Analysis of Spatial Distribution of PM$_{2.5}$ and Human Behavior on Air Pollution in Jakarta

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Abstract. Particulate matter is one of the threatening pollutants harmful to health. Currently, many researchers focus on the problem of PM$_{2.5}$ concentrations in urban areas. This study aims to estimate the spatial distribution of PM$_{2.5}$ and identify human behavior on air pollution in Jakarta. The method used were Spline with Tension to build the PM$_{2.5}$ models, and multiple linear regression models to analyze human behavior on air pollution. The results showed that the annual average of PM$_{2.5}$ in the last two years tends to be high in western, southern, and eastern parts of Jakarta. In addition, there was a decrease of PM$_{2.5}$ concentration in 2020 compared to 2019 assumed as a result of Covid-19 Pandemic restrictions. Besides, analysis results showed a significant association between knowledge and attitude aspects on the action aspect. Based on descriptive analysis, people have good knowledge of air pollution and also concern to reduce air pollution. However, the actions for air pollution control are still not maximized which may cause high PM$_{2.5}$ concentrations in Jakarta. We conclude that to reduce air pollution, the government should focus on the border areas of Jakarta and it can be done by increasing public knowledge and raising awareness for air pollution.

1. Introduction

Jakarta is one of the world’s most polluted cities in 2020 in Indonesia and in the fifth-ranked of the highest air pollution city in the world based on the latest data sourced from IQAir [1]. The degradation of the air quality can have adverse impacts on the environment and humans, including environmental damage, decreased air visibility, global warming, and also increased health impacts on humans [2–10]. One pollutant considered harmful to human health, especially in urban areas, is particulate matter [3]. Particulate Matter, or PM, is a mixture of solids and liquids with different chemical sizes and characteristics, like dust, dirt, soot, smoke, and water droplets emitted in the air [11]. Particulate matter is divided into several types according to the size of its diameter. The kind of PM that humans can inhale is particulates that have a diameter equal to less than 10 μm (PM$_{10}$), particulates with a diameter of fewer than 2.5 μm is called PM$_{2.5}$ [11]. Nowadays, PM$_{2.5}$ is one of the types of particulates considered as a threatening pollutant to human health. These particles pose the most significant health risk, as these pollutants are small enough to penetrate the lung’s natural defense mechanisms. For one thing, PM$_{2.5}$ can penetrate further into the lungs. In addition, these small particles often consist of toxic or carcinogenic combustion products (cancer causes) [12]. Previous research has shown an association between PM$_{2.5}$ concentrations and respiratory, cardiovascular, and even death [3,13–15].
The primary sources of air pollution can be classified as physical, chemical, and biological sources, while the second source comes from anthropogenic and natural [16]. The primary source in urban areas is anthropogenic. Sources of air pollution from anthropogenic are derived from transportation, burning of fuel in stationary sources, various industrial processes, solid waste disposal. Other sources such as agricultural activities and boron emissions from highways can be sources derived from human activities [16].

Activities carried out by humans are influenced by the presence of behavior. Behavior is an action caused by stimulus and generates a response in activities that can be seen directly or the thing behind the action that cannot be seen directly but can be asked and measured through questionnaires [17]. Urban human behavior may be the main problem of air pollution (anthropogenic). Therefore, there needs to be research on human behavior towards increasing air pollution seen from various aspects. So, we will know if there is an association from one aspect to another. In this study, the indicators used as the basis for measurement are the behavior of urban people. The behavior to be analyzed will cover three aspects: knowledge, attitudes, and actions based on the theory of community behavior developed in previous research [18].

