Modeling and the Validation Model of PM10 Concentration due to the Changes in the Dominant Wind Direction to the Road in the Roadside Area

Vera Surtia Bachtiar¹, Purnawan², Reri Afrianita¹, Iqbal Mustofa¹, Randa Anugerah¹

¹Environmental Engineering Department, Andalas University, Indonesia
²Civil Engineering Department, Andalas University, Indonesia

*verasurtia@eng.unand.ac.id

Abstract. This study aims to model and validate the PM10 concentration from the transport sector and its relationship to the characteristics of traffic, wind speed and wind direction. PM10 was analyzed using the gravimetric method. Sampling were taken twice, with the first sampling carried out at 3 monitoring points representing the different angles of arrival of the wind direction towards the road (α), i.e. 0°, 30° and 60°. For validation, a second sampling was carried out at 0°, 45° and 90° angles. The statistical analysis used correlation and regression tests. Validation tests were carried out using the Pearson Product Moment formula and the Two Variance Test. The sampling results showed that the highest concentration was on a road with an angle of 60° with a concentration of 107.748 µg/Nm³ (number of vehicles 3,219 units and wind speed 0.3 m/s). The lowest concentration was at an angle of 0° with a concentration of 19,298 µg/Nm³ (number of vehicles 680 units and wind speed of 0.98 m/s). Increased traffic volume and density was found to be proportional to the increase in PM10 concentration. Vehicle speed and wind speed have an inversely related relationship with increasing PM10 concentration. There was a decrease in PM10 concentration in traffic volume from α 90° to 60° by 26%, α 90° to 30° by 29% and α 90° to 0° by 61%. There was a decrease in PM10 concentration at the traffic density from α 90° to 60° by 17%, α 90° to 30° by 33% and α 90° to 0° by 51%. The results of the Two Variance Test showed there to be no significant difference in the yield variability between the two PM10 parameter concentrations. This is indicated by the value of the Test Ratio (RUF) being lower than the Critical Point. The validation test conducted using the Pearson Product Moment formula shows that the two equations tested can be declared valid and used to determine the concentration of PM10. This is indicated by the value of R (correlation coefficient) having been calculated as greater than the value of the R table for all parameters.

1. Introduction

Transport activities are the main source of air pollution in urban areas. The growth in the number of ownerships of vehicle use in cities has had a severe impact on the environment. The data shown by [1] confirms that motor vehicles are a major source of pollution in urban areas. Motorized vehicles,
inclusive of trucks, buses, cars and motorbikes, produce air pollutants when the vehicle is used, refueling, in the manufacturing processes and post-use. The development of the number of motorized vehicles in big cities increasingly makes the transportation sector the dominant pollutant source [2].

One type of air pollutant from the vehicle sector that has a major impact on human health is particulate matter (PM10) because it is respirable. This triggers respiratory problems. Particulate matter is a mixture of particles in the form of solids and liquids suspended in the air. These particles can be produced from motorized vehicles. Small particles of 10 microns (PM10) can enter the respiratory tract and lungs which can cause asthma, respiratory diseases, cardiovascular disease and death. Meteorological factors include wind speed and direction, air humidity, air temperature and air pressure. These factors have an influence on the PM10 concentration. According to [3], a change in the PM10 concentration was caused by changes in the meteorological conditions. The meteorological factor does not necessarily cause an increase in PM10 concentration but it can decrease the PM10 concentration. One example of meteorological factors is that wind speed affects the level of particulate concentration. When the wind blows hard, the particulates will spread more widely and thus reduce their concentration. Conversely, when the wind blows slowly, the particulates do not spread and instead accumulate in one area, and thus the concentration increases.

Padang city does not only having roads that are perpendicular to the direction of the dominant wind. There are many variations of the road angle towards the dominant wind direction. Thus there is a need for research on the effect of α (angle of wind direction on the road) on the dispersion of the concentration of PM10 on the roadside air in the city of Padang. In this study, the measurements were focused on the changes in α (the angle of arrival of the wind towards the road) using roads with angles of 0°, 30° and 60° towards the dominant wind direction in the city of Padang.

2. Methodology
The research consisted of field sampling and laboratory analysis. The sampling of PM10 was undertaken twice, first for the modeling and the second for validation.

