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Research Article

Modelling of NO₂ Dispersion based on Receptor Position Due to Transport Sector in Padang City, Indonesia

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Abstract

Background and Objective: Nitrogen dioxide (NO₂) is one of the pollutants produced by transport. NO₂ concentration in the transportation sector was influenced by traffic characteristics, meteorological factors and receptor distance from the source. This study aims to model the patterns of nitrogen dioxide (NO₂) dispersion in the roadside area based on the distance of receptor position from the roadway. **Methodology:** Model developed from the relation between the concentration of NO₂ and traffic characteristics and meteorological conditions, such as traffic volume, traffic density, traffic speed and wind speed. NO₂ was obtained by measuring the NO₂ gas at 25 points ambient air sampling conducted with a certain distance from the edge of the roadside. At the same time, was also carried out measurements of traffic characteristics and meteorological conditions. NO₂ concentrations were measured by Griess Saltzman method, using impinger and a spectrophotometer. Statistical analysis was used to validated the model using t-test analysis. **Results:** The results show NO₂ concentration varied in all sampling locations with the concentration of NO₂ at point A 1 m is higher than the point B (5, 10, 25, 50 and 100 m). Regression models between NO₂ with traffic characteristics and wind speed obtained from a distance of 1, 5, 10, 25, 50 and 100 m from the roadside. The model then was used to predict NO₂ using the data traffic characteristics and the current wind speed measurements at 40 measurement points, for the distance of receptors were 1, 5, 10, 25, 50 and 100 m to view the NO₂ dispersion. **Conclusion:** T-test analysis showed that the model can be used to predict dispersion of NO₂.

Key words: Nitrogen dioxide (NO₂), traffic volume, traffic density, traffic speed, Griess Saltzman method

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The growth of motor vehicles on regional scale has becoming a major cause of rising levels of air pollution¹. The major source of emission in the worldwide come from road transport. In Europe, road transport produces 40.5% emissions of oxides of nitrogen (NO_x)². The increase in the number of motor vehicles have also occurred in the city of Padang. Padang city serves as a center of trade, services, education, tourism, transportation and industry. Therefore, the city of Padang should be able to provide adequate services in the field of transport to improve the welfare of society. Based on data from the Central Bureau of Statistics of Padang³ the increase in the number of vehicles was quite rapid in the last 2 years which is from 392.967 units in 2013 up to 427.235 units in 2014.

The increasing number of vehicles in Padang city affected the increase the concentration of pollutants in ambient air, one of them is nitrogen dioxide (NO₂). According to Pandey *et al.*⁴, NO_x is most widely produced by vehicular activities. Nitrogen oxide (NO) produced from the waste transportation fuel combustion process will be oxidized in the atmosphere to form NO₂. NO₂ is odorless, pale yellow that interferes with visibility and can irritate the respiratory organs⁵. Therefore, one of the pollutants that should receive the attention was NO₂ and that was a harmful gas inhalation⁶. Given the dangers of air pollution on health⁷, monitoring should be done to determine the concentration of NO₂ in the city of Padang. NO₂ concentration was measured by two units of impinger placed at a certain distance from the side of the road at the same time to see the NO₂ dispersion. From measurements of NO₂ concentration, traffic characteristics and meteorological conditions, NO₂ dispersion modeling was done of the receptor distance, with a parameter of traffic characteristic and meteorological conditions. Objective of the research was to look at the relationship of NO₂ concentration with traffic characteristics and meteorological factors. Furthermore, modelling the relationship of NO₂ concentration with traffic characteristics and meteorological factors, based on receptor distance from source (highway), such as 1, 5, 10, 25, 50 and 100 m. So, it can be seen the dispersion of NO₂ due to the traffic characteristics and meteorological factors.

MATERIALS AND METHODS

This study was performed to model NO₂ dispersion in roadside area for a distance 1, 5, 10, 25, 50 and 100 m from the edge of the roadside, based on the traffic characteristics and meteorological conditions, which carried out in Padang city on

March until July 2016. The concentration of dispersion describes the distribution of concentration. Data meteorological conditions necessary for the calculation were temperature (°C) and atmospheric pressure (mm Hg) with a pocket digital appliance Weatherman, wind direction with compass and wind speed with an anemometer tool.

The sampling was conducted for primary data collection was carried out for 1 h of measurements for each sampling point using an impinger. Griess Saltzman method is the method used to determine the concentration of NO₂. NO₂ was then reacted with Griess Saltzman reagent (absorbent) forming compounds which are pink. Measures of sampling and laboratory analysis was adapted from Indonesian National Standard 19-7119.2-2005, Indonesian Government⁸, on how to measure nitrogen dioxide (NO₂) by Griess Saltzman method using a spectrophotometer. NO₂ measurements performed at sampling point A with a distance of 1 m and point B varied at a distance of 5, 10, 20, 50 and 100 m from the edge of roadside. NO₂ concentration measurement data serves to determine the NO₂ concentration reduction based on the distance of receptor.

