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Analysis of $PM_{2.5}$ Level Related to Vehicle Activities in Campus Parking Lot

Achmad Y T Panuju[1*], M Dyan Susila[1], Endro P Wahono[2], Sri Ratna Sulistiyanti[3] and Gusri A Ibrahim [1]

[1] Department of Mechanical Engineering, Faculty of Engineering, Universitas Lampung, Gedung H Lt. 2, Jl. Prof. Soemnantri Brojonegoro No. 1, Bandar Lampung 35143, Indonesia
[2] Department of Civil Engineering, Faculty of Engineering, Universitas Lampung, Gedung H Lt. 2, Jl. Prof. Soemnantri Brojonegoro No. 1, Bandar Lampung 35143, Indonesia
[3] Department of Electrical Engineering, Faculty of Engineering, Universitas Lampung, Gedung H Lt. 2, Jl. Prof. Soemnantri Brojonegoro No. 1, Bandar Lampung 35143, Indonesia

*Corresponding Author: achmad.yahya@eng.unila.ac.id

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Abstract
The number of vehicle usage, especially motorcycles, in Indonesia has significantly increased in the past 10 years, particularly among young people. This has had an impact on the declining air quality in public places, including on campus grounds. $PM_{2.5}$, as one of the hazardous pollutants to health, needs to be given special attention regarding its dispersion concentration in areas heavily frequented by the public, such as parking lots on campus. This study analyzes the level of $PM_{2.5}$ concentration in the campus parking lots at Universitas Lampung, with the aim of observing the pattern of $PM_{2.5}$ pollution in the campus area, considering the increasing number of motorcycles entering the campus every year. The measurement of $PM_{2.5}$ levels was conducted using a light scattering sensor in two parking lots with different microenvironments, and then its correlation with motorcycle activities at each location was analyzed using simple regression. Based on statistical analysis, it was found that the differences in microenvironments affect $PM_{2.5}$ levels significantly. The number of motorcycle activities also has a positive correlation with the level of $PM_{2.5}$, where the average $PM_{2.5}$ concentration recorded has exceeded the threshold set by the government, which is 15 $\mu g/m^3$ per day. However, the effect of the microenvironment in this study is stronger than the number of vehicles. Therefore, in the future, appropriate policies and strategies are needed to reduce $PM_{2.5}$ concentrations in public areas, especially on campuses, to prevent the associated risks of the pollution.

Keywords: $PM_{2.5}$ Concentration, Air Pollution, Campus Parking Lot

1. Introduction

The transportation patterns in many developing and emerging countries, including Indonesia, have undergone significant changes in the past decade due to the rapid growth of personal motor vehicle ownership [1]. Motor vehicles have become relatively more accessible to individuals through credit programs offered by banks or leasing companies, motivating not only the upper-middle class but also individuals from lower-income groups and young people to

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purchase motor vehicles [2]. On the other hand, the public's interest in using public transportation in these countries is low due to the perceived inconvenience and lack of safety associated with public transport [3]. For example, in many cities in Indonesia, the number of public transportation vehicles has drastically decreased, replaced by the widespread use of motorcycles on the roads. Motorcycles are not only used for short-distance transportation within cities but also for intercity travel [2].

The increasing use of motorcycles has become prevalent among various segments of society in their daily activities, including commuting to work, going to campus, shopping, and other activities [4]. The high number of motorcycles can be observed on urban roads and in public places, including within campus areas. Campuses with many students, staff, and lecturers, such as Universitas Lampung, have also experienced an increase in the number of vehicles, especially motorcycles, entering the campus area every day. This has led to several negative impacts, including reduced road comfort, parking capacity constraints, and declining air quality caused by motor vehicles.

One of the hazardous pollutants in such air conditions is $PM_{2.5}$, which refers to fine particles suspended in the air with a diameter smaller than 2.5 microns. These particles have been proven to be a contributing factor to dangerous diseases in humans, as they can enter cells within the body through the respiratory system causing severe illnesses [5]. In relation to motor vehicles, $PM_{2.5}$ is generated by various factors, including incomplete combustion of fuel and dust raised from the ground due to tire-road friction. $PM_{2.5}$ particles can remain suspended in the air for extended periods due to their lightweight nature and can disperse rapidly in various directions with the assistance of wind from their original sources [6].

