Preliminary study: health risk analysis of PM$_{2.5}$ and PM$_{10}$ mass concentrations in Bandung Metropolitan

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Abstract. Particulate matters with sizes below 10 (PM$_{10}$) and 2.5 (PM$_{2.5}$) micrometers under polluted air have been causing not only climate change directly/indirectly but also public health problems. These were depended on the level concentrations of PM, chemical species, duration of exposure, as well as meteorological conditions, and how close we are to the emission sources. The aim of the preliminary study is to observe how air pollution concentrations can affect human health. We selected Bandung Metropolitan as a pilot project and located several instruments at Telkom University in the period of 2018-2019. PM$_{2.5}$ and PM$_{10}$ data were produced and calculated from microsensors. Health data and related patients from the hospital within 6 km were added to AirQ+ for short and long-term exposure analysis. Results show that temporal data of PM$_{2.5}$ and PM$_{10}$ were identified as <20 µg/m$^3$ (in a wet season) to >100 µg/m$^3$ (dry season). In long-term exposure to polluted air, PM$_{2.5}$ contributed to mortality caused by Chronic Obstructive Pulmonary Disease (COPD) and ischemic heart disease. Meanwhile, post-neonatal were observed under PM$_{10}$ mass concentrations. In a short-term period of measurement, March to April and July to August, the respiratory disease has dominant across seasons. Therefore, the coupling of changes in climate and air pollution level will be negatively contributed to more effect on human health.

1. Introduction

Air pollution is a problem that often arises in various areas, particularly in urban regions. A study in 2015 was stated that the average contributor to polluted air in several cities in the world came from anthropogenic (i.e., transportation (25%), industrial activities (15%), household emissions (20%), and others (22%)) and natural sources (18%) [1]. Particulate matter (PM) concentrations, for example, are one of the most common pollutants that were found in urban areas [2]. It is well-known identified that the PM was classified based on their aerodynamic size and their impact on health, such as PM$_{10}$ with an aerodynamic size of less than 10 µm and PM$_{2.5}$ for the size of less than 2.5 µm. PM$_{2.5,10}$ can penetrate the lungs without being filtered out by the nose hair. Meanwhile, PM$_{2.5}$ when inhaled, cannot be filtered in the upper respiratory system, and it will get into the deepest part of the lungs and heart, causing acute respiratory infections, lung cancer, cardiovascular disease, and even death [3][4].

World Health Organization in 2018 reported that estimation of around 7 million people dies each year due to PM. It is caused by several respiratory diseases, such as pneumonia, stroke, ischemic heart disease, Chronic Obstructive Pulmonary Disease (COPD), and lung cancer. Associated chemical composition of PM$_{10}$ mass concentration typically is mineral dust, organic and elemental carbon, trace elements, sea salt, secondary inorganic aerosol, and monosaccharides [5]. Over certain level concentrations and how long period exposure of PM$_{10}$ to the human body will cause chronic bronchitis
in adults, the prevalence of bronchitis in children, and post neo-natal in infants [6]. Meanwhile, Park et al. [7] reported the level toxicity of PM$_{2.5}$ from various combustion and non-combustion sources. PM$_{2.5}$ mass concentrations are linked to respiratory systems such as heart disease, stroke, COPD, lung cancer, and Acute Lower Respiratory Infections (ALRI) [8].

On the other hand, recent climate change is exacerbating the detrimental effects of air pollution on human health. Emissions resulting from human and natural activities will have an impact in an area related to, for example, the formation of fresh and aged particulates in the air through a physio-chemical transformation and the accompanying meteorological factors. Orru et al. [9] conducted a literature study regarding the interaction between climate and primary/secondary pollutants, the environment, and their effects on human health. Projected mortality through climate change against global air quality measurements, i.e., concentrations of O$_3$ and PM$_{2.5}$, with a model approach as well as various mitigation scenarios, have been continuing to increase [10][11]. This will worsen and impact poor and developing countries with high population levels. With various schemes approach to preventing premature death due to air pollution-related to climate change, it is hoped that it will be able to reduce the wider impact both economically and socially.

