

Urban Scale SO₂ Dispersion Model due to Transport Sector in Padang City, Indonesia

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Abstract— The main purpose of the study was to model and map the dispersion of Sulfur dioxide (SO₂) concentrations from transport activities in Padang City. The sampling of SO₂ was carried out for 1 hour at 25 monitoring sites. The samples of SO₂ were then analyzed with *Pararosanilin* methods using a spectrophotometer. SO₂ concentration samples were analyzed to develop a statistical model. Statistical models are developed based on traffic volume, traffic density, traffic speed, and wind speed. Validation was carried out to determine whether the model is valid or not statistically. Then, the model used to determine the concentrations of SO₂ at 40 monitoring points for traffic characteristics measurements. SO₂ concentration modeled ranges from 31.42 to 301.17 $\mu\text{g}/\text{m}^3$. SO₂ concentration model showed a very strong correlation to the volume of traffic ($r = 0.822$); strong against the traffic density ($r = 0.7820$); strong against the traffic speeds ($r = 0.6939$); and weak against wind speed ($r = 0.3271$). The validation test confirmed that SO₂ regression model does not have a significant difference between the model and the measurement results. This means that the model is statistically valid and can be used to predict SO₂ concentration. SO₂ gas dispersion mapping shows the concentration of SO₂ ranges from 25-300 $\mu\text{g}/\text{Nm}^3$. The highest concentration of SO₂ at 40 monitoring points found located on Khatib Sulaiman Road and Sudirman Road. SO₂ concentration value indicated that air quality in Padang City is still below the national air quality standard value (900 $\mu\text{g} / \text{Nm}^3$).

Keywords— modelling; validation; mapping; SO₂; transport sector.

I. INTRODUCTION

Padang is the capital city of West Sumatera Province with high growth, migration, and urbanization rate. Padang city has rapid economic development that is followed by the increase of the population and vehicle numbers. Based on the data of “*Padang in Figures 2015*,” there was a rapid increase in the number of motor vehicles from 392.967 units in 2013 to 427.235 units in 2014 [1]. Transportation activity produced exhaust gas caused by fossil fuel burning; one of them is Sulfur dioxide (SO₂). SO₂ resulted from this activity contributes to urban air pollution [2]. Air pollution in this urban area due to SO₂ will be higher than air pollution in rural areas [3]. The main consequence of SO₂ gas contamination to humans is respiratory system irritation [4]. According to [5], 0.75 ppm SO₂ can cause a respiratory effect. SO₂ high levels in the air can cause damage to the material. Several studies have been done to find out that SO₂ can cause metallic rusting, weathering of rocks, and the formation of stains on buildings. The presence of SO₂ in the

air could also cause acid rain [6], [7]. For knowing SO₂ concentration of roadside area, sampling can be done with certain sampling equipment with a fairly expensive cost. The second thing that can be done is to use a model, so that it does not need the equipment to find out the air quality due to SO₂. Currently, there are not many models that can be used to determine SO₂ concentration. This study aims to determine the model that can be used to predict the amount of SO₂ concentration in the roadside area.

II. MATERIAL AND METHOD

Primary data collected includes meteorological conditions, SO₂ concentrations, and traffic characteristics. Meteorological conditions measured and tools used in this study were temperature (K) and air pressure (mmHg) using pocket weatherman, wind speed using an anemometer, and wind direction using compass. The sampling for SO₂ concentrations was done for 1 hour for each sampling point, which amounted to 25 points with a sampling point location on 11 roads in Padang City (see Fig. 1).