Currently, the lack of PM$_{2.5}$ data in Jakarta is a problem faced by researchers to analyze the influence of PM$_{2.5}$ on human health and the distribution of PM$_{2.5}$ in urban areas. Moreover, Jakarta is a unique city, because it is bordered by the sea and industrial cities. Therefore, this study uses the right interpolation method to identify realistic PM$_{2.5}$ distribution model. We choose the best interpolation method by literature review because other methods have the potential to generate models with wrong result and interpretation caused by misleading spatial information, thereby producing false spatial patterns [19–21]. We use the Spline method because this method is suitable for flexible surfaces where it relies on a physical model with the flexibility provided by the changes in the elastic properties of the interpolation function. This model can create fairly accurate and visually appealing surface data based on only a few sample points [19,22].

Spatial distribution mapping is crucial, especially in urban areas, to know the distribution of pollutants in a specific area. A spatial distribution map of PM$_{2.5}$ can help determine the right policy in air pollution control by PM$_{2.5}$ concentrations. Based on the gap mentioned before, this study aims to (1) estimate the spatial distribution of PM$_{2.5}$ concentration in Jakarta, and (2) identify human behavior on air pollution.

2. **Method**

2.1. **Study area**

The research was conducted in Jakarta Province. In this study, Kepulauan Seribu is not included in the study because it is assumed that the activity or source derived from anthropogenic in Kepulauan Seribu does not contribute significantly to air pollution in Jakarta. Jakarta is astronomically located at 6°12’ South Latitude and 106° 48’ East Longitude with an average altitude of 7 meters above sea level. Jakarta, as a coastal megacity, has an area of 662.33 km$^2$. Jakarta is an area that has monsoonal rainfall patterns. The highest rainfall occurred at the peak of the rainy season in February was 457.8 mm, and the lowest at the peak of the dry season in July was 7.25 mm [23].

2.2. **Data collection**

This study used time-series data on monthly and daily PM$_{2.5}$ concentrations in the period 2019 to 2020. The data is obtained from the Department of Environment of Jakarta Province (DLH), the Indonesia Ministry of Environment and Forestry (KLHK), and the United States Embassy (US Embassy). PM$_{2.5}$ data is then calculated into annual average data, where the missing data is filled (gap-filling) using a simple linear regression method with Microsoft Office Excel 2019. The PM$_{2.5}$ data used were taken at eight points of the Air Quality Monitoring Station (AQMS), spread across Jakarta. The location of AQMS can be seen on a Map in Figure 1.
The data used for the analysis of human behavior on air pollution is primary data obtained from questionnaires. Questionnaire data includes knowledge information, attitudes, actions, and other information related to air pollution in Jakarta. Questionnaires distributed to respondents have undergone validity and reliability tests using Pearson Correlation and Cronbach alpha [24].

2.3. Spatial interpolation method
The method used to estimate the spatial distribution of PM$_{2.5}$ concentration is the spatial interpolation method using ArcMap 10.8 software [22,25–27]. The spatial interpolation method used to build the PM$_{2.5}$ concentration distribution model is Spline with Tension method.

2.4. Multiple linear regression
Analysis of human behavior used in this study used the multivariate statistical analysis using IBM SPSS version 21. We used data obtained through research instruments in questionnaires. The sampling method used in this study were determined using purposive sampling techniques (Nonprobability sampling) [28,29]. The respondents' criteria are workers who ride motorcycles, domiciled (currently residing) in Jakarta, between the age of 17-64 years, and male or female. To determine the number of samples, we used Slovin formulas with an error rate of 10 %. The number of samples used in this study was 184 respondents.