Traffic characteristics were measured by volume, vehicle speed and traffic density. Measurement of traffic characteristics are intended to determine the correlation of concentrations of NO₂ obtained in the measurement. NO₂ dispersion pattern was carried out based on regression models obtained. This pattern shows the spread and reduction in NO₂ concentrations based on the distance of receptor.

Statistical analysis: Statistical analysis was used to validated the model using t-test analysis. T-test analysis was conducted between NO₂ concentration predicted from the model and NO₂ concentration resulted from the measurement. The model is valid if $t_{\text{value}} < t_{\text{critics}}$.

RESULTS

Meteorological conditions: The data of the meteorological conditions at the time of measurement is required in determining the concentration of NO₂. Summary data of meteorological conditions at the time of measurement of the concentration can be seen in Table 1.

Based on the Table 1 above, the temperature ranged between 24.2 and 33.4°C with average was 28.4°C. The average pressure obtained was 757.06 mm Hg. The average wind speed at several research sites ranged between 0.04 and 1.59 m sec⁻¹.

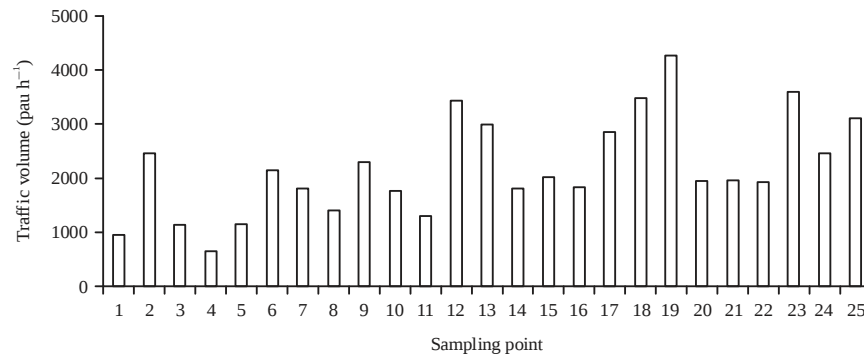


Fig. 1: Traffic volume

Table 1: Meteorological conditions

Sampling point	Name of the road	Temperature (°C)	Pressure (mm Hg)	Wind speed (m sec ⁻¹)	Wind direction
1	M. Yunus	26.6	758.44	0.18	West
2	Sutomo	24.6	756.92	0.58	Southwest
3	Lubuk Begalung	24.2	748.23	0.22	Calm
4	Wahidin	26.4	757.94	0.06	Calm
5	Sutan Syahrir	30.8	758.29	0.42	West
6	Perintis Kemerdekaan	26.2	756.36	0.66	East
7	Adinegoro I	28.0	758.34	0.50	West
8	Adinegoro II	27.0	758.29	0.68	West
9	Adinegoro III	27.0	758.19	0.38	West
10	Adinegoro IV	26.0	757.89	0.14	West
11	Adinegoro V	26.0	753.28	0.04	Calm
12	Hamka I	27.0	758.60	0.28	West
13	Hamka II	27.6	760.27	0.36	West
14	Hamka III	31.0	758.75	0.68	West
15	Hamka IV	31.0	758.75	0.68	West
16	Hamka V	30.0	758.75	0.94	West
17	Khatib Sulaiman I	28.0	756.87	0.68	West
18	Khatib Sulaiman II	27.6	756.77	0.64	West
19	Khatib Sulaiman III	27.0	756.72	0.36	West
20	Bagindo Aziz Chan I	29.0	757.94	1.14	West
21	Bagindo Aziz Chan II	30.0	758.34	1.10	West
22	Bagindo Aziz Chan III	31.0	758.65	0.82	South
23	Bagindo Aziz Chan IV	33.4	760.27	1.10	West
24	Sudirman I	32.4	760.73	1.58	West
25	Sudirman II	31.4	760.83	1.76	West
Average		28.4	757.06	0.68	Barat

Characteristics of traffic: Traffic characteristics used here such as volume, speed and traffic density. The number of vehicles passing through the sampling locations were converted into the form passenger car unit/h (pcu h⁻¹). The traffic density was obtained from the division of traffic volume with vehicle speed.