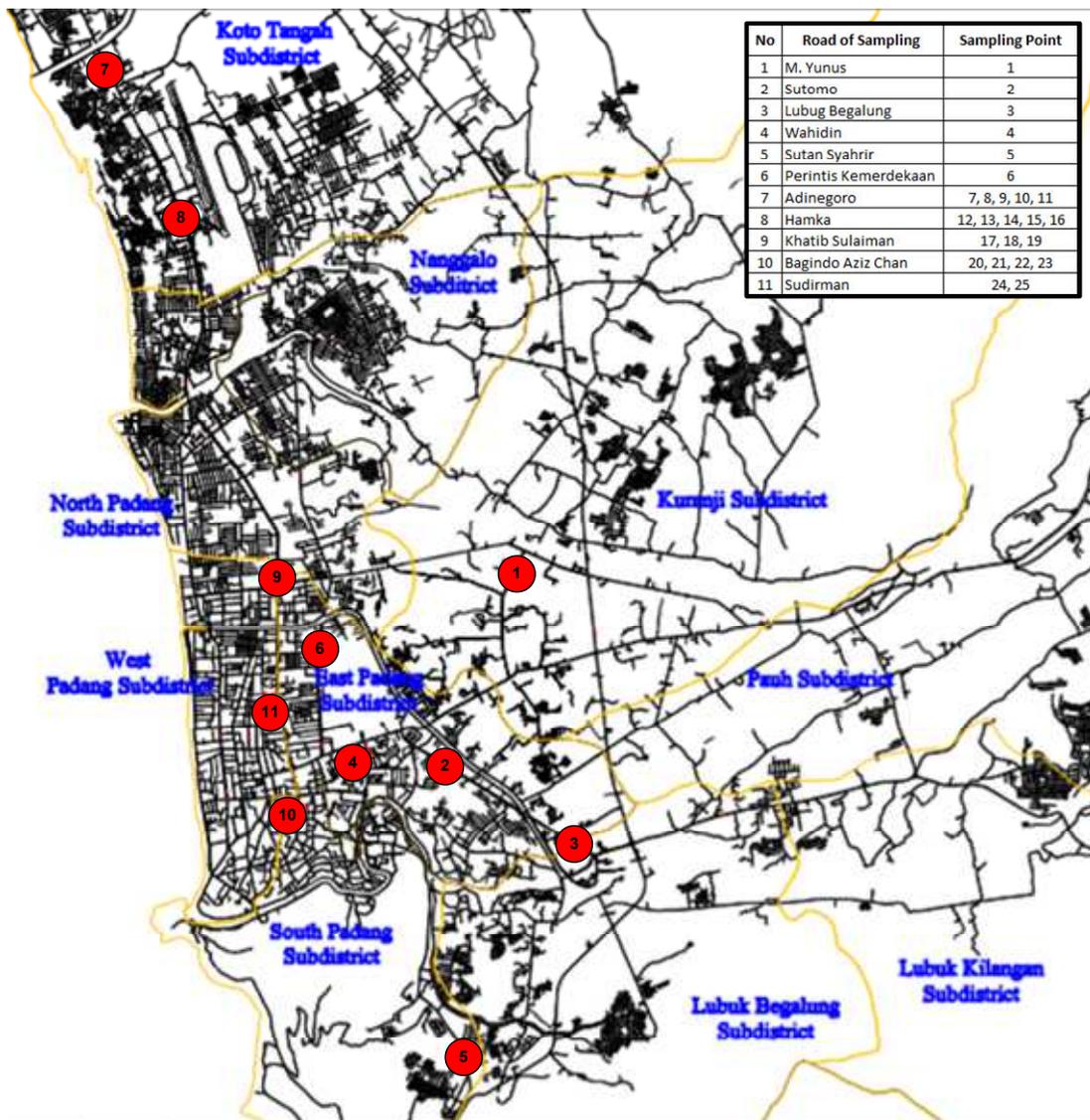


Fig. 1 The Road Number for Sampling Points

Sampling and laboratory SO₂ gas analysis steps were adjusted [8] to the method of SO₂ concentration by the *pararosaniline* method using a spectrophotometer. In this method, the gas of SO₂ is absorbed in a solution of *tetrachloromercurate* absorber (TCM) and form complex *dichlorosulfonatomercurate* compounds. This method adds a solution of *pararosaniline* and formaldehyde into the *dichlorosulfonatomercurate* compound. Next step is form a purple *pararosaniline* methyl *sulphonate* compound. Finally, the concentration of the solution is measured at a wavelength of 550 nm.