Sampling for PM10 Modelling
For the PM10 modeling, the first sampling of PM10 concentration was accomplished in 9 days over 3 monitoring points regarding the meteorological factors and traffic characteristics. Sampling was conducted using a Low Volume Sampler with a digital pocket weatherman, compass and anemometer. At each monitoring point, the sampling was carried out for 3 days with measurements every 1 hour for 10 hours/day starting at 07.00-17.00 WIB. The total number of samples collected for the 3 points was 90 samples. The sampling location chosen for α 0° was on A. Yani Road, 30° was located on Andalas Road, and 60° was on Prof. Dr. Hamka Road. The sampling locations were chosen based on the consideration of the dominant wind direction with reference to the Padang City windrose in 2012 - 2016. For more details, the sampling locations can be seen in Figures 1 through to 3. Meanwhile, the windrose on Padang City between 2012 and 2016 can be seen in Figure 4.
Sampling for PM10 Model Validation

The second sampling for validation was done over 3 days with measurements every 1 hour for 10 hours/day for each point starting at 07.00 - 17.00. The total number of samples collected for the 3 validation points was 30 samples. The sampling was performed using a Low Volume Sampler with a digital pocket weatherman, compass and anemometer. The sampling location chosen for $\alpha = 0^\circ$ was on A. Yani Road, $45^\circ$ was located on By-Pass Road, and $90^\circ$ was on Prof. Dr. Wahidin Road. The $\alpha$ was chosen from $0^\circ$, $45^\circ$ and $90^\circ$ to represent an $\alpha$ value that ranged between $0^\circ$ and $90^\circ$ [4]. The sampling locations can be seen in Figures 5 through to 7.
Modelling of PM10 Concentration

The PM10 measurement data from the first sampling at 3 monitoring locations was used to create multiple linear regression models. The traffic characteristics measured were traffic volume, traffic speed and traffic density. The next step was the calculation and processing of the data to analyze the relationship of PM10 concentration with the characteristics of the traffic, the meteorological factors and the magnitude of changes in concentration due to changes in $\alpha$ (the wind angle against the road).

Validation of PM10 Model

Model validation is a simulation process that is used to ascertain whether a model can be used to model a given parameter. The data from the validation sampling was used to test the validity of the PM10 pollutant concentration equation due to the influence of wind direction on roadside ambient air using the Two Variance Test formula [5] and the Pearson Product Moment formula [6].
3. Results and Discussion

Relationship between PM10 and Meteorological Conditions

Figure 8 shows the relationship between PM10 concentration and wind speed in (A) $\alpha = 0^\circ$, (B) $\alpha = 30^\circ$, (C) $\alpha = 60^\circ$.

![Figure 8](image)

Based on Figure 8, the PM10 concentration shows a strong correlation with wind speed, with the coefficient of the correlation (R) values at $\alpha = 0^\circ$, $30^\circ$ and $60^\circ$ being 0.866, 0.852 and 0.930 respectively. The coefficient of determination ($R^2$) at $\alpha = 0^\circ$, $30^\circ$, and $60^\circ$ is 0.8653, 0.7271 and 0.7505 respectively. This means that 86.5%, 72.7% and 75.0% of the PM10 concentration is influenced by wind speed. Figure 8 shows that the PM10 concentration will decrease with the increasing wind speed [7]. The higher the wind speed, the wider the area affected by PM10 so therefore the PM10 concentration becomes lower.

Relationship between PM10 Concentrations and Traffic Characteristics

The relationship between PM10 concentration and traffic density has been shown in Figure 9.

![Figure 9](image)

Based on Figure 9, the PM10 concentration shows a strong correlation with wind speed, with the coefficient of the correlation (R) values at $\alpha = 0^\circ$, $30^\circ$ and $60^\circ$ being 0.910, 0.892 and 0.956 respectively. The correlation between the concentration of PM10 and the traffic density is very strong on $\alpha = 0^\circ$ and $30^\circ$. Meanwhile, the correlation is strong on $\alpha = 60^\circ$. The coefficient of determination ($R^2$) on $\alpha = 0^\circ$, $30^\circ$ and $60^\circ$ was 0.8283, 0.7971 and 0.9141 respectively, which means that 82.8%, 79.7% and 79.71% of
the PM10 concentration was influenced by traffic density. The above results show that the higher the density of traffic, the higher the PM10 concentration.