For those reasons, we selected Bandung Metropolitan as a pilot project to initiate and analyze the impact of air pollution on public health, with a focus on exposure to PM$_{10}$ and PM$_{2.5}$ mass concentrations. In addition, Bandung has a unique topography in the form of a plateau and in the shape of a basin. The Greater Bandung has several administrative cities such as Bandung City, Bandung Regency, West Bandung Regency, and Cimahi City. The total area of Bandung Metropolitan has reached 327,649.05 Ha with a population of >8 million. Seeing the impact of PM$_{10}$ and PM$_{2.5}$ which are quite risky for health, such as against several strokes, heart, and other cardiovascular diseases, it is necessary to analyze health risks in the Bandung Metropolitan air basin area. This study is expected to estimate the proportion of particulates caused by several disease parameters such as heart disease, stroke, COPD, lung cancer, and ALRI, post-neo-natal, bronchitis and chronic bronchitis, using the AirQ+ software. Then we mapped patients’ location and meteorological conditions to look deeper into the effect of emission sources. Furthermore, research on health risks due to PM$_{10}$ and PM$_{2.5}$ is also urgently needed by policymakers.

2. Research methodology

2.1. Site and measurements period
The site for air quality measurement is located at Telkom University (-6.970, 107.629), Bandung, Indonesia (Figure 1). The instrument used is based on low-cost sensors, both for measuring air quality and for meteorological parameters. The device is mounted >600 m above sea level (or 30 m above ambient ground level), so measurements are avoided from very close exposure to local emissions. Typical sources of local emissions in this area are industrial and residential areas, transportation, and direct waste burning within 6 km of the measurement location. Meanwhile, transboundary polluted air comes from marine transportation, biogenic, and photochemical reactions. It depends on meteorological conditions which depend on two main seasons, namely the rainy season and the dry season. The regional winds move from southeast to northwest in the dry season and vice versa in the rainy season. Calibration of measuring instruments and details of measurement locations are further described by Syabani et al [12].

2.2. Data collection of air pollution-related disease
In this study, PM$_{2.5}$ and PM$_{10}$ mass concentration data were obtained from field observation on 20 August 2018 - 19 August 2019. PM$_{2.5}$ and PM$_{10}$ have their respective risks to health. Long-term exposure to PM$_{2.5}$ such as Acute Lower Respiratory Infection (ALRI) or commonly known as "Infeksi Saluran Pernapasan Akut (ISPA)" is an acute infectious disease that attacks one or more parts of the airway starting from the nose (upper tract) to the alveoli (lower tract), including adnexal tissues (sinuses, middle ear cavity, and pleura) [13]. Other respiratory diseases are Chronic Obstructive Pulmonary Disease (COPD) or so-called "Penyakit Paru-paru Obstruktif Kronik (PPOK)" is a term that describes a chronic
lung disease that causes limited airflow to the lungs; Lung Cancer (LC) is a dangerous tumor that grows in the lungs; Ischemic Heart Disease (IHD) is a disease in the heart area; Stroke is the second leading cause of death in the world and the third leading cause of disability in the world. Furthermore, short-term exposure to PM$_{2.5}$ is also harmful. Diseases caused by this exposure is cardiovascular disease or diseases caused by impaired function of the heart and blood vessels, such as coronary heart disease (CHD), heart failure/disease, hypertension, stroke, and respiratory diseases which include ALRI, tuberculosis, bronchitis, pneumonia, and others that damage the respiratory organs.

Figure 1. Measurement site of PM$_{2.5}$ mass concentrations and others air quality and meteorological low-cost based sensors at Telkom University (−6.970, 107.629), Bandung, Indonesia. The data of PM$_{10}$ is estimated from PM$_{2.5}$-sensors data.

Meanwhile, diseases caused by long-term exposure to PM$_{10}$ are chronic bronchitis which is a respiratory disease characterized by coughing and excessive sputum production accompanied by fatigue/weakness and discomfort due to chronic cough with phlegm [14]; Exogenous infant mortality or post-neonatal mortality is infant mortality that occurs after one month of age until before the age of one year caused by factors related to the influence of the external environment [15]; and bronchitis in children. For diseases caused by short-term exposure to PM$_{10}$, there are asthmatic symptoms, namely chronic inflammatory disorders of the airways that involve many inflammatory cells such as eosinophils, mast cells, leukotriene, and others.

2.3. AirQ+ software

AirQ+ is a software for conducting health risk assessment from air pollution issued by World Health Organization (WHO) [16, 17]. AirQ+ features calculations that allow quantification of the health effects of exposure to air pollution, including estimates of reduced life expectancy, also known as mortality rates. Estimating the health impact on AirQ+ requires some input data such as the average concentration of PM$_{2.5}$ and PM$_{10}$ every day for 1 year, the total population, the number of risks of being exposed to the population based on the incidence of each disease, the concentration quality standard value, and the Relative Risk (RR). Various case studies using AirQ+ have been widely used in various countries [18-23].

