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Analysis of PM_1 Concentration on Primary Arterial Roads in Padang City and Correlation with Meteorological Conditions and Traffic Characteristics

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ABSTRACT

This study aims to analyze PM_1 concentration and the correlation of PM_1 concentration with meteorological conditions and traffic characteristics on Padang City Primary Arterial Roads. The research location is perpendicular to Padang City Bypass II Road which is 5m from the roadside. PM_1 measurements were carried out using an EPAM 5000 real-time particulate air monitor. Measurements were made during morning rush hour (06.30-08.30 WIB), midday off-peak hours (11.00-13.00 WIB), and evening rush hour (16.00-18.00 WIB). The results showed that the average PM_1 concentration and standard deviation in the morning, midday, and evening were 17.48(3.05) $\mu g/m^3$, 22.87(2.76) $\mu g/m^3$, and 34.60(7.68) $\mu g/m^3$ respectively with the highest concentration obtained in the evening reaching 42.63 $\mu g/m^3$ and the lowest concentration in the morning 12.83 $\mu g/m^3$. The results of the correlation between PM_1 concentrations and meteorological conditions have a reasonably strong to very strong correlation. PM_1 concentrations are directly proportional to temperature and wind speed and inversely proportional to humidity. The correlation results of PM_1 concentrations to traffic characteristics are directly proportional, such as traffic volume, vehicle speed, and traffic density have a reasonably strong to very strong correlation. These results indicate meteorological factors and traffic characteristics as the main contributors to road air pollution. The recommendation from this study is to optimize air quality monitoring and traffic management.

Keywords: *Primary Arterial Road; Haz-Dust EPAM 5000; Traffic Characteristics; Meteorological Conditions; PM_1.*

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INTRODUCTION

Emissions from traffic, namely motor vehicles, contribute significantly to the source of particulate matter in ambient air in urban areas [1]. High concentrations of particulate matter near highways can negatively impact human health. Communities living near high-traffic highways are more likely to experience diseases such as asthma [2], and children living near high-traffic highways are six times more likely to develop cancer than those living further away from major highways [3]. PM_1 has a greater impact than $PM_{2.5}$ and PM_{10} for children aged 4 years or younger [4]. This is because PM_1 consists of primary organic aerosols, sulfates, ammonium, nitrates, and chlorides [5]. In addition, the size of PM_1 is much smaller than $PM_{2.5}$ and PM_{10}, which allows pollutants to reach the lower lobes of the lungs, causing greater damage to respiratory health [4].

Padang City is one of the big cities in West Sumatra Province. The density of motorized vehicles in Padang City reached 496,662 units [6]. Every year there is an increase in the population which will also increase the number of vehicles in Padang City. The increase in the number of vehicles will certainly be directly proportional to traffic density. High traffic density

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will increase the concentration of particulates on the side of the highway [7]. The congestion that occurs will increase the level of air pollution, especially due to PM which will endanger the health of the people of Padang City. One of the roads with busy traffic is Bypass Road II, Padang City, which is a primary arterial road. According to data from the Balai Pelaksanaan Jalan Nasional (BPJN) III in 2020, the density of Bypass Road II had a traffic density of 2152 cpu/hour.

Research on PM_1 concentration on the side of the highway has been carried out in several countries in the world, but it is still limited in Indonesia, especially in Padang City. Research on air quality monitoring on highways in Padang City is more focused on coarse and fine particulates (PM_{10} and $PM_{2.5}$). Based on the description above, it is necessary to research the concentration of PM1 in the ambient air along the edge of Bypass Road II, Padang City, and its correlation with meteorological conditions and traffic characteristics, although there are no national and international regulations governing the quality standards for PM_1.

METHOD

The research location is a road perpendicular to the dominant wind direction and traffic, namely Bypass Road II Padang City with coordinates 0 ° 55'44.53 "S, 100 ° 23'55.12" E (Figure 1). The selection of the measurement location is also based on traffic volume and the availability of unobstructed space with buildings and plants from the side of the road. The distance of the measurement location point is 5 m (0 m indicates the side of the road) on the right (East) of the road section. This device is a portable device capable of capturing PM data in real-time and accurately. Measurement of PM_1 concentration using the EPAM 5000 Real Time Particulate Air Monitor. This device operates on the principle of near-front light scattering using infrared radiation. Particles in the air that pass through the device's infrared beam scatter light, which is detected by a photodetector placed at a 90-degree angle to the light source. The intensity of the scattered light is proportional to the particle concentration, allowing precise measurement of PM levels in mg/m^3. To ensure reliability, the device features an internal signal processing system that minimizes noise and drift correction, resulting in high resolution, low detection limits, and a stable baseline [8].