Traffic characteristics measurement was conducted in conjunction with measuring SO₂ concentration. Besides, measurement of traffic characteristics were also conducted for mapping the 40 predicted SO₂. Measurement of traffic characteristics for mapping SO₂ at 40 monitoring sites for 1 hour started at 17.00. Traffic characteristic at 17.00 was used to predict the concentration of SO₂ pollutants at those locations by using the model obtained from the SO₂ concentration relationship with traffic characteristics and meteorological conditions. SO₂ dispersion modeled using regression analysis. Traffic characteristics measured were

vehicle volume, vehicle speed, and traffic density. Measurement of vehicle numbers when was done manually in the sampling point use counter. Measurement of vehicle number when mapping was done using a counter and video camera.

III. RESULT AND DISCUSSION

A. Traffic Characteristics and Meteorological Conditions

Traffic characteristics and meteorological conditions include traffic volume, traffic speed, traffic density and wind speed [9]. Traffic volume is the actual number of vehicles observed or estimated through a point over a given time range. Traffic volume units are expressed in units of passenger cars (pcu)/hour. Traffic speed is defined as a rate of movement, such as distance per unit time (km/h). Traffic density is defined as the number of vehicles occupying a certain length of lane or road and averaged over time. The number of traffic volume, traffic speed, traffic density, and wind speed counted, can be seen in Figures 2, 3, 4, and 5.

Fig. 2 shows the varying traffic volumes at the study sites. The highest traffic volume is at the sampling site 19, which

is 4,265.15 pcu/h. The lowest traffic volume is at the sampling site 4, which is 673.8 pcu/h.

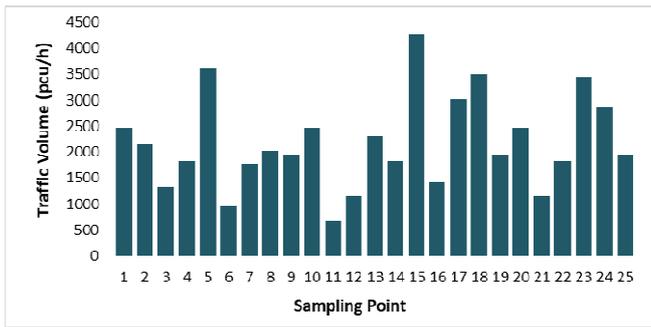


Fig. 2 Traffic Volume

Fig. 3 shows the speed of traffic at the study site. Traffic speeds vary from 20.4 km/h to 46.4 km/h.

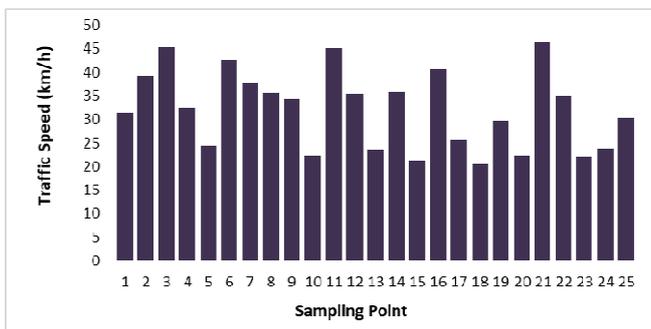


Fig. 3 Traffic Speed

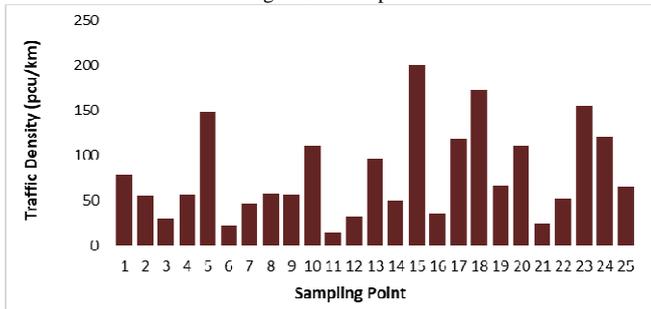


Fig. 4 Traffic Density

Fig. 4 shows the traffic density at the study site. Traffic volume and traffic speed can determine traffic density. The highest traffic density was at the sampling site 19 is 199.32 pcu/km. The lowest traffic density was found in the sampling location 4, which reached 14.91 pcu/km. This traffic density was affected by the speed of traffic flow.