Considering the characteristics of this pollutant as described above, researchers have conducted numerous studies to analyze the distribution patterns of $PM_{2.5}$ and the factors that contribute to its concentration increase or decrease. However, studies specifically analyzing the micro-distribution of $PM_{2.5}$ in specific areas, particularly in the Lampung region, are still relatively scarce. Therefore, this study aims to provide an overview of $PM_{2.5}$ distributions within the Universitas Lampung campus area and analyze its correlation with motor vehicle activities. The findings from this research are expected to contribute to related academic fields and serve as a basis for formulating solutions to improve air quality in the Lampung region specifically

2. Related Works

$PM_{2.5}$ is a more hazardous pollutant compared to PM_{10}, its predecessor, which was previously widely used to measure ambient air quality standards. It has been classified as a hazardous group of pollutants and is known to possess carcinogenic properties, thus raising global concerns over the past decade [7, 5]. Reported death rates attributed to this pollutant have exceeded 8 million, and continue to rise, making the discussion in this field a serious global issue [8, 9]. In response to these conditions, numerous studies discussing the distribution of $PM_{2.5}$ concentrations in various regions have been conducted, employing various methods and comparative aspects [10, 11]. What causes an increase in the concentration of this pollutant in the air, and what factors can make it decrease? Under what conditions is its concentration at its highest, and in what events does its concentration become the lowest? These questions have been attempted to be answered by experts in numerous scientific writings. Understanding the patterns of $PM_{2.5}$ concentration distribution is crucial to formulate appropriate solutions. It is not only important to know the concentration distribution but also the trends of increase or decrease in order to classify each region as high, moderate, or low risk [12].

Based on various studies, it can be generally stated that $PM_{2.5}$ concentrations increase in parallel with human activities, including industrial activities, population growth, and mobilization [13, 14]. These activities have generated emissions, including fine particles, which then persist in the ambient air for a certain period and subsequently get distributed to other areas with the assistance of wind and human mobility. Additionally, the $PM_{2.5}$ concentrations are also influenced by location and climatic factors such as the presence of green open spaces, rainfall, and wind [15]. Consequently, areas with high population densities and relatively dry climates, such as certain locations in India and China, experience very high levels of $PM_{2.5}$. Rainfall will significantly aid in reducing these fine particles to the ground, preventing them from being inhaled by humans. However, in some developed

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countries with high economic activities but more environmentally friendly behaviors, such as those in Europe and the United States, $PM_{2.5}$ levels are found to be low and declining [12]. Environmentally friendly behaviors include the use of public transportation as a means of transportation [16] and the use of environmentally friendly products [17]. In those developed countries, their communities have even shown a trend towards using environmentally friendly technologies to generate electricity and adopting alternative vehicles with lower emissions, such as fuel cell-powered buses and electric vehicles.

$PM_{2.5}$ is also closely associated with transportation activities, where an increase in the number of motor vehicles is followed by an increase in ambient $PM_{2.5}$ concentrations. This is due to incomplete combustion processes in the engine and other factors related to motor vehicle activities on the roads. Therefore, the age of the vehicle and its maintenance history will undoubtedly determine the amount of fine particles and harmful gases emitted by a vehicle, although field studies capable of verifying this statement are still very difficult to find [18, 19, 20].

Although it is not the sole determining factor of $PM_{2.5}$ concentration levels in ambient air, these studies have shown a positive correlation between increased motor vehicle activity and increased $PM_{2.5}$ concentrations. However, due to the complexity of other factors involved, analyzing $PM_{2.5}$ concentrations in different locations with varying micro and climatic conditions can yield different results. Even in micro scales, differences in relatively nearby locations can lead to interesting conclusions.