Characteristics of traffic in research sites: It can be seen in Fig. 1-3 that the highest traffic volume amounted to 4265.15 pcu h⁻¹ and the highest traffic density of 199.31 pcu km⁻¹ located at Khatib Sulaiman III. The lowest traffic volumes is 673.80 pcu h⁻¹ and the lowest traffic density of 14.91 pcu km⁻¹ is located at Wahidin. The highest vehicle speed obtained was 46.40 km h⁻¹ were at Lubuk

Begalung and the lowest speed of 20.40 km h⁻¹ on Khatib Sulaiman II. Variations in the number of volume, density and speed of traffic is influenced by a number of different vehicles and different measurement time at the sampling location.

Based on Fig. 4, 5 and 6 it can be seen the highest traffic volume amounted to 4285.15 pcu h⁻¹ at Khatib Sulaiman I and highest traffic density of 108.35 pcu km⁻¹ located on Bagindo Aziz chan I. The lowest traffic volumes of 791.40 pcu h⁻¹ was located at Jl. Bandar Purus and traffic density as low as 13.93 pcu km⁻¹ was located at Bandar Damar. The highest vehicle speed obtained was 57.00 km h⁻¹ at Pattimura and the lowest speed of 38.00 km h⁻¹ were found at Bagindo Aziz chan I.