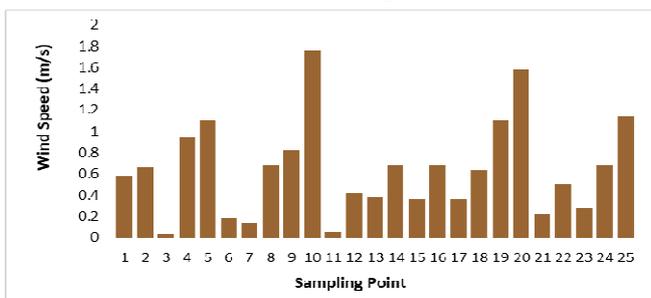


Fig. 5 Wind Speed

Based on Fig. 5, the measured wind speed when conducting the sampling varies greatly. The measured wind speed range is 0.04 m/s - 1.76 m/s. This wind speed range is quite close to wind speed range in Padang city in 2015 [10], namely 0.0 m/s - 1.25 m/s.

B. SO₂ concentrations and comparison with the National Air Quality Standard

The values of SO₂ concentration measurement can be seen in Figure 6. The highest SO₂ concentration was found on point 23 at 301.17 µg/Nm³, while the lowest concentration on point 4 at 31.42 µg/Nm³. Based on the National Air Quality Standard No. 41/1999 on Air Pollution Control, the maximum concentration of SO₂ pollutants in ambient air that can be tolerated is 900 µg/Nm³ for the time measurement of 1 hour. The comparison between SO₂ concentrations and the ambient air quality standard can be seen in Fig. 6. The SO₂ concentration does not exceed the standard value. So it can be stated that SO₂ concentration in Padang City is not harmful to health. However, according to EU's ambient air quality standards are detailed in Directive 2008/50/EC, the maximum concentration of SO₂ pollutants in ambient air is 350 µg/Nm³ for 1-hour measurement. Meanwhile, US-EPA gives limit 75 ppb (196.5 µg/Nm³) for a 1-hour measurement of SO₂. So, there are some sampling points that exceed the quality standard of US-EPA.

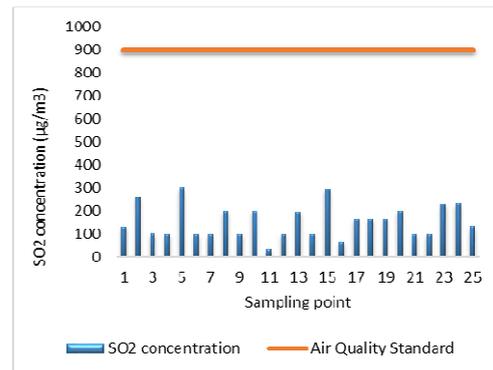


Fig. 6 SO₂ concentrations and national air quality standard

C. Correlation Analysis of SO₂ concentrations with traffic characteristics and wind speed

Traffic volume is one of the traffic characteristics that has a relationship with air pollutant concentrations [11]-[15]. The correlation between SO₂ gas concentration and total vehicle volume can be seen in Fig. 7.