Measurements were carried out for two hours during the morning rush hour period (06.30-08.30 WIB), midday off-peak hours (11.00-13.00 WIB), and evening rush hour (16.00-18.00 WIB) at an interval of 7 days. This aims to see variations in traffic patterns which provides a comprehensive temporal analysis of PM_1 concentrations. Measurement of meteorological conditions was carried out using an environment meter at a height of 1.5 meters. Measurement of meteorological condition data was carried out for two hours of measurement and recorded every 10 minutes. Meanwhile, the calculation of the number of vehicles is done using a smartphone-based traffic counter. The measurement of the number of vehicles is carried out simultaneously with the sampling time. Vehicles are classified into three categories motorcycles (MC), cars and taxis, or Light Vehicles (LV) and trucks/Heavy Vehicles (HV). Vehicle speed measurements are carried out using a speed gun.

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Figure 1. Map of Research Locations

RESULTS AND DISCUSSION

Meteorological conditions

The temperature at the measurement location of Bypass Road II, Padang City ranges from 27.00 - 31.65 ^{o}C and the relative humidity ranges from 62.67 - 66.10% which shows the temperature and relative humidity (RH) values that vary but are still in normal conditions. As shown in Table 1. the wind speed at the research location ranges from 0.53 - 0.66 m/s. The dominant wind direction at the research location comes from the East and West as seen in Figure 2. As shown in Table 2, it can be seen that the highest average traffic volumes are in the Evening at 4293.01 pcu/hour, midday at 2321.02 pcu/hour, and morning at 2112.23 pcu/hour.

Table 1. Data on Meteorological Conditions of Padang City Bypass II Road

Days	Temperature (C)	RH* (%)	Wind Speed (m/s)
Day 1	27.88	66.10	0.54
Day 2	30.34	62.75	0.66
Day 3	28.17	62.86	0.56
Day 4	27.00	65.13	0.53
Day 5	31.65	62.67	0.66
Day 6	29.03	63.34	0.62
Day 7	28.26	63.45	0.66
Average	**28.91**	**63.76**	**0.61**
STD	**1.47**	**1.23**	**0.06**
Max	**31.65**	**66.10**	**0.66**
Min	**27.00**	**62.67**	**0.53**

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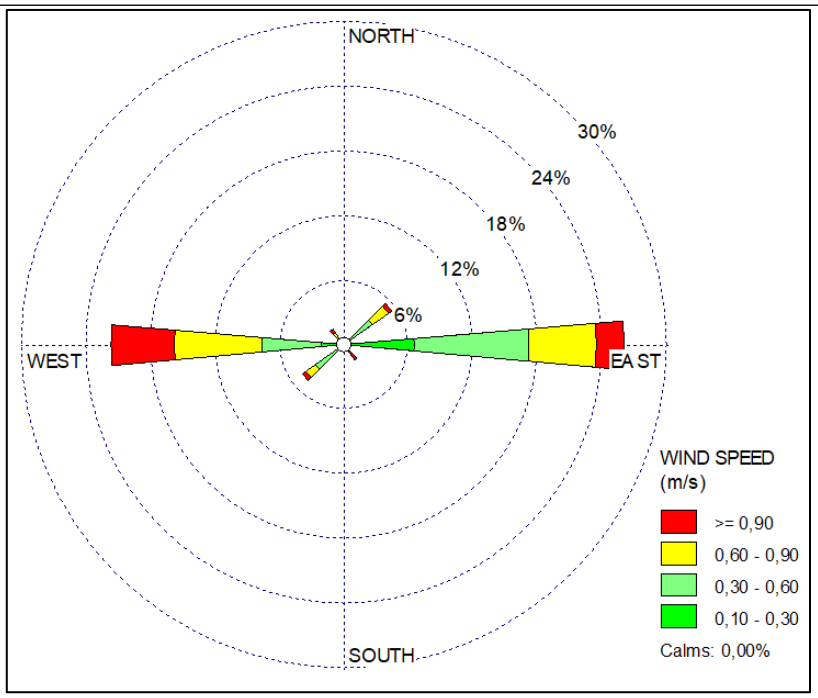