3. Results and discussion

3.1. Measurements of PM$_{2.5}$ and PM$_{10}$ mass concentrations

The measured parameters are PM$_{2.5}$, temperature (T), relative humidity (RH), and wind speed/direction (WS/WD). PM$_{10}$ data is calculated from the PM$_{2.5}$ data. Temperature and RH are used to determine the weather such as sunny or rainy, as well as to correct PM$_{2.5}$ values in the air. Meanwhile, WS and WD were used to analyze potential sources of air pollutants. Results show that the highest mass
concentrations of PM$_{2.5}$ and PM$_{10}$ occurred on 29 August 2018, that is 108 µg/m$^3$ for PM$_{2.5}$ and 118 µg/m$^3$ for PM$_{10}$ (Figure 2). Meanwhile, the annual average PM$_{2.5}$ and PM$_{10}$ mass concentrations were 48 µg/m$^3$ and 53 µg/m$^3$, respectively. The data were exceeded WHO quality standards for PM$_{2.5}$ (25 µg/m$^3$) and PM$_{10}$ (50 µg/m$^3$).

![Figure 2](image-url) **Figure 2.** Measurement data for mass concentration of PM$_{2.5}$ and PM$_{10}$, temperature (T), and relative humidity (RH) on 20 August 2018 - 19 August 2019 at Telkom University, Bandung, Indonesia.

Figure 2 shows that PM$_{2.5}$ and PM$_{10}$ mass concentrations tend to be higher than the WHO standard. However, based on Indonesian Government Regulation Number 41 of 1999 concerning air pollution control, the daily average PM$_{2.5}$ and PM$_{10}$ are 65 µg/m$^3$ and 150 µg/m$^3$, respectively. Therefore, the data of PM$_{2.5}$ and PM$_{10}$ mass concentration tend to be below the threshold. The mass concentrations of PM$_{2.5}$ and PM$_{10}$ have different data trends in each measurement period. The mass concentration of PM$_{2.5}$ and PM$_{10}$ on 20 August-11 September 2018 and 19 February-31 March 2019 tended to be higher than that on 1 April-13 August 2019. This was due to several factors such as seasons, how many sources of pollutants around the area (motorized vehicles, industrial activities, and open residential-waste burning). Meanwhile, the mass concentrations of PM$_{2.5}$ and PM$_{10}$ in July-August tend to low, even though this month is the dry season. This is because the measurement site is located in the campus area, where the month is the summer holiday so that the potential source of pollutants in the form of motor vehicle emissions tends to be less than normal days. Other potential remote pollutant sources also affect the high mass concentrations of PM$_{2.5}$ and PM$_{10}$ such as fires and volcanic eruptions.

3.2. Effects of PM$_{2.5}$ and PM$_{10}$ on health
Health data were obtained from patient medical records from the hospital within a radius of fewer than 6 kilometers from the measurement location. Health data were divided into two categories based on long and short-term exposure PM$_{2.5}$ and PM$_{10}$. The number of cases caused by long-term exposure to PM$_{2.5}$
that occurred in the August 2018-August 2019 measurement period is shown in Table 1. From this data, the highest mortality rate related to PM$_{2.5}$ occurred in COPD of 927 cases and the lowest mortality occurred in lung cancer as many as 9 cases. While the number of cases caused by several disease parameters related to long-term exposure PM$_{10}$ that occurred during the same period, the highest morbidity occurred in chronic bronchitis as many as 6597 cases and the lowest case number occurred in post-neo-natal (108 cases).

Table 1. The number of cases per disease parameter due to long-term exposure to PM$_{2.5}$ and PM$_{10}$.

| Parameter  | Age | N*  | Parameter           | Age | N*  |
|------------|-----|-----|---------------------|-----|-----|
| ALRI       | 0-5 | 27  | Post neo-natal      | 0-1 | 108 |
| COPD       | 35+ | 927 | Bronchitis          | 0-12| 2961|
| LC         | 35+ | 9   | Chronic bronchitis  | 12+ | 6597|
| IHD        | 25+ | 891 |                     |     |     |
| Stroke     | 25+ | 603 |                     |     |     |