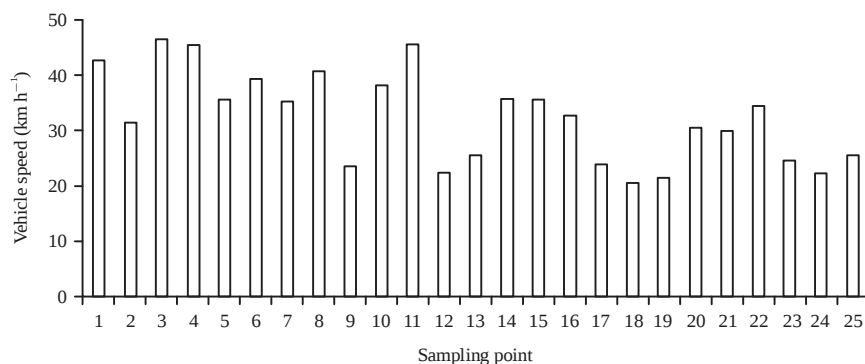


Fig. 2: Speed of vehicle

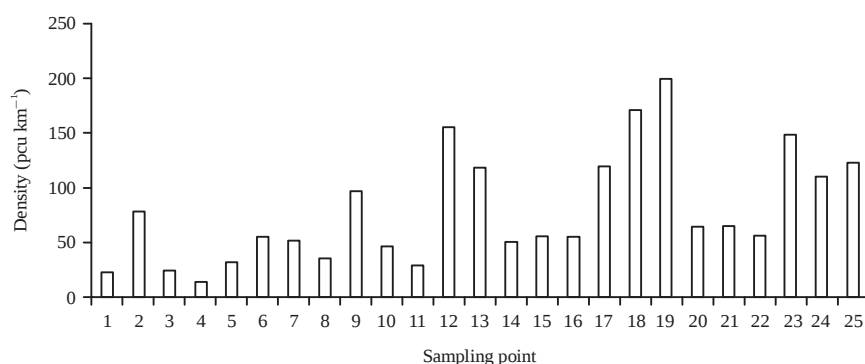


Fig. 3: Traffic density

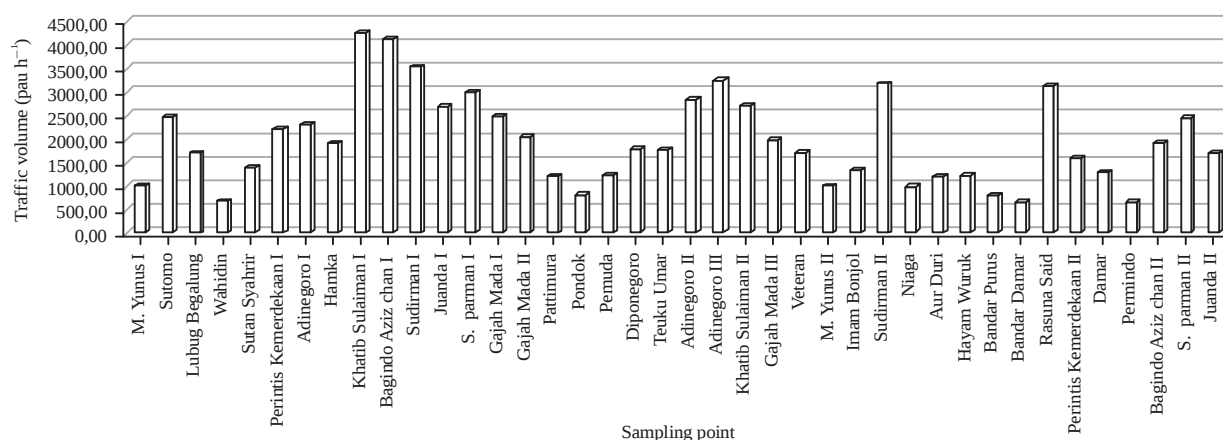


Fig. 4: Traffic volume

Concentration of NO₂: NO₂ concentration measurements were carried out for 1 h at each sampling point. NO₂ concentration measurements in ambient air were performed using an two impinger for each point. A point impinger tool was placed 1 m from the side of the road, while impinger point B was placed varies with the distance of 5, 10, 25, 50 and 100 m. This different placement at point B is meant to determine the dispersion of NO₂ concentrations based on the distance from

the edge of the roadside. NO₂ concentration measurement results from research sites and the fluctuation in concentration can be seen in Fig. 7, 8, 9, 10 and 11.

Based on Fig. 7, 8, 9, 10 and 11, NO₂ concentration at each sampling location varies, the results of NO₂ concentration measurement at point A 1 m at all sampling locations is higher than the point B (5, 10, 25, 50 and 100 m) from the edge of the roadside.