Figure 2. *Windrose Road Bypass II During the Day*

Table 2. Data on Speed, Vehicle Volume, and Traffic Density on Bypass II Road

Days	Traffic Speed (km/h)	Traffic Volume (cpu/h)	Traffic Density (CPU/km)
Morning (06.30-08.30 WIB)			
Day 1	46,94	2549,65	54,32
Day 2	59,14	2266,55	38,32
Day 3	56,73	1689,30	29,78
Day 4	55,25	1305,73	23,63
Day 5	44,79	2463,98	55,01
Day 6	56,33	1950,60	34,63
Day 7	57,67	2559,80	44,39
Average	**53,84**	**2112,23**	**40,01**
Midday (11.00-13.00 WIB)			
Day 1	47,74	2590,63	54,26
Day 2	54,85	2541,83	46,34
Day 3	52,04	2486,85	47,79
Day 4	52,44	2204,70	42,04
Day 5	44,66	1976,25	44,25
Day 6	55,12	2350,43	42,64
Day 7	51,63	2096,48	40,60
Average	**51,21**	**2321,02**	**45,42**
Evening (16.00-18.00 WIB)			
Day 1	48,55	4749,53	97,83
Day 2	57,00	4891,20	85,81
Day 3	52,17	3488,53	66,87
Day 4	45,20	3579,30	79,20
Day 5	48,55	3898,18	80,29
Day 6	51,50	4958,35	96,28
Day 7	57,80	4486,00	77,61
Average	**51,54**	**4293,01**	**83,41**

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PM_1 Concentration

The average, maximum, and minimum PM_1 concentrations during morning, midday, and evening measurements are shown in Table 3 and Figure 2. The average concentrations and standard deviations in the morning, midday, and evening were 17.48(3.05) μg/m^3, 22.87(2.76) μg/m^3, and 34.60(7.68) μg/m^3. The highest PM_1 concentration was obtained in the evening reaching 42.63 μg/m^3 while the lowest concentration was obtained in the morning12.83 μg/m^3. The average PM_1 concentration obtained was lower than the results from other cities in Indonesia. For example, roadside PM_1 observed in Jambi showed an average daytime concentration of 42,1 μg/m^3 [9]. When compared to the average concentration obtained in other countries, the PM_1 concentration obtained was also smaller compared to cases in Iran 28.4(4.9) μg/m^3[10], Hongkong 35.9(12.4) μg/m^3[11] dan Algeria 13.46 - 25.59 μg/m^3 [12].

Tabel 3. PM_1 Concentration on Padang City Bypass II Road

Days	Konsentrasi PM_1		
	Morning (06.30-08.30 WIB)	**Midday (11.00-13.00 WIB)**	**Evening (16.00-18.00 WIB)**
Day 1	15.17	21.57	34.90
Day 2	19.97	24.67	42.63
Day 3	14.40	21.10	38.89
Day 4	12.83	18.32	21.10
Day 5	18.93	22.11	42.56
Day 6	21.47	27.17	36.50
Day 7	19.57	25.17	25.63
Average	**17.48**	**22.87**	**34.60**
STD	**3.05**	**2.76**	**7.68**
Max	**21.47**	**27.17**	**42.63**
Min	**12.83**	**18.32**	**21.10**