3. Results and discussion
3.1. Spatial distribution of annual PM$_{2.5}$ concentration in Jakarta
Figure 2 and Figure 3 are 2D maps that illustrate a model created using the Spatial Interpolation method Spline with tension. Based on 2D visualization on Figure 2, PM$_{2.5}$ concentration tends to be higher in Jakarta's western and southern parts. Almost all areas of South Jakarta and a small part of West Jakarta show red contours. Moreover, PM$_{2.5}$ concentration in the East Jakarta area tends to be relatively high, illustrated by orange contour. On the other hand, concentrations of PM$_{2.5}$ in some areas in the northern and central parts of Jakarta tend to be lower than in the southern, western, and eastern parts of Jakarta. While, the North area of Jakarta is the region with the lowest PM$_{2.5}$ concentration level, shown by green contours.
The color contour in Figure 3 shows that the average annual PM$_{2.5}$ concentration in Jakarta is high in a small part of West Jakarta, South Jakarta, and East Jakarta. Meanwhile, the Central and North Jakarta areas tend to show green contours, which means the concentration of PM$_{2.5}$ annual average in these areas tends to be lower. The annual average PM$_{2.5}$ concentration in 2020 is consistent when compared to 2019, where in the last two years, the concentration of PM$_{2.5}$ in the western, southern, and eastern parts of the Jakarta area tends to be higher.

Overall, the western, eastern, and southern parts of Jakarta showed a high annual average PM$_{2.5}$ concentration in 2019 and 2020. We assume that pollutant sources from industry and transportation influence the high concentration in several area in Jakarta. Jakarta is a very dense area of transportation activity. Moreover, the border area of Jakarta like Tangerang, Bekasi, and Bogor is industrially dense, so there is a possibility of accumulation of pollutants in the Jakarta region on borders area [30]. Previous research has stated that the potential for high concentrations of pollutants in the region, such as in west area of Jakarta, can come from street dust and soil [31]. In addition, besides pollutant sources, meteorological factors, topography, structure, and urban settlement problems affect the perceived, commenced, and the process of transformation of pollutants [32]. Furthermore, there needs to be further analysis on the sources and causative factors of high concentrations of PM$_{2.5}$ in Jakarta.

On the other hand, the Jakarta area which borders the sea in the North area shows a low concentration of PM$_{2.5}$. This discovery is supported by the literature that local winds induced by the coastline may have a major influence on the spread of air pollution (dispersion) [33, 34]. Dispersion is the combined impact of diffusion and transportation, whereby it is affected by the presence of intense gradients from surface flux, roughness, turbulence, insolation, mixing depth, and horizontal and vertical winds of the coastal zone [34].

However, when described as a whole, there is a change in concentration from 2019 to 2020. The annual average PM$_{2.5}$ concentration in 2020 decreased compared to the previous year. Spatially, contour colors indicated in 2020 (Figure 3) dominated with yellow and green colors, while in 2019 (Figure 2), contour colors on the map are dominated with orange and red colors. In addition, the highest concentration shown by color bars in 2020 is lower at 52.98 μg/m$^3$, while in 2019, it reaches 61.26 μg/m$^3$. The Covid-19 pandemic is assumed to be one of the driving factors in the decline of the annual average of PM$_{2.5}$ concentration in Jakarta in 2020. We assume that the decline was caused by the...
influence of one of the government's programs; Large-Scale Social Restrictions. Large-Scale Social Restrictions is one of the government's policies to reduce the spread of the Covid-19 virus in several regions in Indonesia, including Jakarta. The implementation of the restrictions program can reduce air pollution sources derived from human activities (anthropogenic) as the primary source of air pollution in urban areas. Previous researches shown that during the Covid-19 Pandemic, there has been a decrease in air pollution in DKI Jakarta [35,36].

3.2. Human Behavior to Air Pollution in Jakarta

Based on government information, the primary source of air pollution in Jakarta are transportation dan industrial activities [37]. Motorcycle riders are the major private traffic users in Jakarta [37]. Therefore, we conduct research on human behavior on air pollution that focuses on motorcycle riders.

**Figure 4.** Pie chart of respondents’ knowledge (a), attitude (b), and action (c) to reduce air pollution in Jakarta.

Behavior is a form of a person's reaction to an object in the form of an action [38]. The analysis of human behavior in this study consists of three aspects: the knowledge aspect, attitude aspect, and action aspect [18]. The first aspect is knowledge. Human behavior in daily activities is influenced by knowledge, either sourced from the media or directly received [18]. Knowledge has a vital role to play in influencing human's actions. In this study, the knowledge referred to is the respondent's knowledge of air pollution, the source of air pollution, the dangers of air pollution, and the government's policy in reducing air pollution.