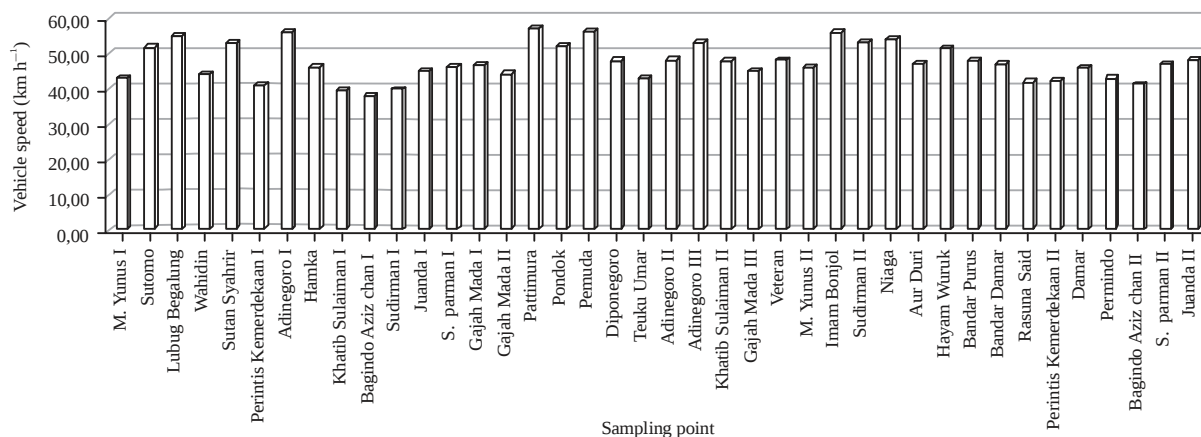


Fig. 5: Speed of vehicle

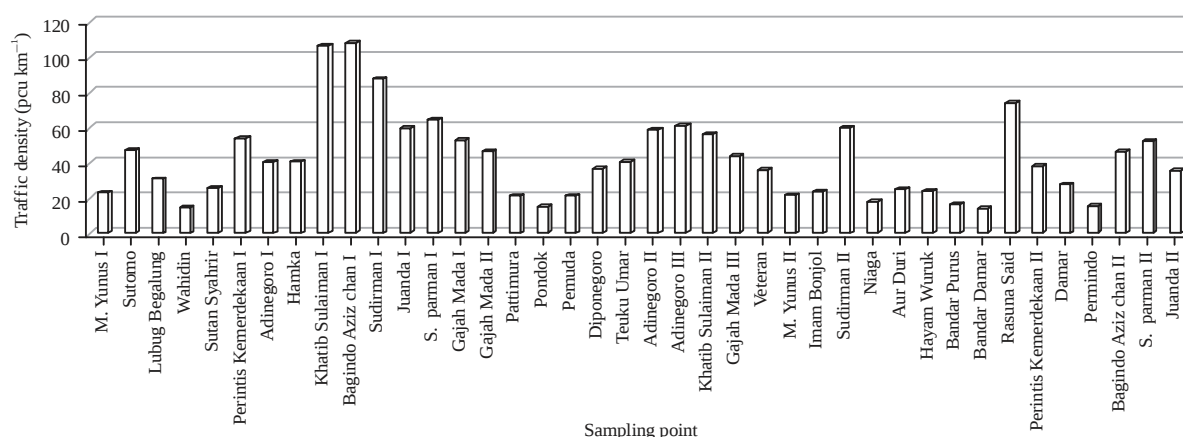


Fig. 6: Traffic density

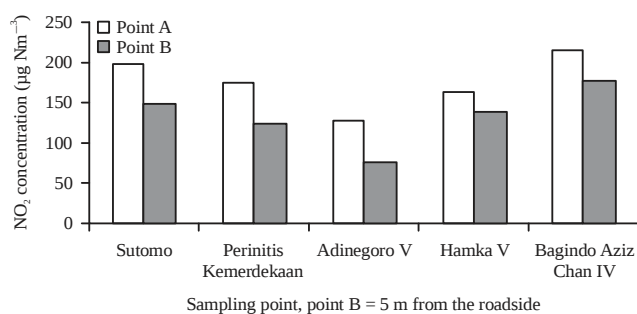


Fig. 7: Comparison of NO₂ concentration between point A (1 m) and point B (5 m)

The highest NO₂ concentration measurement obtained was 238.64 µg Nm⁻³ at point A with a distance of 1 m that was located on Khatib Sulaiman III. While at point B (25 m) the concentration of NO₂ gas obtained was 98.86 µg Nm⁻³. NO₂ concentration at Khatib Sulaiman I at point A with a distance of 1 m was measured at 188.40 µg Nm⁻³ and point B within 100 m also was measured at 60.93 µg Nm⁻³.

DISCUSSION

Meteorological conditions: Based on data from Table 1, it can be seen that the temperature, pressure, wind speed and wind direction changes accordingly. Current conditions sampling is also fickle, sometimes sunny, cloudy, or rainy. Atmospheric stability can be determined from the meteorological data at

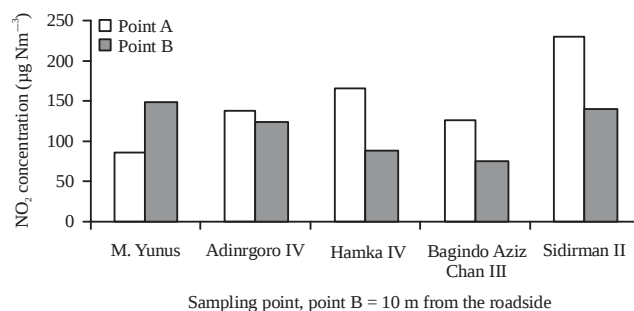


Fig. 8: Comparison of NO₂ concentration between point A (1 m) and point B (10 m)

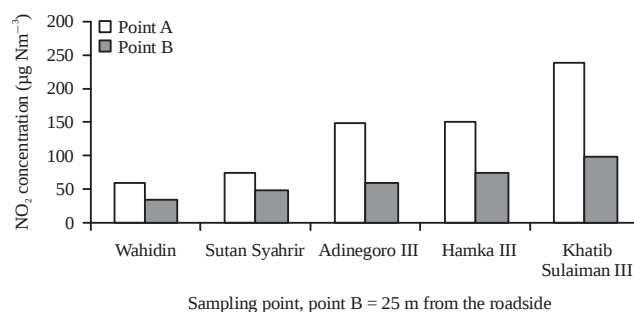


Fig. 9: Comparison of NO₂ concentration between point A (1 m) and point B (25 m)

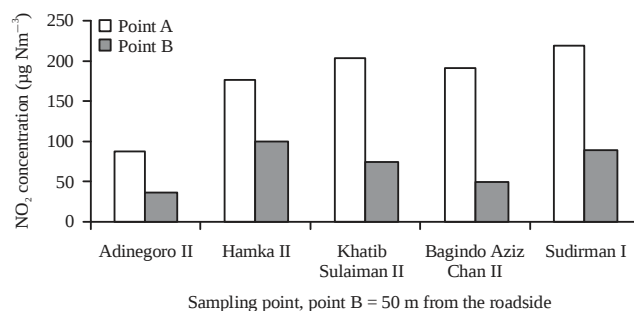


Fig. 10: Comparison of NO₂ concentration between Point A (1 m) and point B (50 m)