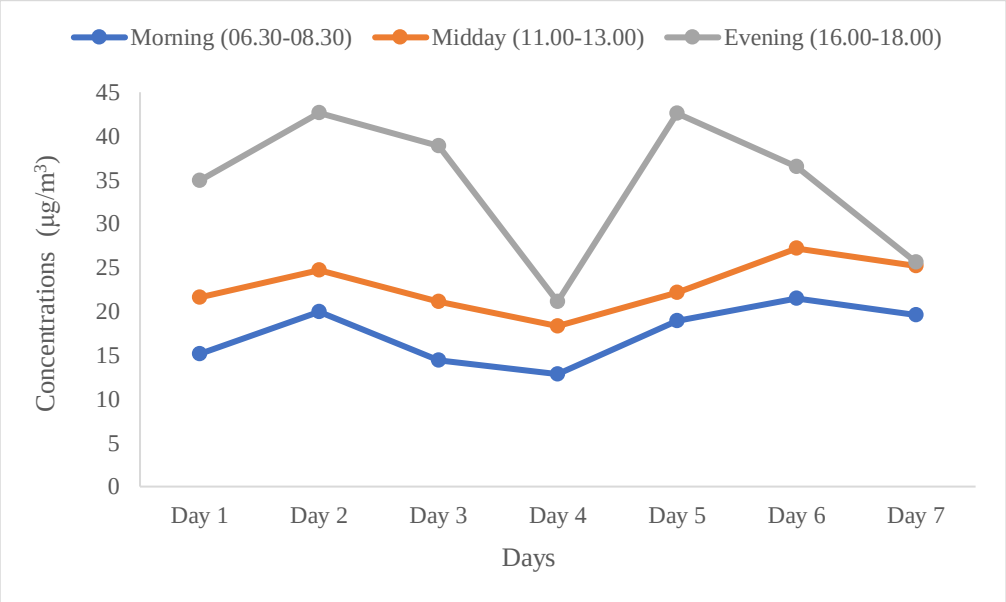

Figure 3. PM_1 Concentration in Morning, Midday, and Evening

During the 7 days of measurement (Figure 3), the PM_1 concentration in the morning was relatively low and stable ranging from 12.83 to 21.47 μg/m^3. This may be due to the small vehicle emissions produced by motor vehicles during the measurement. Based on Table 2, the

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average vehicle volume recorded in the morning was 2112.23 units. The PM_1 concentration showed a slight increase compared to the morning and was relatively stable during the 7 days of measurement ranging from 18.32 to 27.17 μg/m^3. Meanwhile, in the evening, in general, there was an increase in PM_1 concentration, almost twice the morning and midday concentration, except for measurements taken on day 4, where the increase in concentration was smaller compared to other measurement days. This is possible due to meteorological factors such as wind direction and temperature at the time of measurement.

Analysis of the relationship between PM_1 concentration and meteorological conditions

Referring to Figure 4, it can be seen that the coefficient of determination (R2) of PM_1 concentration is 77.53%, which shows that temperature affects PM_1 concentration by 77.53% and the rest is influenced by other factors. The strength of the correlation between temperature and PM1 concentration is seen from the correlation coefficient value (r). The influence and strength of the correlation between temperature and PM_1 concentration are very strongly correlated (0.88). Temperature has a positive effect on particulate concentration [11] [12]. Temperature can affect particle formation where high temperatures can encourage photochemical reactions between particulate precursors [13]. In addition, the increased temperature can cause the formation of a boundary layer, which can cause accumulation of particulate concentration because the movement of particulates is hampered [14].

As shown in Figure 5, wind speed affects PM_1 concentration. PM_1 concentration is affected by wind speed by 77.53% and the rest is affected by other factors, where the average wind speed in this study is not too large, namely 0.61 m/s. The correlation between wind speed and PM_1 concentration is very strong (0.88). When the wind speed is high enough, the wind can transport large amounts of particulates [13]. So that the concentration of particulates in the area becomes large. Wind speeds of more than 5 m/s are considered the maximum conditions that have a major effect on particulate concentration, where the particulate concentration will reach 4 times more than before [15].