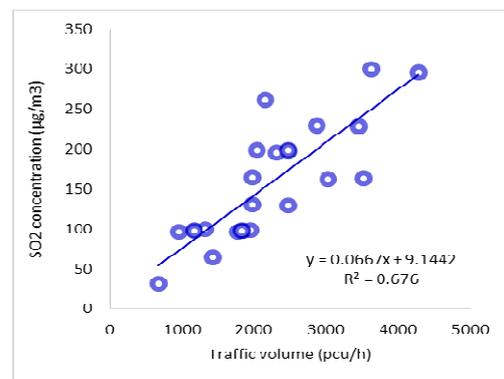


Fig. 7 Correlation between SO₂ concentration and traffic volume

Based on Fig. 7, the value of determination coefficient (R²) obtained was equal at 0.676. These shows that traffic volume effect SO₂ concentration is 67 %. The value of correlation coefficient (r) obtained was equal at 0.822. The value of coefficient correlation indicates that traffic volume has very strong correlation with SO₂ concentration.

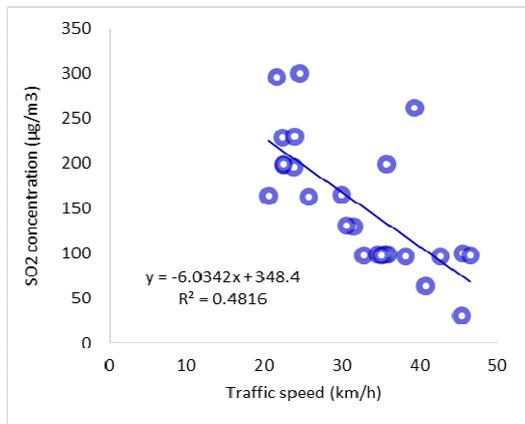


Fig. 8 Correlation between SO₂ Concentration and Traffic Speed

Fig. 8 shows the correlation between SO₂ concentration and traffic speed. The coefficient of determination (R²) between SO₂ concentration and traffic speed is equal to 0.4816. The correlation coefficient (r) between SO₂ concentration and traffic speed is 0.6939. The value of coefficient correlation indicates that traffic speed has a strong correlation with SO₂ concentration. The equation obtained from the linear regression results showed the variable x was negative. These prove that the value of traffic speed is inversely proportional to the SO₂ gas concentration. So, the higher of traffic speed, the amount of SO₂ gas concentration is less in the air.

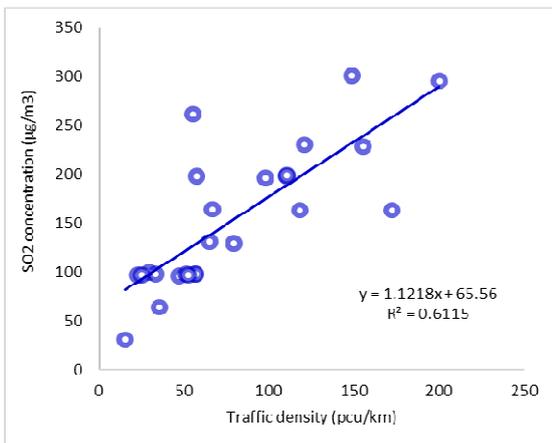


Fig. 9 Correlation of SO₂ Concentration with Traffic Density

Fig. 9 showed the correlation between SO₂ and the traffic density. The coefficient of determination (R²) between SO₂ concentration and traffic density is found at 0.6115. This indicates that 61% of the SO₂ concentration was affected by the traffic density. The value of correlation coefficient (r) between SO₂ concentration and traffic density was equal to 0.7820. The value of coefficient correlation indicates that traffic density has a strong relation with SO₂ concentration. The equation obtained from the linear regression results

shows the variable x was positive. This shows that the value of traffic density magnitude is directly proportional to the SO₂ concentration.

