pollution from antropogenic sources reaches 65%. The high contribution of $PM_{2.5}$ concentration is caused by an increase in the number of motorized vehicles, as well as consumption of fossil fuels for industrial activities. The ratio between PM $_{2.5}$ and PM_{10} is shown in Figure 5.

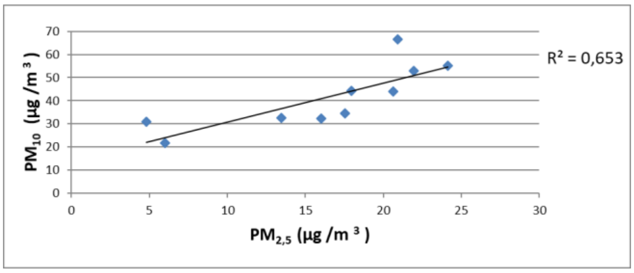

Figure 5. Correlation $PM_{2,5}$ and PM_{10}

In the study of Holst, et al, 2008, it was found that the difference between the maximum temperature value and the minimum value correlated significantly with the average daily PM concentration. Rain also greatly affects the PM concentration which causes airborne particulates to float in the air bound to raindrops which then descend towards the surface of the earth [11].

$PM_{2.5}$ is a dust particle that has a diameter of 2.5 micrometers or less. Its size is so small that it can't be seen invisible to the eye, making these particles easily infiltrate the smallest respiratory tract. Long-term exposure can increase the deposition of the respiratory tract in the bronchi and alveoli regions thereby reducing gas exchange [1].

Estimated pollutant sources for $PM_{2.5}$ and PM $_{2.5-10}$ correspond to the results of studies conducted in various places which concluded that the source of fine particle emissions ($PM_{2,5}$) was largely the result of anthropogenic emissions contributions. The results of anthropogenic emission contributions come from the transportation sector and the industrial sector. While coarse particle emissions are dominated by primary emissions from natural sources such as soil dust and sea salt.

The mass concentration of PM at the time of monitoring in an area is due to an increase in pollutant source activity activities for both natural and artificial sources of emissions. However, PM mass concentration is not only due to an increase in PM pollutant activity activities, but is also strongly influenced by weather factors (temperature and humidity) and meteorology (speed and wind direction).

B. Conditional Probability Function

The following are the results of the CPF method for estimating pollutant sources PM $_{2.5}$ (figure 6) and PM $_{10}$ (figure 8) based on the results of elemental concentrations of wind direction and speed data.

The CPF method is a method of combining mass concentration data of pollutant to meteorological data on wind direction and speed. Wind direction and speed are assessed using Kestrel 5500 with the same height as the gent stack. The average wind speed ranges from 0 to 6 m/s (average: 1 m/s), the average temperature is from 23.2°C to 37.7°C, and relative humidity ranges from 48.3% to 100% (value average: 81.47%).

Based on the CPF results, the location of $PM_{2.5}$ pollutant sources originates from the southwest direction with a probability of 0.6. Based on the survey results around the measurement location, that in the southwest direction there is heavy traffic activity that occurs on Bridgen Katamso road, Waru, where the road is used as vehicle transportation traffic for industrial activities and other housing activities (Figure. 7). Possible sources of pollutants come from the traffic activity and for the estimation results of the location of pollutant sources that the PM_{10} pollutant source is likely to originate from north to east with a probability of 0.45 to 0.35. Based on the survey results around the measurement location, there are Brebek and Rungkut Industrial Areas in the north to east, activities in the industrial area start warehousing, heavy transport activities, loading and unloading of goods, production processes of each -Each industry, the possibility of pollutant sources can come from the industrial activities of these industries (Figure. 8). This is according with the research of [1] which states that particulate composition comes from the results of human activities such as the use of fossil fuels that produce sulfur dioxide, combustion of biomass to produce black carbon (BC) and organic carbon. Transportation activities, incinerator, metal smelting industries and coal-fired power plants that produce sulfates, nitrates and BC. Meanwhile, land conversion and building construction activities can increase the concentration of soil dust emissions in fine particulates.

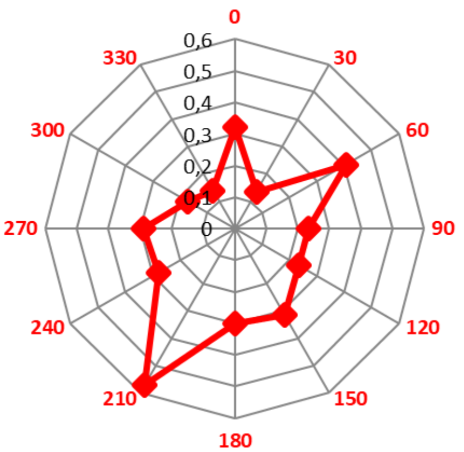

Figure 6. CPF for $PM_{2,5}$ in Waru, Sidoarjo, Jawa Timur

Figure 7. CPF plot for $PM_{2,5}$ in Waru, Sidoarjo, Jawa Timur

In addition, the location of the sampling site is surrounded by housing activities, highways and industrial estates. The existence of the highway 700 m from the sample point and the Waru- Juanda Toll Road 281 m, and 2.4- 8 km from the steel mill, and surrounded by 400 m of Brebek Industrial area from the sampling point. The list of industries in the Brebek Industrial Area can be seen in Annex 2, and there is a Ngingas Village located 1.8 km from the sampling point, there are several small metal industries.

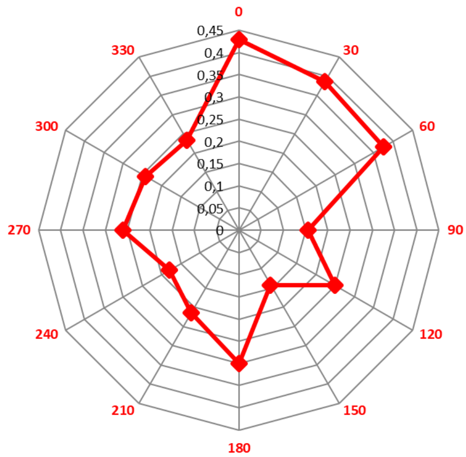

Figure 8. CPF for PM_{10} in Waru, Sidoarjo, Jawa Timur

Figure 9. CPF plot for PM_{10} in Waru, Sidoarjo, Jawa Timur

IV. CONCLUSION

Air Quality around Waru District, Sidoarjo has PM $_{2.5}$ concentration has not exceeded the standard value daily quality, but there is the highest concentration of PM $_{2.5}$ which is equal to 24.13 µg/m^3, for PM $_{10}$ concentration amounting to 66.53 µg/m^3 so that it exceeds standard threshold value at WHO. The source of origin of pollutants comes from vehicle activities and industrial activities. Mass concentration for $PM_{2.5}$ and PM_{10} at the time of measurement in the form of time series does not exceed the national quality standard value but exceeds the WHO quality standard. However, the monitoring and evaluation of PM parameters in ambient air around the Waru Sub-district remains to be done because it is part of controlling the quality of air pollution.

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