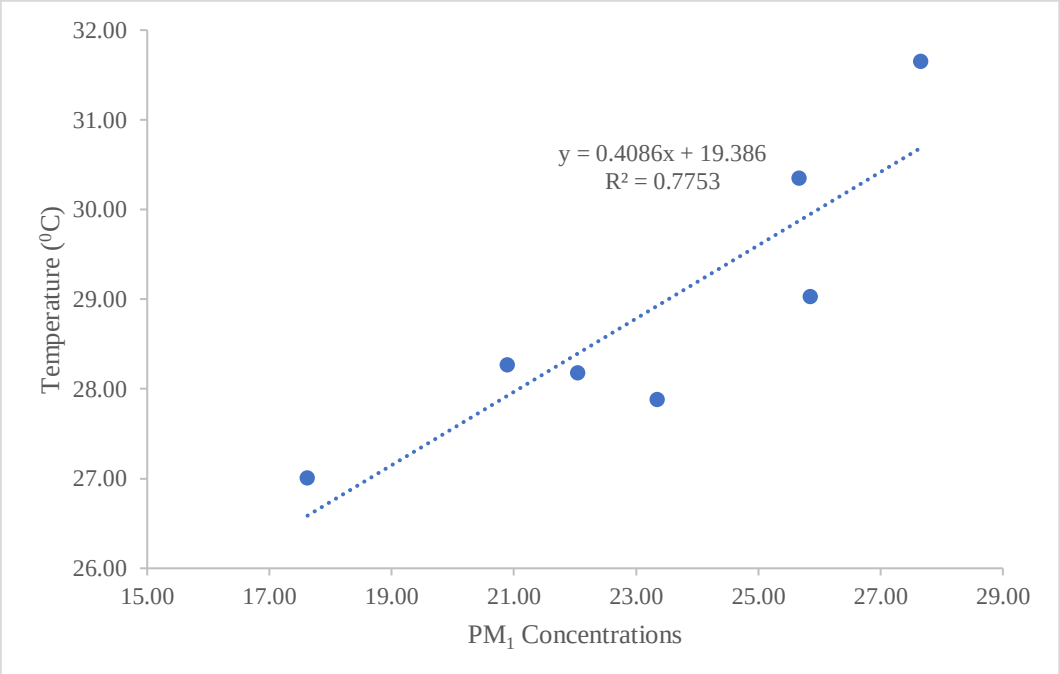

Figure 4. Relationship between PM_1 Concentration and Temperature

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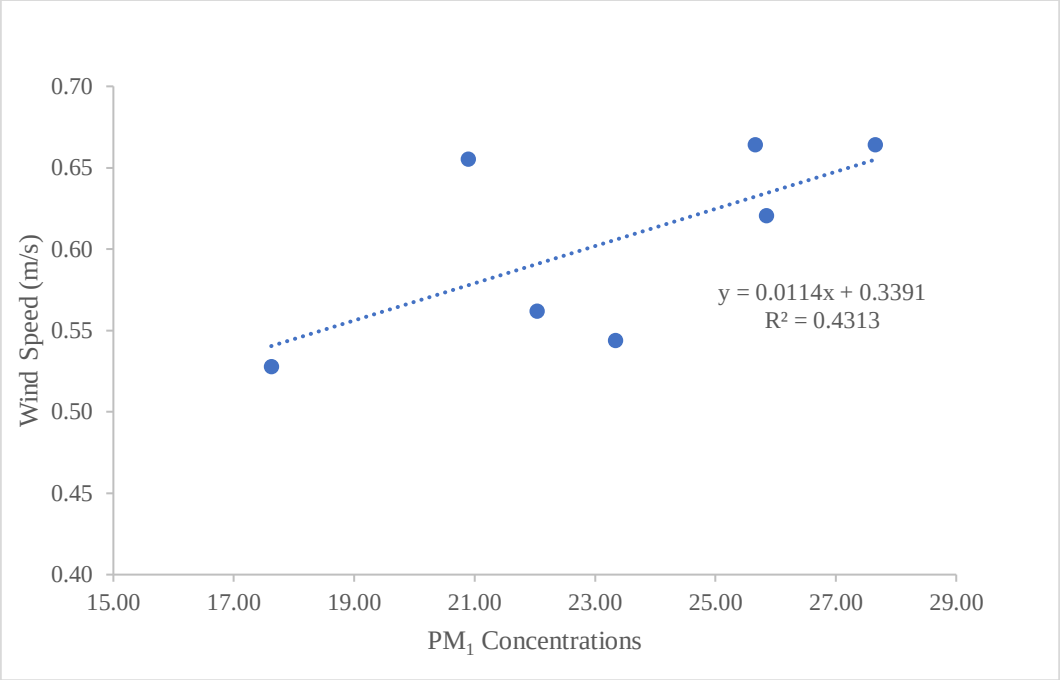

Figure 5. Relationship between PM_1 Concentration and Wind Speed

Based on Figure 6, it is known that the results of linear regression show that PM_1 concentration with humidity has an inverse relationship. When humidity increases, particles adhere to more water vapor, causing an increase in hygroscopic particulates to form [16]. As shown in Figure 6, humidity affects PM_1 concentration (26.20%). Meanwhile, the influence and strength of the correlation between humidity and PM_1 concentration are quite strongly correlated (0.51). The negative effect of humidity on particulate concentration occurs because increased humidity makes particulates wet and heavy enough to stay in the air for a long time, resulting in dry deposition or wet deposition which results in a decrease in particulate concentration [13].

