ALKIMIA : Jurnal Ilmu Kimia dan Terapan

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Spatial distribution of SO_2 and NO_2 in Bogor City's Air via Passive Sampling Method

Uswatun Hasanah[a]* Sutanto[a], Herlina Febbiyanti[a]

Abstract. Air pollution arises when substances such as sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) are released into the atmosphere due to human activities, resulting in the degradation of air quality and potentially contributing to respiratory problems. This study seeks to assess the levels and spatial distribution of SO_2 and NO_2 concentrations in Bogor City through the passive sampling method, in accordance with SNI 7119-16:2023 and SNI 7119-17:2023. Sampling was performed at nine locations over a 14-day period. NO_2 concentrations were determined using spectrophotometry, while SO_2 levels were measured via ion chromatography. The passive sampling technique relies on the diffusion of pollutant molecules into a filter impregnated with an absorbent solution. The concentrations obtained were used to calculate the Air Quality Index (ISPU), and the spatial distribution was mapped using Surfer 11 software. The results revealed that NO_2 concentrations ranged from 7.46 to 13.53 µg/m^3, while SO_2 concentrations ranged from 3.77 to 13.25 µg/m^3. The corresponding ISPU values ranged from 4.66 to 9.59 for NO_2 and 3.62 to 12.74 for SO_2, both of which fall within the "good" category (0–50) as defined by Ministry of Environment and Forestry Regulation No. 14 of 2020. The spatial distribution of pollutants demonstrated an increasing concentration from the southern and western regions toward the northern and eastern areas of Bogor City, which is likely associated with elevated vehicular traffic in these zones.

Keywords : Ambient Air, Sulfur Dioxide, Nitrogen Dioxide, Passive Sampler, Spatial Distribution

[a]*Chemistry, Faculty of Mathematics and Natural Science, Universitas Pakuan, Bogor 16129, Indonesia*
Correspondence and requests for materials should be addressed to Uswatun Hasanah (email: uswatun.hasanah@unpak.ac.id)

Introduction

Based on data from the Central Bureau of Statistics of West Java, the number of motorized vehicles in Bogor City in 2018 was 478,879 units, in 2019 it increased to 488,283 units, in 2020 it was 459,211 units, in 2021 it was 462,030 units, in 2022 it reached 467,720 units, and in 2023 it was 467,719 units [1]. It can be observed that the number of motorized vehicles in Bogor City increased significantly from 2018 to 2019, from 2020 to 2021, and from 2021 to 2022. Motorized vehicles using gasoline or diesel release NO_2 and SO_2 as a result of fuel combustion. This is one of the largest sources of pollution in big cities, particularly from cars, trucks, buses, and motorcycles [2]. Fossil fuels containing sulfur, especially in diesel-fueled vehicles and some other types of fuel oil, are sources of SO_2 gas in the air [3].

SO_2 gas is a colorless gas that easily dissolves in water to produce sulfuric acid (H_2SO_4). SO_2 gas can cause various respiratory diseases, reduced lung function, and exacerbate asthma, especially in children exposed to it in the short term. Nitrogen oxides are commonly referred to as NOx because nitrogen oxides exist in various forms with different properties. However, the main pollutant with health impacts is nitrogen dioxide (NO_2). Nitrogen dioxide is considered a major pollutant not only due to its health effects but also because it absorbs visible radiation and has the potential to directly contribute to global climate change [4].

The distribution pattern of SO_2 and NO_2 gas pollutants has previously been studied on arterial roads in Malang City using an active sampling method, which showed that pollutants spread along the roads and residential areas. The farther the observation point from the residential area, the lower the concentration of pollutants [5]. Air quality based on certain pollutant levels can be assessed by converting the pollutant concentration into the Air Pollutant Standard Index (ISPU). ISPU is a unitless numerical indicator used to describe ambient air quality conditions at a given location. The active sampling method showed ISPU values at the monitoring location on Jl. Dr. Cipto Mangunkusumo (Tegal City Terminal) of 21.25 for SO_2 and 48 for NO_2. Both parameters fall within the range of 0–50, which is categorized as good [6]. The ISPU monitoring results by the Ministry of Environment and Forestry (KLHK) station in Tanah Sareal, Bogor City, on January 20, 2024, at 3 p.m., showed an SO_2 ISPU value of 33 and an NO_2 ISPU value of 4, which are also within the good category [7].

Air quality monitoring of SO_2 and NO_2 gases can be carried out using passive and active sampling methods. The active sampling method uses a suction pump to draw surrounding pollutants into an absorbing solution, while the passive method does not use a suction pump and relies on the diffusion of gas into the sampler. Active sampling methods consist of various techniques, including continuous measurement methods such as using an Air Quality Monitoring System (AQMS) and instantaneous measurement methods such as using a high-volume sampler. However, both active methods require equipment and costs that are often limiting factors [8]. The comparison between SO_2 and NO_2 gas concentrations measured using passive and active methods shows a strong and significant correlation coefficient. The addition of meteorological factors improves the correlation coefficient further [9].