3. Methodology

The measurement of $PM_{2.5}$ in this study utilized calibrated light scattering sensors. Light scattering sensors for measuring $PM_{2.5}$ concentrations are increasingly being used due to their affordability and ease of operation. Although the measurement accuracy of these sensors may not be as good as the gravimetric method, previous studies analyzing the calibration results of light scattering sensors have shown consistent positive correlations with gravimetric reference instruments [21]. Additionally, data from light scattering sensors can detect changes in ambient air conditions more quickly and can be connected to a data logging system, facilitating the data collection process [22]. This makes it easier to develop further systems using internet of things and additional algorithms, enabling real-time air quality analysis without being constrained by distances.

In this research, $PM_{2.5}$ levels were measured at two motorcycle parking areas with relatively similar sizes: Engineering Faculty and Law Faculty parking lots at Universitas Lampung, each for three days. Measurements were taken at three different times each day: the first from 7:30 to 8:30, the second from 9:30 to 10:30, and the last from 12:30 to 13:30. The selection of these three times was based on observations that motorcycles were most frequently entering and leaving the parking lots during these periods. During each time interval, $PM_{2.5}$ levels were measured every 10 minutes, resulting in 6 data points of $PM_{2.5}$ concentration per hour. In addition to $PM_{2.5}$ levels, other data collected included temperature, air pressure, humidity, wind speed, and wind direction. The sensors were placed at the periphery of the parking lots to avoid interfering with the movement of vehicles entering and exiting. At the same time, the research team counted the number of motorcycles actively present in the parking lots, defining activity as when the motorcycles' engines were turned on, whether they were entering or leaving the parking area.

The obtained $PM_{2.5}$ concentration data from these measurements were then analyzed in a time-series manner. It is predicted that differences in microenvironments would have a significant influence on the $PM_{2.5}$ concentrations at both locations. Furthermore, the $PM_{2.5}$ concentration data will be compared with the data on motorcycle activity, assuming a weak positive correlation between the two. This correlation analysis will be conducted using simple regression. Another analysis conducted is regarding the microenvironment conditions of each location, as both locations have distinct conditions. The observations will be made in a general sense, meaning the reports will not be highly detailed. It is assumed that these microenvironment differences will also have a significant impact on the distribution of $PM_{2.5}$.

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4. Results and Discussions

The measurements, as described in the methodology section, were conducted in May and June of 2023, during campus examination time which the conditions were moderate in terms of campus activity levels, as it was the end of the academic semester before the holiday period.

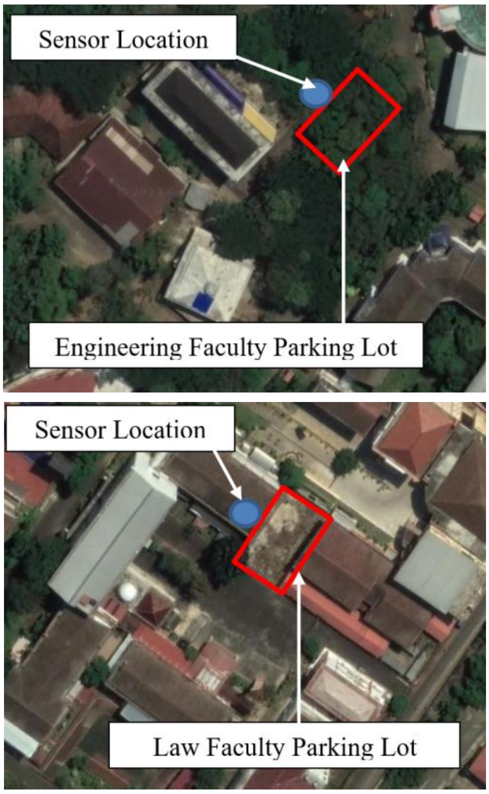

Figure 1. Microenvironment of Measuremant Location in Engineering and Law Faculty

The Engineering Faculty (EFPL) and Law Faculty (LFPL) parking lots have different microenvironments, as shown in the image obtained from Google Earth (Figure 1). EFPL is surrounded by more trees and is located approximately 200 meters from the main road of the campus and 250 meters from the city highway in Bandar Lampung. In fact, the parking lot is shaded by dense foliage, making it less visible from above. However, the location of this parking lot is marked by a red box in the image. The sensor positions are indicated by blue dots, so the measurement configuration between EFPL and LFPL is the same. On the other hand, LFPL has different characteristics as it is surrounded by academic buildings and located about 10 meters from the busy main road of the campus, which serves as the border with a densely populated residential area. These differences are expected to affect the air quality in both locations. Firstly, there is a difference in the level of greenery [12], and secondly, it is due to the proximity to busy roads and residential areas [6, 20]. With such conditions, theoretically, the concentration of $PM_{2.5}$ in LFPL will have a higher value. However, based on motor vehicle activities, the overall number of motorcycles entering and exiting EFPL is higher compared to LFPL. Therefore, the differences in parameters will be interesting to observe the results.