Based on Figure 4 (a), more than 70 % of respondents have good knowledge of the air pollution problem in Jakarta. It means that respondents are well aware of air pollution issues, sources of air pollution, air pollution hazards, and government policies to reduce air pollution. Based on respondent demographic data on education, 57.8 % of respondents are undergraduate graduates. Education is the process of changing the attitudes and behaviors of a person or group of people [18]. Thus, education background is a determining factor in the percentage of knowledge about air pollution of respondents.

Based on Figure 4 (b), 51 % of respondents showed that they "strongly agree", and 45 % chose "agree" to participate in various efforts to reduce air pollution and fully support government's policies to reduce air pollution. We conclude that the government's efforts in raising public awareness of air pollution have been implemented well. In this case, the
government is a role model with persuasive capabilities [18]. The results of a questionnaire on the actions aspect of respondents who have the potential to reduce air pollution in Jakarta in Figure 4 (c) showed that as many as 22 % of respondents routinely take actions that can reduce air pollution. In comparison, the other 29 % never do at all. It showed that only a small percentage of respondents conduct activities that can reduce air pollution in Jakarta.

We analyze the association of knowledge and attitude on actions to see if there is a significant association of knowledge and attitude simultaneously on respondent’s actions. We build multiple linear regression models consisting of independent variables of attitude and knowledge. On the other hand, the action aspect is a dependent variable. Based on the results of statistical calculations using IBM SPSS version 21, the regression of variable X (Knowledge) and variable XX (Attitude) to variable Y (Action) is generated R² value 0.15. That means that the percentage of knowledge and attitude that simultaneously associates with actions are 15.1 %, and 84.9 % is associated by other variables not discussed in this study. The value of R² indicates the magnitude of the association of knowledge and attitude on a respondent’s actions to reduce air pollution. However, the value of R² in this research is low, so it can be said that the association of knowledge and attitude is minimal. We assume that the R² value is too small because the number of samples in the study was few. Based on the results of the F test, it is known that F values are 16,094 with the F table 3.05. So based on the F test, it can be known that knowledge and attitude of respondents simultaneously affect respondent’s actions to reduce air pollution.

Based on the T-test, the value indicated by the result of variable T-test on variable X (knowledge) to variable Y (action) is 3.465 greater than T table 1.65, with a significance of less than 0.05. That means that there is a significant association between knowledge and action. Similarly, the T-test results in variable XX (attitude) to variable Y(action), resulting in a T value of 1.96, more significant than the T table with a significance equal to 0.05. That means there is a significant association between attitude and action. Based on the T-test we knew that knowledge is more influential than attitude on action.

From the multiple linear regression model, we can assume that if the government wants to increase the role of the community in reducing air pollution, then the government should improve their knowledge and attitude. This suggestion is one of the many strategies that can be used to control the air pollution issue in Jakarta.

4. Conclusion

The annual average of PM₂.₅ concentration in 2020 was consistent when compared to 2019, where in the last two years, the concentration of PM₂.₅ has been higher in the western, southern, and eastern parts of Jakarta. Probably, it is because there are so many industrial and transportation activities that contribute to emissions in the air in that area. The annual average of PM₂.₅ concentration in 2020 decreased compared to the previous year. The decrease of PM₂.₅ concentration in 2020 is due to total large-scale social restrictions activity, which is suspected to significantly influence the decrease in concentration. There need to be further studies on the leading causes and sources that affect the spread of PM₂.₅ concentration, be it based on aspects of topography, meteorology, polluting sources, and others. In addition, air pollution by PM₂.₅ in Jakarta needs to be a concern for all the stakeholders, including citizens. Based on the regression models, we can see that aspects of knowledge and attitudes simultaneously affect respondents’ actions. Thus, it can be an input for the government in implementing policies for the community in reducing air pollution.

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