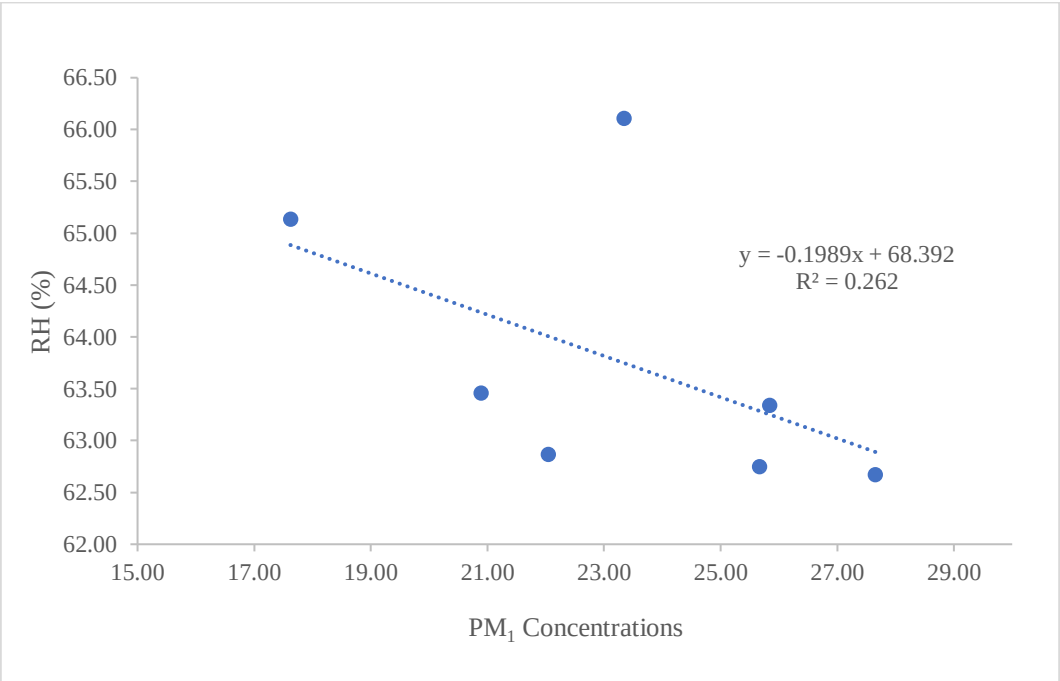

Figure 6. Relationship between PM_1 Concentration and Relative Humidity

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Analysis of the relationship between PM_1 concentration and traffic characteristics

Referring to Figure 7, PM_1 concentration with traffic volume has a direct relationship where the higher the traffic volume, the greater the particulate concentration. This is the same as the research conducted by [9] [7] in which traffic volume has a positive relationship affecting particulate concentration, where the higher the traffic volume, the higher the particulate concentration. High traffic volume will produce a lot of emissions and will increase the concentration of particulates on the road [7]. Likewise, the relationship between PM_1 concentration and vehicle speed (Figure 8) has a direct relationship. The results of this study are the same as those obtained by [7], [17] which state that vehicle speed and particulate concentration have a positive relationship, if the vehicle speed is high, the particulate concentration will also be high. High vehicle speed will lift particulates on the road into the air so that the particulates will be high. Figure 9 also shows where, the higher the traffic density, the higher the particulate concentration, the higher the particulate concentration [7], [17].