The relationship between PM10 concentration and traffic volume has been shown in Figure 10.

The relationship between PM10 concentration and traffic volume has been shown in Figure 10.

Based on Figure 10, the R value for \( \alpha = 0^\circ \), \( 30^\circ \), and \( 60^\circ \) is 0.785, 0.929 and 0.954 respectively. The correlation between the concentration of PM10 and the traffic density is very strong at \( \alpha = 0^\circ \) and \( 30^\circ \). Meanwhile, the correlation is strong at \( \alpha = 60^\circ \). The coefficient of determination (\( R^2 \)) on \( \alpha = 0^\circ \) (A. Yani Road), \( \alpha = 30^\circ \) (Andalas Road) and \( \alpha = 60^\circ \) (Prof. Dr. Hamka Road) is 0.7845, 0.8633 and 0.9098 respectively. This means that the 78.45%, 86.33% and 90.98% PM10 concentrations were influenced by the traffic volume. The above results show that traffic volume caused the increase in pollutant concentration [8].

Dispersion of PM10 Concentration based on the Angle of Dominant Wind Direction

The relationship between PM10 concentration and the angle of dominant wind direction is as shown in Figure 11.

Based on Figure 11, the determination value (\( R^2 \)) obtained was 82.5% with a coefficient of correlation (R) of 0.908. This shows that the correlation is very strong. The positive variable x in the equation on
the chart indicates that the relationship of PM10 concentration with the angle of dominant wind direction to the road is directly proportional. If there is an increase of $\alpha$ every 10 degrees, the PM10 concentration will increase for 8,418 $\mu$g/Nm3. The higher the angle of arrival of the wind on the road, the higher the concentration of PM10. This means that the pollutant concentration can be affected by the wind angle direction to the road [9].

**PM10 Concentrations Models**

The PM10 concentration model was created using variations in the concentration related to traffic characteristics, wind speed and the dominant wind angle direction to the road. The model produced:

- **Model A**  
  Model A shows the PM10 concentration with the influence of traffic volume, vehicle speed, wind speed and the dominant wind direction angle on the road.

- **Model B**  
  Model B shows the PM10 concentration with the influence of traffic density, wind speed and the dominant wind direction angle on the road.

The regression models produced can be seen in Table 1.

### Table 1. PM10 Concentration Models

| Model | Formula | R    |
|-------|---------|------|
| A     | $C_{PM} = 0.011V_T - 0.579S_T - 4.370S_W + 0.695\alpha + 35.286$ | 0.971 |
| B     | $C_{PM} = 0.368D_T - 2.52S_W + 0.712\alpha + 16.029$ | 0.970 |

Where:
- $C_{PM}$ = PM10 concentration ($\mu$g/Nm³)
- $S_T$ = traffic speed (km/hour)
- $V_T$ = traffic volume (pcu/hour)
- $D_T$ = traffic density (pcu/km)
- $S_W$ = wind speed (m/s)
- $\alpha$ = wind angle direction to the road

Table 1 shows Model A and Model B with a coefficient correlation of (R) 0.971 and 0.970. This correlation shows that there is a very strong relationship between the PM10 concentration and traffic volume, traffic density, traffic speed, wind speed and the wind angle direction to the road.

**Model Validations**

The validation of the PM10 model using the Two-Varians Test and the Pearson Moment Formula can be seen in Tables 2 and 3.

### Table 2. Validation using the Two-Varians Test

| Parameter | Critical Value | $RU_f$ Density | $RU_f$ Volume |
|-----------|----------------|----------------|---------------|
| PM10      | 2.102          | 1.449          | 1.510         |

Table 2 shows the two-variance test between the PM10 sampling model and the PM10 sampling for validation. The value of the test ratio between the sampling concentration and the validation concentration is 1.449. This value indicates that $RU_f$ is smaller than the value of the critical point ($RU_f<2.102$). This means that there is no significant difference in the yield variability of the two concentrations. The results of the two-variance test between the sampling concentration and the concentration of the results of the volume equation show that the value of the test ratio ($RU_f = 1.510$) is smaller than the value of the critical point ($RU_f<2.102$). This also shows that there is no significant
difference between concentrations of PM10 sampling model and concentrations of PM10 for validation.