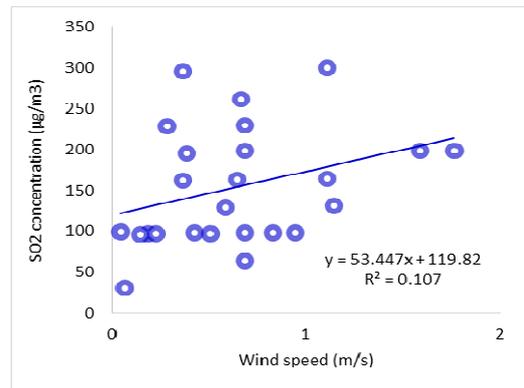


Fig. 10 Correlation of SO₂ Concentration with Wind Speed

In addition to traffic characteristics, meteorological conditions also affect SO₂ concentration [16]. Fig. 10 shows the correlation between SO₂ concentration and wind speed. The coefficient of determination (R²) between SO₂ concentration and wind speed at 0.107. The value of correlation coefficient (r) between SO₂ concentration and wind speed is 0.3271. The correlation coefficient value indicates that wind speed has a weak correlation to SO₂ concentration. The equation obtained from the linear regression results shows the variable x was positive. Fig. 10 shows that the value of wind speed is directly proportional to the SO₂ concentration value. This correlation should be negative [17], [18]. This is probably due to the wind velocity that is not very varied, so the traffic characteristics more influence SO₂ concentration. In addition, wind speed affects the spread of air pollutants [19], where increased wind speed will increase concentration spreading [20], [21].

D. SO₂ Concentration Modelling

SO₂ concentration modelling was done by looking at the correlation between pollutant concentration and influencing factors, such as traffic characteristics and meteorological conditions [22]. SO₂ concentration modelling showed relationship SO₂ concentration with traffic characteristics and meteorological conditions. Modelling of ambient air pollutant concentration can use several ways, such as by regression analysis [23], Gaussian model [24], artificial intelligent techniques [25], High resolution multi-scale air quality modelling [26]. In this study, models were made using multiple regression models [9], [27]. It can be seen in Table 1.

TABLE I
SO₂ CONCENTRATION MODELS

| Model | Equation | R |
|-------|--|-------|
| A | $C_{SO_2} = 0.082V + 2.433V_v + 34.291V_w - 123.994$ | 0.829 |
| B | $C_{SO_2} = 0.070V + 0.452V_v - 13.261$ | 0.823 |
| C | $C_{SO_2} = 0.064V + 20.506V_w + 1.674$ | 0.831 |
| D | $C_{SO_2} = 1.072D + 21.845V_w + 55.508$ | 0.794 |

where: C_{SO_2} = SO₂ concentration (µg/Nm³)
V = traffic volume (pcu/hour)

- V_v = mean speed of vehicles
- V_w = wind speed (m/s)
- D = traffic density (pcu/km)
- R = coefficient of correlation

E. Validation of SO₂ Concentration Model

Validation is the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model [28]. The validations were aimed to test whether the model can produce similar results to the measured data. Validations of the model were conducted using the measured data and verified using statistical analysis.

In this study validation was carried out on model C which had the greatest correlation (R) value. Validation is performed statistically using the t-test. The t-test is a type of statistical test to determine whether there is a difference from the estimated value with the value of the statistical calculation. The testing criteria are the initial hypothesis (H₀), that is there is no difference from the factors investigated, accepted if t-count < t-table. The results of the t-test can be seen in Table 2.

TABLE II
VALIDATION TEST OF SO₂ REGRESSION MODEL

| Model | t-count | t-count | t-table |
|-------|---------|---------|---------|
| C | 0.055 | 0.055 | 2.776 |

The t-test calculation in Table 2 uses a 95% confidence level and $\alpha = 0.05$. Table 2 shows the absolute value of t-count is smaller than the value of t-table. This means that the SO₂ regression model does not have a significant difference

between the model and the measurement results. This means that the model is statistically valid and can be used to predict SO₂ concentration due to traffic.

F. Concentration Mapping of SO₂

The map of SO₂ gas dispersion created is SO₂ concentration that were obtained using model C. Model C was used because it has the greatest R value. For more details, the predicted concentrations in 40 monitoring points can be seen in Fig. 11.