* Number of cases

$^a$ Acute Lower Respiratory Infection

$^b$ Chronic Obstructive Pulmonary Disease

$^c$ Lung Cancer

$^d$ Ischemic Heart Disease

Meanwhile, estimates of the number of diseases caused by short-term exposure from PM$_{2.5}$ and PM$_{10}$ mass concentrations were also carried out. The health effects of this short-term exposure were taken in the measurement period July-August 2019 (dry season) compared to the measurement period in the rainy season (March-April 2019). The parameters for disease caused by short-term exposure PM$_{2.5}$ are cardiovascular and respiratory disease at all ages. Meanwhile, the disease parameters caused by short-term exposure PM$_{10}$ are asthmatic symptoms in children (0-12 years). Health data related to these diseases is shown in Table 2. From this table, the highest rates of disease occurred in respiratory diseases, that is 9216 and 12924 cases. Meanwhile, the lowest number of diseases occurred in asthmatic symptoms (144 and 261 cases). From these two periods, all related diseases occurred in the dry season with a high difference in case numbers compared to the rainy season.

Table 2. Number of cases per disease parameter due to short-term exposure to PM$_{2.5}$ and PM$_{10}$.

| Parameter                  | Age       | Number of cases (period) | Maret-April | Juli-August |
|----------------------------|-----------|--------------------------|-------------|-------------|
| Cardiovascular disease     | All       |                          | 5704        | 11745       |
| Respiratory disease        | All       |                          | 9216        | 12924       |
| Asthmatic symptoms         | 0-12      |                          | 144         | 261         |

3.3. Health risk assessment

Health risk assessment uses the application from WHO, AirQ+, which is a useful application for estimating mortality/morbidity due to exposure to ambient air pollutants. Table 3 shows the attributable proportion (AP) and the number of cases of death caused by long-term exposure PM$_{2.5}$. The highest AP rate occurred in ALRI as much as 24.25%, although the cases that occurred were very small (7 cases). Meanwhile, the mortality rate due to IHD also has a high AP (21.2%) with the highest number of cases (186 cases). This proves the WHO's statement that IHD is the highest cause of death among diseases caused by air pollution, which is around 34%. Furthermore, the mortality rate due to COPD and stroke were 20.9% and 19.06% with 186 and 111 causes of death, respectively. The lowest AP value and the...
number of cases due to long-term exposure PM$_{2.5}$ occurred in the lung cancer mortality rate (17.68% and 2 cases).

Meanwhile, the attributable proportion (AP) and the number of cases caused by long-term exposure PM$_{10}$ can be seen in Table 3. The lowest AP value occurred in post-neonatal, 15.39%, with the number of diseases as many as 18 cases. While the largest AP occurred in chronic bronchitis in adults (37.58%) and the number of cases as high as 2479 cases. This condition is very high compared to the number of diseases caused by other diseases. In general, around 300-800 premature deaths in the Greater Bandung air basin could be prevented if the PM$_{2.5}$ mass concentration did not exceed 10 µg/m$^3$, which is the threshold recommended by WHO. Moreover, if the daily average PM$_{10}$ mass concentration does not exceed 20 µg/m$^3$, about 1000-5000 people can avoid post-neonatal disease, bronchitis, and chronic bronchitis.

Table 3. Attributable proportion (AP) and excess case due to long-term exposure PM$_{2.5}$ and PM$_{10}$.

| Parameter      | Estimated AP, % (min-max) | Exceeded Cases, # (min-max) | Attributable cases per 100,000 population, # (min-max) |
|----------------|---------------------------|-------------------------------|------------------------------------------------------|
| ALRI           | 24.25 (15.02-31.49)       | 7 (4-8)                       | 0.20 (0.13-0.26)                                     |
| COPD           | 20.09 (12.86-29.66)       | 186 (119-275)                 | 5.81 (3.72-8.58)                                     |
| LC             | 17.68 (11.79-23.01)       | 2 (1-3)                       | 0.05 (0.03-0.06)                                     |
| IHD            | 21.20 (14.16-40.61)       | 189 (126-362)                 | 5.89 (3.94-11.29)                                    |
| Stroke         | 19.06 (11.23-30.14)       | 111 (66-176)                  | 3.48 (2.05-5.50)                                     |
| Post neo-natal | 15.39 (8.09-25.04)        | 18 (9-29)                     | 0.56 (0.29-0.92)                                     |
| Bronchitis     | 27.95 (8.99-50.34)        | 828 (266-1550)                | 25.82 (8.30-48.35)                                   |
| Chronic bronchitis | 37.58 (15.39-52.17)    | 2479 (1015-3442)              | 77.36 (31.67-107.37)                                 |

Table 4. Attributable proportion (AP) and excess case due to short-term exposure PM$_{2.5}$ and PM$_{10}$.