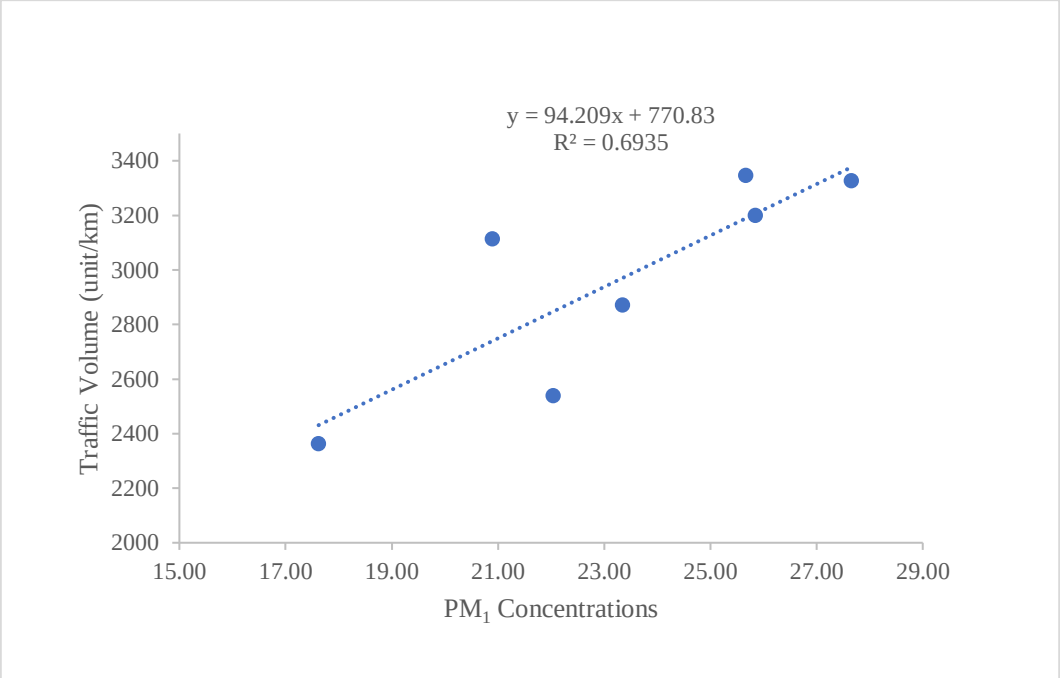

Figure 7. Relationship between PM_1 Concentration and Traffic Volume

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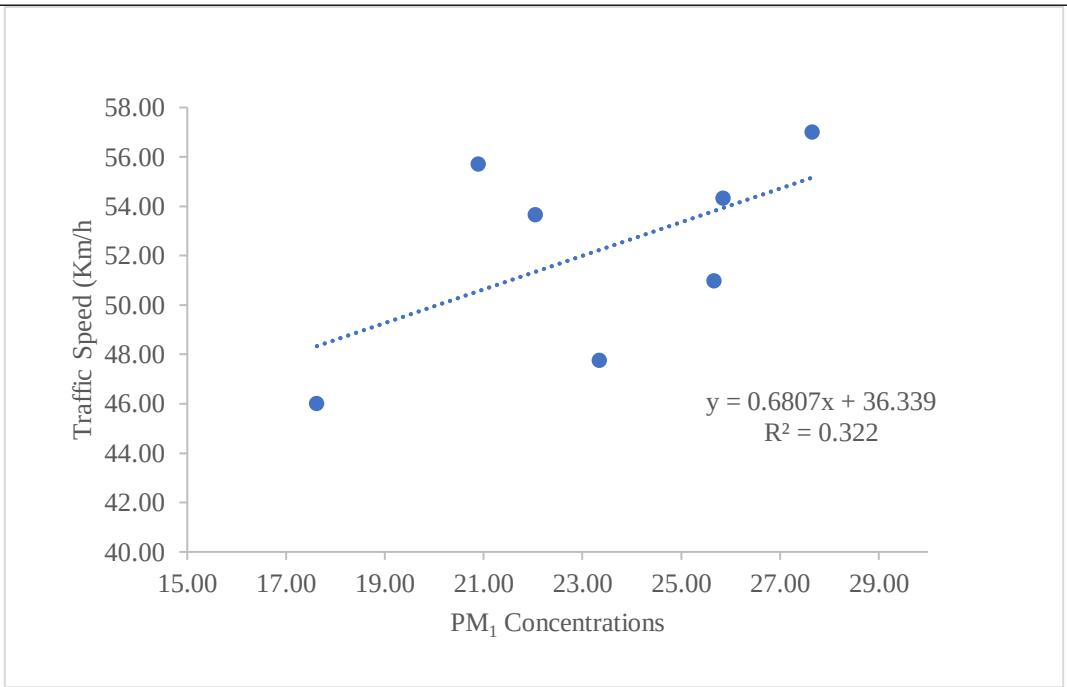