$PM_{2.5}$ concentration measurements have been conducted at the parking lots of the Engineering Faculty and Law Faculty in May and June 2023. The results of the time-series measurements can be seen in Figure 2 and Figure 3.

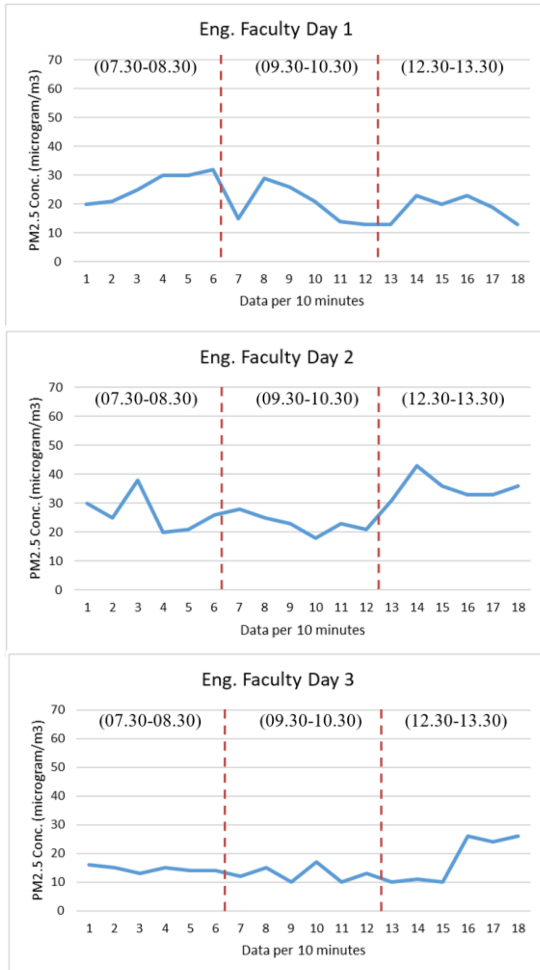

Figure 2. $PM_{2.5}$ in Engineering Faculty

The temperature during the measurements ranged from 26-27 degrees Celsius in the morning, slightly increasing to 29-32 degrees Celsius during the day. Meanwhile, the relative humidity ranged from 54-84%. The humidity in the morning tended to be higher and became drier during the day unless there was rainfall.

Throughout the measurement process, there were two instances of light rain, which occurred during the third session of the first three days at LFPL and the second session of the third day at LFPL. The windiest day was the first day at EFPL, with wind speeds ranging from 0-2.3 $m.s^{-1}$, while the least windy day was the second day at LFPL, with an average wind speed below 0.3 $m.s^{-1}$.