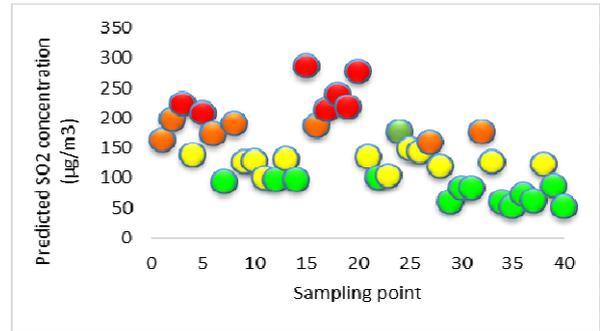


Fig. 11 The Predicted SO₂ Concentrations

The highest SO₂ concentration is approximately greater than 200 µg/Nm³. The red color indicates this concentration range. The location showed by the color is the primary arterial road, which is connecting the national activity and regional activity centers. The road is a high enough traffic volume. Fig. 12 showed the map of predicted SO₂ concentrations.

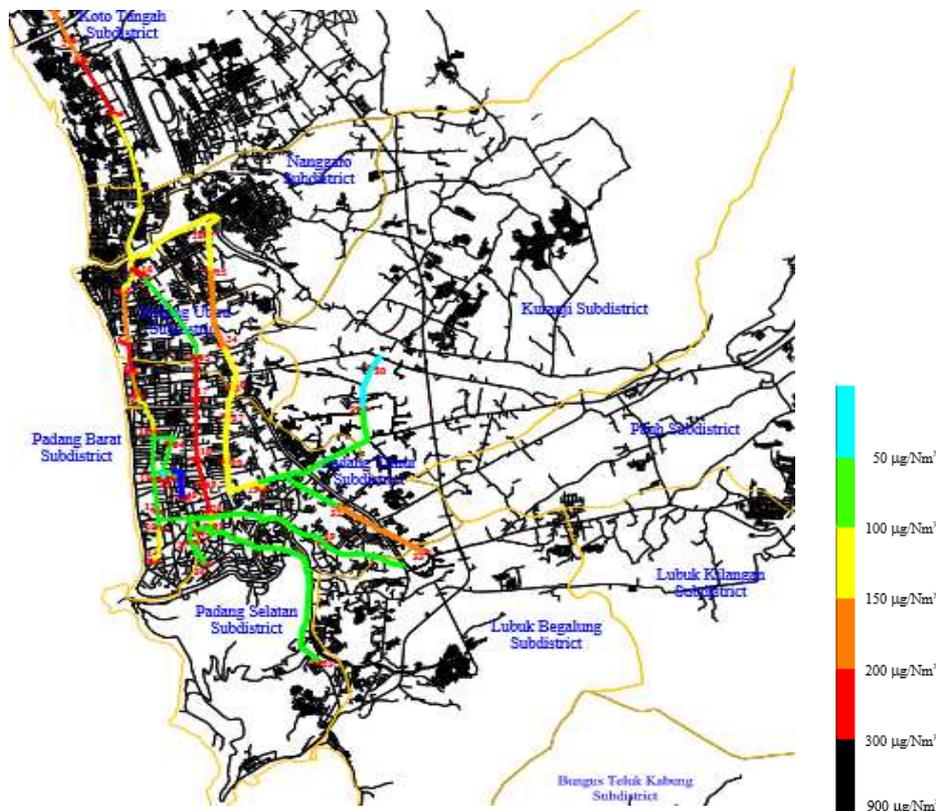


Fig. 12 SO₂ Dispersion

IV. CONCLUSION

Based on this research, it can be concluded that the traffic volume, traffic density, traffic speed and wind speed effect SO₂ concentration on the roadside area. Traffic volume and traffic density have positive correlation with SO₂ concentration in which the increase of these traffic characteristics will increase SO₂ concentrations on the roadside area. On the contrary, traffic speed has negative correlation with SO₂ concentrations where the increase of traffic speed will decrease SO₂ concentrations on the roadside area. Meanwhile, a weak correlation occurs between wind speed and SO₂ concentrations. It is caused by the low variation of wind speeds while the data collections. The SO₂ concentration model has resulted from the relationship of traffic density and wind speed with SO₂ concentrations, which has a good correlation between them. The validation test showed that the model is statistically valid and can be used to predict SO₂ concentration due to transport sector.

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