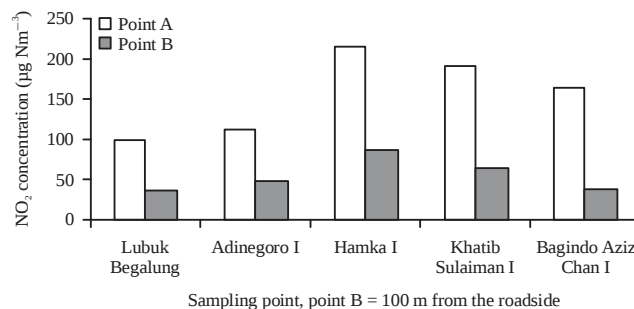


Fig. 11: Comparison of NO₂ concentration between point A (1 m) and point B (100 m)

the time of measurement in the field. The difference in temperature at different locations are due to several factors, such as the length of solar radiation, the slope

of the sun and the state of the cloud. High temperatures will cause the air to be distant, so that the pollutant concentration becomes lower and lower. In contrast to the

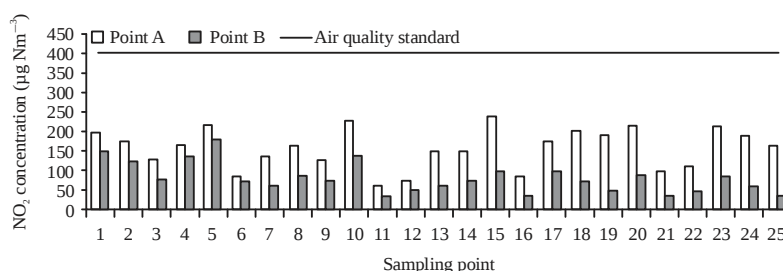


Fig. 12: Comparison of NO₂ concentration at point A and point B with Indonesian Government Regulation No. 41 (1999)

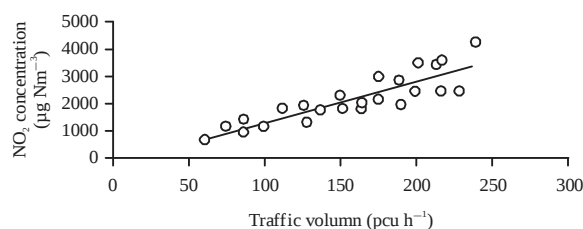


Fig. 13: Correlation between NO₂ and the volume of vehicle at 1 m

cool temperatures makes the air more dense, so the concentration of pollutants in the air becomes higher⁹.

The air pressure is affected by altitude and temperature. The air pressure will decrease every 100 m and the higher the temperature, the pressure would be lower. Even if there is little difference, this is caused by differences in air temperature due to uneven heating of the atmosphere by sunlight¹⁰.

The higher wind speed in an area, then the mixing of pollutants from sources of emissions in the atmosphere will be even greater, so that concentrations of contaminants will dilute and pollutants will be reduced¹¹. Wind speed also affects the distribution of pollutants, pollutant concentrations are reduced when the wind is strong therefore will distribute pollutants horizontally and vertically¹². Strong wind speed will carry pollutants everywhere and pollute the air other areas¹³.

Analysis of NO₂ concentration: Figure 7-11 shows that the concentration of NO₂ was dispersed and measured up to 100 m. Dispersion of NO₂ concentration can be affected by various factors such as meteorological conditions and traffic characteristics^{4,14-16}. Several meteorological factors are temperature, pressure, wind speed and wind direction changes at each sampling site. Current conditions sampling is also unstable, sometimes sunny, sometimes cloudy or rainy. Based on research by Bachtiar *et al.*¹⁷, fluctuation varying meteorological conditions can affect the dispersion of pollutants in the atmosphere. Weather can affect the accuracy

of the measurement results, meaning that the gas levels at the same location will be different if the weather is different.

Comparison of NO₂ concentration with national air quality standards:

NO₂ concentration data that have been obtained is then compared with the quality standards on Indonesian Government Regulation No. 41 (1999)¹⁸, on air pollution control. The maximum concentration of NO₂ pollutants in ambient air that is tolerated is 400 µg Nm⁻³ for time measurement of 1 h. Comparison of NO₂ concentration with quality standards can be seen in Fig. 12.

Based on Fig. 12, NO₂ gas concentration data both at point A and point B on the sampling location are still below the air quality standards. It shows the concentration of NO₂ in Padang city is still safe and not harmful to health. The increasing number of vehicles every year, it is likely that the NO₂ concentration will also increase. If the prevention is not done, environmental quality decreases.

Correlation analysis of NO₂ concentration with traffic characteristics and wind speed:

The volume of traffic is one of the characteristics of the traffic that has a relationship with the concentration of NO₂. The correlation between the concentration of NO₂ and total vehicle volume can be seen in Fig. 13.

Determination (R²) between the concentration of NO₂ gas with total vehicle volume which is equal to 0.7545, so the correlation (r) at point A is 0.869 with the interpretation of the correlation is very strong as shown in Fig. 13. The very strong correlation showed that the greater the volume of traffic, the greater the concentration of NO₂ produced. According to Kendrick *et al.*¹⁹, the relationship between the volume of traffic to the NO₂ concentration is directly proportional. The greater the volume of traffic, the greater the concentration of NO₂ is generated and vice versa.