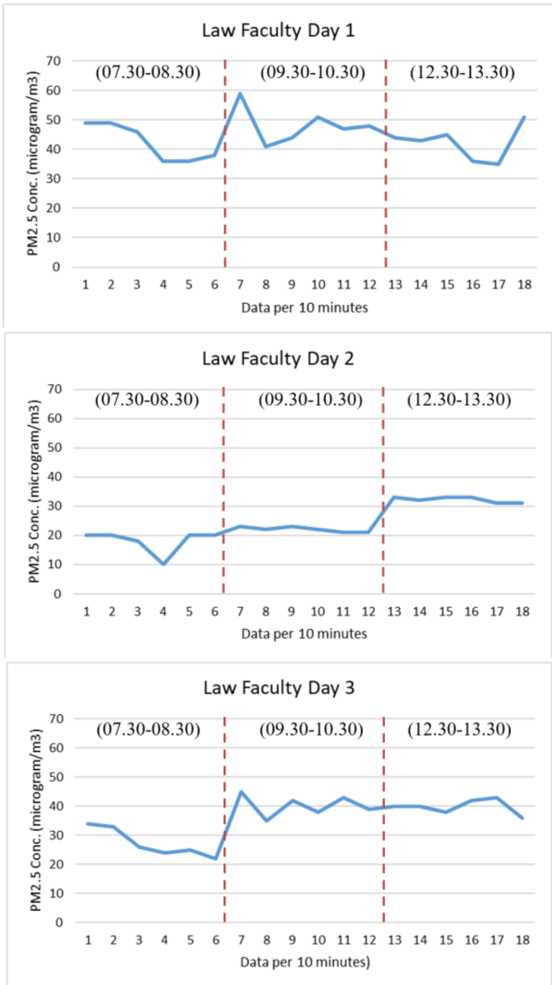

Figure 3. PM2.5 Level in Law Faculty

The $PM_{2.5}$ concentration fluctuations appear to lack a consistent pattern for each measurement session conducted. The measured $PM_{2.5}$ levels ranged from 10-59 $\mu g.m^{-3}$, with the lowest data obtained at the Engineering Faculty parking lot and the highest at the Law Faculty parking lot. It should be noted that the first day of measurement at EFPL is not the same as the first day of measurement at LFPL. The first day at EFPL showed a decreasing trend from morning to noon, the second day exhibited a more erratic up-and-down trend, while the third day remained relatively stable in the first two sessions and slightly increased in the third session. The first day of measurement at LFPL showed fluctuations at relatively high levels, while the second and third days exhibited similar increasing trends. Based on the analysis of the time-series graph, it can be observed that each day has a unique pattern of $PM_{2.5}$ concentration.

Based on the boxplot graph in Figure 4, it can be observed that the average $PM_{2.5}$ concentration at LFPL (C2) is higher at 34.7 $\mu g.m^{-3}$, compared to 21.6 $\mu g.m^{-3}$ at EFPL (C1). The variability in LFPL is also larger, although the lower limit of LFPL data is still higher than the average value of EFPL. Therefore, it can be assumed that the microenvironment differences at the two locations have a significant impact on $PM_{2.5}$ concentrations. Generally, it can be said that the concentration of $PM_{2.5}$ at both locations is in the moderate range but exceeds the government's standard limit of 15 $\mu g.m^{-3}$. The World Health Organization (WHO) has set a higher limit at 34.5 $\mu g.m^{-3}$. Therefore, the average $PM_{2.5}$ concentration at LFPL has slightly exceeded this threshold, while the concentration at EFPL is below it. However, the measurements were not taken during the busiest campus conditions, so the average concentration values are at risk of being even higher during peak campus activity.

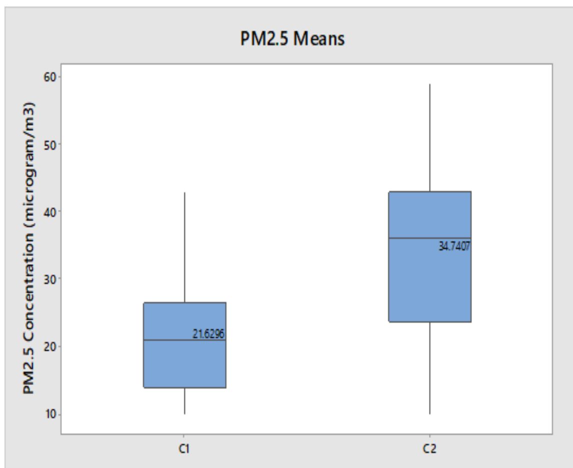

Figure 4. Means of PM2.5 Level in EFPL and LFPL

The $PM_{2.5}$ concentration data is then compared with the data on the number of motorcycles starting their engines and entering or exiting the parking lots. By using simple linear regression, the plot graphs in Figure 5 is obtained for each day of measurement. All the graphs show a positive correlation between the number of motorcycles and the average $PM_{2.5}$ concentration, although the relationship is not strong and influenced by many other factors. This fact is based on the constants of the linear regression equation that was formed and observed positions of data points relative to the pattern line.