| Parameter      | Period        | Estimated AP, % (min-max) | Exceeded Cases, # (min-max) | Attributable cases per 100,000 population, # (min-max) |
|----------------|---------------|---------------------------|-------------------------------|------------------------------------------------------|
| Cardiovascular Disease | Maret-April | 1.97 (0.37-3.56)   | 113 (21-203)                  | 3.51 (0.66-6.33)                                     |
| Respiratory Disease | Juli-Augustus | 1.88 (0.36-3.4)   | 221 (42-399)                  | 6.90 (1.30-12.45)                                    |
| Asthmatic Symptoms | Maret-April | 0.47 (0.1-0.84)   | 1 (0-1)                       | 0.02 (0.00-0.04)                                     |

In addition to long-term exposure PM$_{2.5}$ and PM$_{10}$, the Bandung Metropolitan air basin also has a high health risk, especially for respiratory and cardiovascular events. Based on results, the daily-average of PM$_{2.5}$ and PM$_{10}$ that occurred in March-April was 47 µg/m$^3$ and 52 µg/m$^3$, while in July-August were 46 µg/m$^3$ and 51 µg/m$^3$. These two periods tend to have the same concentrations even though they have different seasonal backgrounds. This is because the monitoring site is in the campus area, where from July to mid-August are student holidays so that activities in the measurement area are small which reduce the potential sources of motor vehicle emissions. Table 4 shows the attributable proportion (AP) and the number of diseases caused by short-term exposure PM$_{2.5}$. The mass concentration of PM$_{2.5}$ in the two measurement periods was above the threshold set by WHO so that the risk of the number of cases due to short-term exposure to PM$_{2.5}$ was also higher. Around 100-900 people in March-April 2019 and 100-1400 people in July-August 2019 can be spared from cardiovascular disease (cardiovascular disease) and respiratory disease if the daily-average PM$_{2.5}$ mass concentration is not more than 25 µg/m$^3$.

The health risk due to short-term exposure PM$_{2.5}$ in July-August which is the dry season is higher than in March-April (rainy season). The rate of respiratory disease is higher than cardiovascular disease,
indicating that short-term exposure PM$_{2.5}$ is more at risk of respiratory disease than cardiovascular disease. Meanwhile, the health risks due to short-term exposure PM$_{10}$ are quite small as shown in Table 4. This is because the PM$_{10}$ concentration is not far from the WHO set a threshold of 52 µg/m$^3$ in March-April and 51 µg/m$^3$ in July-August. However, countermeasures to reduce the number of asthmatics in children by trying to reduce the PM$_{10}$ concentration so that it remains below the predetermined threshold must still be done.

3.4. **Effect of emission sources on disease rates**

Figure 3 shows the distribution of diseases caused by stroke, COPD, ALRI, cardiovascular, post-neonatal around the measurement location (<6 km). The figure shows that the spread of the disease is close to the source of pollutants, such as industrial areas, motorized vehicle emissions, direct burning of household waste, housing construction, and other anthropogenic activities. Both long and short-term exposure to particulate matter has been contributed by local emissions and long-range transport of polluted air. These conditions are also influenced by the local and regional wind based on data from WS/WD which is measured in conjunction with measurements PM$_{2.5}$ and PM$_{10}$.

![Figure 3. Potential emission sources around the monitoring site (<6 km).](image)

4. **Conclusions**

Field observation of air quality and meteorological parameters at Telkom University, Bandung, was conducted from 20 August 2018 to 19 August 2019, using low-cost sensors. We identified high mass concentrations of PM above the WHO standard were affected human health. Results show that the highest case estimate for long-term exposure PM$_{2.5}$ occurs in ischemic heart disease, while the highest rate of disease due to long-term exposure PM$_{10}$ occurs in chronic bronchitis in adults. Estimates of health risks due to short-term exposure PM$_{2.5}$ and PM$_{10}$ have also been carried out in the period March-April and July-August with the parameters of cardiovascular disease, respiratory disease, and asthmatic
disease. These cases were analyzed, and it was occurred higher in July-August (the dry season) compared to March-April which is the rainy season. Health figures related to PM$_{2.5}$ and PM$_{10}$ are caused by pollutant sources around the location of the disease such as proximity to industrial areas, burning garbage, housing construction, and motor vehicle emissions. Changing climate change will cause and affect the local/regional meteorology and it will affect the changing pattern of air pollution, and of course, will cost public health direct/indirectly.

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