(R²) determination result between the concentration of NO₂ gas to vehicle speed is equal to 0.6793, so the correlation (r) at point A value of 0.824 with the interpretation of the

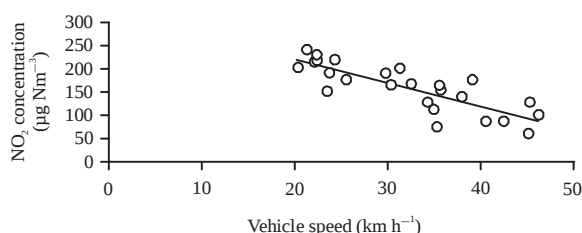
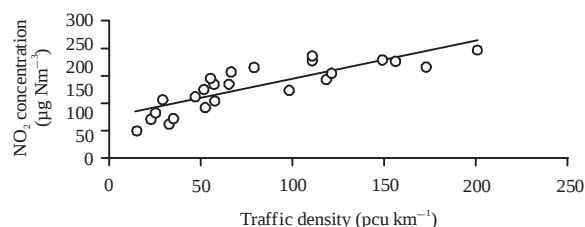
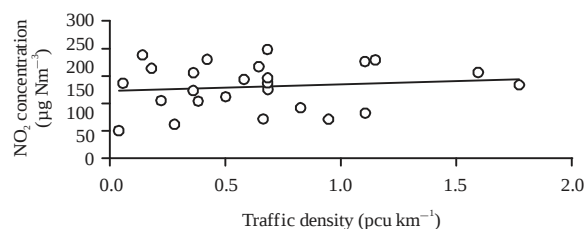
Table 2: Regression model, correlation and deviation standard

Receptor point from the roadside (m)	Predicted model	Correlation (r)	Deviation standard
1	$C1 = 72.549 + 0.752D + 40.112S$	0.899	23.278
5	$C5 = 69.684 + 0.399D + 50.955S$	0.961	14.709
10	$C10 = 54.843 + 0.026D + 42.306S$	0.940	14.611
25	$C25 = 24.389 + 0.277D + 45.361S$	0.973	8.001
50	$C50 = 28.825 + 0.364D + 3.852S$	0.794	22.127
100	$C100 = 33.755 + 0.362D + 19.033S$	0.986	4.981

C1: Predicted NO₂ concentration 1 m from the edge of the roadside ($\mu\text{g Nm}^{-3}$), C5: Predicted NO₂ concentration 5 m from the edge of the roadside ($\mu\text{g Nm}^{-3}$), C10: Predicted NO₂ concentration 10 m from the edge of the roadside ($\mu\text{g Nm}^{-3}$), C25: Predicted NO₂ concentration 25 m from the edge of the roadside ($\mu\text{g Nm}^{-3}$), C50: Predicted NO₂ concentration 50 m from the edge of the roadside ($\mu\text{g Nm}^{-3}$), C100: Predicted NO₂ concentration 100 m from the edge of the roadside ($\mu\text{g Nm}^{-3}$), D: Traffic density (pcu km⁻¹) and S: Wind speed (m sec⁻¹)

Table 3: T-value test result

Statistical model	t-value	t critical
C1	0.01	2.064
C5	0.00	2.776
C10	0.00	2.776
C25	-0.01	2.776
C50	0.00	2.776
C100	-0.01	2.776

Fig. 14: Correlation between NO₂ concentration and vehicle speedFig. 15: Correlation between NO₂ concentration and traffic densityFig. 16: Correlation between NO₂ concentration and wind speed

correlation is very strong as shown in Fig. 14. Strong negative correlation (r) indicates the NO₂ gas concentration is inversely

proportional to vehicle speed. The lower the speed of traffic, the greater the concentration of NO₂ gas produced. This is due to the vehicle moving at low speed will emit greater NO₂. According to Jenkin²⁰, the relationship between the speed of traffic with NO₂ gas concentration is inversely proportional between 30 and 60 km h⁻¹. The higher the speed of traffic, the smaller the concentration of NO₂ is generated and vice versa.

NO₂ concentrations and traffic density have a strong correlations ($r = 0.834$), with determination (R^2) 0.6957. The relationship between NO₂ concentrations and traffic density is directly proportional. As the density of traffic increase, the greater the concentration of NO₂ gas produced (Fig. 15). The greater the density of traffic, the greater the concentration of NO₂ gas is generated and vice versa²¹.