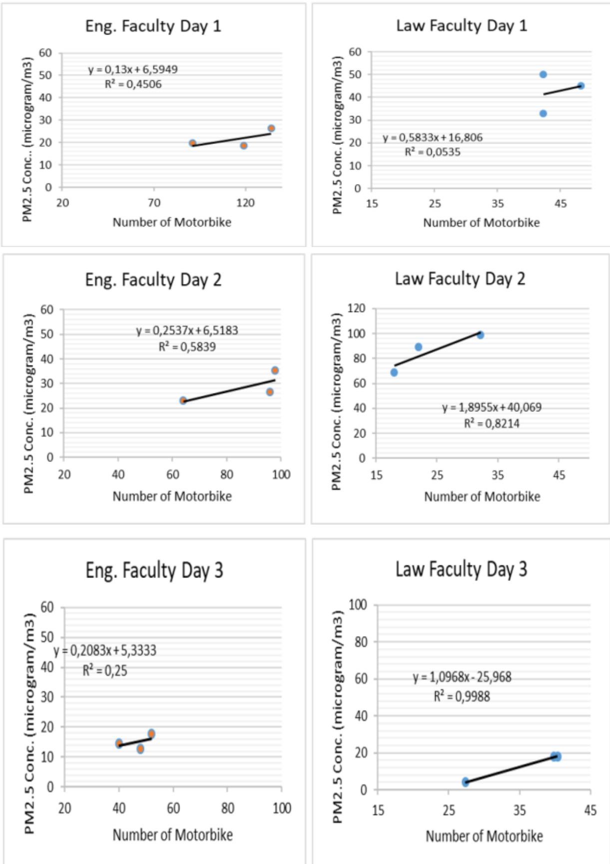

Figure 5. $PM_{2.5}$ Level vs Number of Motorbike Activities

Nevertheless, this positive correlation pattern is limited to the same day. This pattern cannot be obtained if all data are combined, especially when it includes data from both locations. The lowest $PM_{2.5}$ data was found on the third day at LFPL, likely due to rainfall causing the particles to settle to the ground. Meanwhile, the highest data point was also found at LFPL on the second day. Although the wind blew quite consistently, the surrounding "walls" of buildings in the LFPL parking area could prevent the movement of particles to other places. This also causes $PM_{2.5}$ levels to increase gradually on clear days throughout the day. Generally, this positive correlation is a signal to be alert about the increasing number of motor vehicles, including those entering the campus area, where the rise in $PM_{2.5}$ levels can lead to a decline in the health of people within that area.

As a representative of intellectual society, the campus should set an example in managing motor vehicle usage to reduce harmful gas emissions and other pollutants, including $PM_{2.5}$. Environmentally-friendly internal campus transportation options, such as rail-based vehicles or low-emission buses, can be considered to reduce the influx of motor vehicles into the campus area. Additionally, creating comfortable pathways for pedestrians and providing facilities for cyclists can also be taken into account.

5. Conclusion

In this study, $PM_{2.5}$ concentration measurements were conducted at two locations on the campus of Universitas Lampung, namely the parking lots of the Engineering Faculty and the Law Faculty, which have different microenvironments. Generally, it was found that the $PM_{2.5}$ concentrations at both locations were in moderate level but exceed the government's threshold. Thus the air quality is needed to improve based on the findings.

The Law Faculty parking lot has fewer green plants and is closer to public roads and residential areas. This contributes to higher $PM_{2.5}$ concentrations at this location. Additionally, both locations showed a similar pattern of the relationship between $PM_{2.5}$ concentration and the number of motorcycle activities in the parking lots, indicating a positive correlation. This finding supports the theory that the higher the use of motor vehicles in a location, the higher the $PM_{2.5}$ pollution.

With the rapid increase in the number of motor vehicles entering the campus area, especially after the end of the pandemic period, there is a concern that air pollution, particularly $PM_{2.5}$ levels, will continue to rise and pose a risk to human health. Therefore, preventive measures need to be taken, including the implementation of appropriate technologies and policies, to improve air quality on campus, especially in the future.

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