Table 3. Validation using the Pearson Moment Formula

| Parameter | R Value | R Tabel Value | Valid |
|-----------|---------|---------------|-------|
| PM10      | 0.965   | 0.361         | valid |
|           | 0.961   | 0.361         | Valid |

Table 3 shows the validation uses of the Pearson product moment formula. The PM10 parameter shows that the calculated R value uses the Pearson product moment formula of 0.965 for the concentration results of the density equation and 0.961 for the concentration resulting from the volume equation. Both R values indicate that the value is greater than the table R value which is equal to 0.361. The 2 tested equations are valid and can be used to predict the PM10 concentration.

**PM10 Concentration Map Based on the PM10 Model**

Figure 12 is a mapping of the PM10 concentrations obtained from the validated PM10 model. The lowest to highest concentrations in a row are denoted by navy blue, pink, hard blue, purple and maroon colors.

![PM10 Prediction in Padang City](image)
Note:

The highest PM10 concentration was 128,395 µg/Nm³ with traffic volume 6.832 smp/hour, traffic speed 28,87 km/hour, wind speed 0.36 m/s and $\alpha$ 88°. The lowest PM10 was 23,074 µg/Nm³ with traffic volume 677 smp/hour, traffic speed 31,06 km/hour, wind speed 0.84 m/s and $\alpha$ 2°.

4. Conclusion

The validation test conducted using the Two Variance Test obtained a critical point value of 2.102. The Test Ratio Value (RUf) had a value that was smaller than the critical point value. This shows that there is no significant difference between the concentration of the model and the concentration of the validation data. The small value RUf value from the critical point was declared to be valid and this can be used to find the PM10 pollutant concentrations. The validation test conducted using the Pearson Moment Formula produced an R table value of 0.361. The validation of the PM10 model shows that the calculated R value is greater than that of the R table. This shows that all of the equations are valid to use.

This research is supported by the Engineering Faculty of Andalas University under contract No. 026/UN.16.09.D/PL/2019.

References

[1] A. Suleiman, M. R. Tight, And A. D. Quinn, “Assessment And Prediction Of The Impact Of Road Transport On Ambient Concentrations Of Particulate Matter Pm10,” Transp. Res. Part D Transp. Environ., Vol. 49, Pp. 301–312, 2016.
[2] V. S. Bachtiar And M. Ammar, “Diurnal Variation Of Tropospheric Ozone (O3) And Its Precursors (Co And No2) Due To Transportation Activity In The Roadside Areas In Padang City, Indonesia,” Vol. 12, No. 24, Pp. 7012–7023, 2017.
[3] F. Al Jallad, E. Al Katheeri, And M. Al Omar, “Concentrations Of Particulate Matter And Their Relationships With Meteorological Variables,” Sustain. Environ. Res., 2013.
[4] V. S. Bachtiar, Purnawan, R. Afrianita, And R. Anugerah, “Validation Of Co Dispersion Model Due To The Road Position On The Dominant Wind Direction On Transport Sector,” In Matec Web Of Conferences, 2018.
[5] M. Neuhäuser, “Two-Sample Tests When Variances Are Unequal,” Animal Behaviour. 2002.
[6] J. W. Gooch, “Pearson’s Product-Moment Correlation Coefficient,” In Encyclopedic Dictionary Of Polymers, 2011.
[7] B. Sharratt And H. Pi, “Field And Laboratory Comparison Of Pm10 Instruments In High Winds,” Aeolian Res., 2018.
[8] V. S. Bachtiar, Purnawan, R. Afrianita, And S. H. Ritonga, “Modelling Of No2 Dispersion Based On Receptor Position Due To Transport Sector In Padang City, Indonesia,” J. Environ. Sci. Technol., 2017.
[9] V. S. Bachtiar, P. Purnawan, R. Afrianita, And N. Dahlia, “Effect Of Wind Angle Direction On Carbon Monoxide (CO) Concentration Dispersion On Traffic Flow In Padang City,” In Iop Conference Series: Materials Science And Engineering, 2018.