Figure 8. Relationship between PM_1 Concentration and Traffic Speed

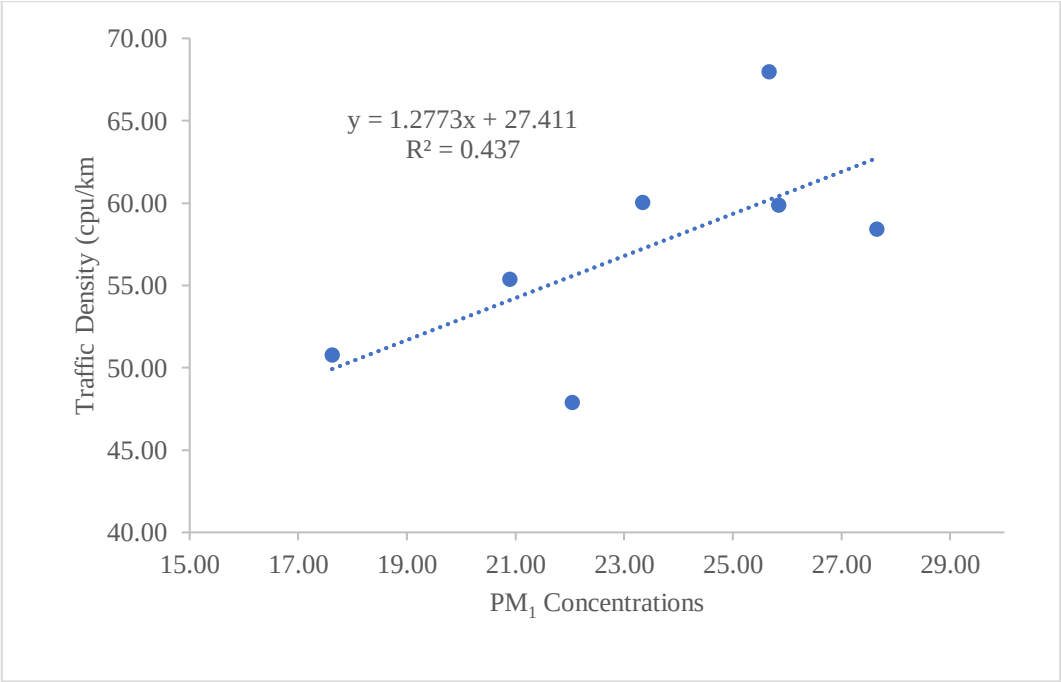

Figure 9. Relationship between PM_1 Concentration and Traffic Density

Recommendations for mitigating ambient air quality on the roadside can be given based on the results of research that has been conducted are recommended to control ambient air quality on the roadside, including increasing air quality monitoring, periodic emission tests on motor vehicles, traffic management such as installing vehicle speed limit signs and maximizing the planting of trees that can absorb particulates from highways.

CONCLUSION

The conclusions that can be drawn from this study are:

1. The average PM_1 concentration and standard deviation in the morning, midday, and evening were17.48(3.05) μg/m^3, 22.87(2.76) μg/m^3, and 34.60(7.68) μg/m^3 respectively with the highest concentration obtained in the evening reaching 42.63 μg/m^3 and the lowest concentration in the morning 12.83 μg/m^3. The average PM_1 concentration obtained was lower than the results of cases in other countries and other cities in Indonesia.
2. The correlation results of PM_1 concentration to meteorological conditions have a fairly strong to very strong correlation. Likewise, the correlation of PM_1 concentration to traffic characteristics has a fairly strong to very strong correlation. This shows that meteorological conditions and traffic characteristics are the main contributors to PM_1 concentration.
3. Policymakers can maximize ambient air quality monitoring and vehicle emission testing as well as improve traffic management.

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