Determination (R^2) between the concentration of NO₂ with wind speed is equal to 0.2924, so the correlation (r) at point A is 0.541, with an interpretation of the correlation is quite strong. Such correlations indicate that the concentration is directly proportional to the wind speed (Fig. 16).

Regression models for NO₂ concentrations: Regression modelling was conducted between NO₂ concentration with traffic characteristics and meteorological conditions. The dependent variable which is the concentration of NO₂ will be combined with the independent variable which is the density of traffic (the result of the calculation of the volume of traffic and the speed of vehicle) and wind speed. The model can be seen in Table 2.

The model obtained has a value of correlation (r) that is very strong. The model obtained is then validated using t-test method. Data can be accepted only if $t_{\text{value}} < t_{\text{critical}}$. t-value test results can be seen in Table 3.

It can be seen that all models fulfill the t-test criteria, so that all models can be used to predict the value of the NO₂ gas concentration. Calculation of t-test used a confidence level of 95% and $\alpha = 0.05$ showed that the calculation results are in the reception area with $t_{\text{stat}} < t_{\text{kritik}}$. The predicted concentration value is at point 1, 5, 10, 25, 50 and 100 m based on the

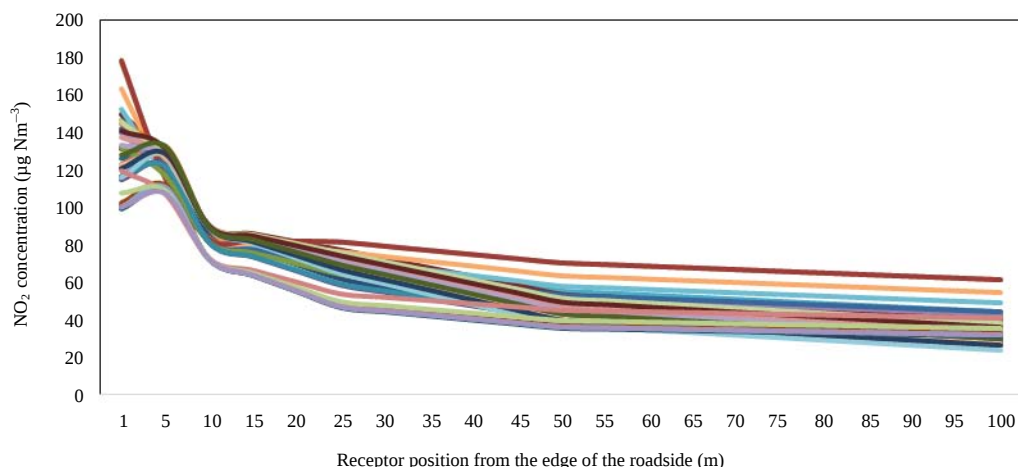


Fig. 17: Concentration of NO₂ Gas at 17.00-18.00

number of vehicles that passed the 40 sampling locations. The models are showing a decrease in concentration corresponding to the distance from the edge of the roadside²². Furthermore, the model is used to predict the value of the concentration on 40 roads in Padang computed at the time of 17:00-18:00. The decreasing result of NO₂ concentration during these hours can be seen in Fig. 17.

It can be seen, a drop in concentration occurred at a point 1-100 m. However, there is no decreasing at the point of 1 and 5 m. Meanwhile, the receptors within 10 m, saw a significant decrease in the concentration. This is because the distance receptors was already dispersed from the highway. The decrease of concentration between 25 and 100 m was not significant. NO₂ dispersion based on distance receptors is likely influenced by other factors such as meteorological conditions and different traffic characteristics in each of the sampling location²³.

CONCLUSION

Based on the results of research analysis and mapping of NO₂ dispersion from transportation activities in Padang city, it can be concluded that the relationship between NO₂ concentration and the traffic characteristics and meteorological conditions vary based on the number of vehicles. NO₂ gas concentration relationships with meteorological conditions namely wind speed relation of NO₂ concentration and traffic characteristics, vehicle speed value and total traffic density were very strong. Data concentration of NO₂ t point A (1 m) and point B (5, 10, 25, 50 and 50 m) at the sampling location is still below the national air quality standard that has been set on Indonesian Government

Regulation No. 41 of 1999 on the Control of Pollution Air. It showed that the concentration of NO₂ in Padang city is still safe and not harmful to health.

SIGNIFICANCE STATEMENTS

This study developed models for predicting NO₂ concentration based on receptor positions. Using the model help stakeholders to predict NO₂ concentrations with an easy manner. This study also showed the pattern of the decreasing of NO₂ concentrations toward the distance of receptors.

ACKNOWLEDGMENTS

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