Passive sampling methods offer several advantages. First, the sampling protocol is simple, reducing the risk of inter-operator error, sampling costs, and the level of training required for sampling personnel. Second, passive samplers are small and lightweight, making them easy to deploy and less expensive to transport. Third, passive samplers can operate without the risk of power failure or clogging or leakage in the sampling tubes. Lastly, this method can be used for long sampling durations, ranging from one day to three months for certain compounds [8].

In principle, monitoring data obtained through active and passive methods at specific sampling points only reflect the air quality or quantity at those particular positions. Other nearby locations are described through approximation or assumed to have the same quality as the nearest monitoring point. Therefore, pollutant dispersion modeling can be an alternative solution to this issue [10].

Experimental

The Research stages. This study was conducted in five stages. The first stage involved identifying the surrounding conditions in Bogor City through direct observation in each district (Kecamatan) with a high level of urban activity. The second stage involved a 14-day sampling period to measure air quality of sulfur dioxide (SO_2) and nitro-

Table 1. Sampling Point Coordinates

No	Subdistrict	Village	Location	Latitude	Longitude
1	Bogor Selatan	Mulyaharja	Masjid Bogor Nirwana Residence	-6.6250	106.7959
2	Bogor Selatan	Batutulis	Stasiun Batutulis	-6.6259	106.8096
3	Bogor Timur	Baranangsiang	Terminal Baranangsiang	-6.6059	106.8068
4	Bogor Tengah	Paledang	Depan Istana/Balaikota	-6.5952	106.7937
5	Bogor Tengah	Babakan	Depan Siloam Hospital	-6.5957	106.8047
6	Bogor Utara	Cibuluh	Perempatan Pomad	-6.5480	106.8235
7	Tanah sereal	Kedungbadak	Universita Ibn Khaldun	-6.5611	106.7924
8	Tanah sareal	Cibadak	SPBU BP (Perempatan Yasmin 1)	-6.5566	106.7793
9	Bogor Barat	Cilendek Barat	Mcd Semplak	-6.5639	106.7631

gen dioxide (NO_2) at nine locations representing districts across Bogor City. The passive sampler method used for sampling sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) in ambient air followed SNI 7119-16:2023 for SO_2 and SNI 7119-17:2023 for NO_2. In the third stage, the passive samplers used for sampling were analyzed in a laboratory to determine the concentration of sulfur dioxide (SO_2) using HPLC-IC and nitrogen dioxide (NO_2) using UV-VIS Spectrophotometer. The fourth stage involved calculating the Air Pollutant Standard Index (ISPU) based on Regulation of the Minister of Environment and Forestry (PermenLHK) No. 14 of 2020. The fifth stage involved mapping the pollutant distribution in Bogor City using the Surfer 11 application to obtain the spatial distribution patterns of SO_2 and NO_2 pollutants in ambient air in Bogor City.

Sampling Equipment Preparation. The passive sampler method used for sampling sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) in ambient air is based on SNI 7119-16:2023 for SO_2 and SNI 7119-17:2023 for NO_2. Before sampling, all equipment must be properly prepared. First, all parts of the equipment should be disassembled and washed in a plastic bag using demineralized water three times or cleaned using an ultrasonic cleaner for 30 minutes. The parts are then dried in a drying cabinet at 40 °C and assembled according to the specified configuration (see Figure 1).

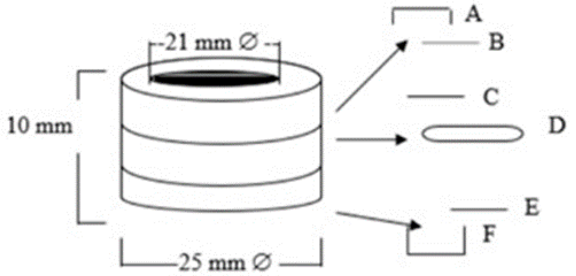

Figure 1. Example Scheme of a Sampling Device for SO_2 or NO_2 Diffusion Test. A is the polyethylene top cover, B is the stainless-steel mesh, C is the Teflon filter, D is the polypropylene ring, E is the filter, F is the polyethylene bottom cover.

Two passive samplers are prepared for each sampling point, with one designated for SO_2 and the other for NO_2. Next, absorbent solutions for SO_2 and NO_2 are prepared. To prepare the SO_2 absorbent solution, dissolve 0.5 g of NaOH in a 50 mL volumetric flask with approximately 5 mL of water, then dilute to the mark with methanol and homogenize. For the NO_2 absorbent solution, dissolve 0.44 g of NaOH in a 50 mL beaker with about 5 mL of water, add 3.95 g of NaI, transfer the solution to a 50 mL volumetric flask, dilute to the mark with methanol, and homogenize. After preparation, inject 50 µL of the SO_2 absorbent solution onto the surface of the filter used for SO_2 sampling and 50 µL of the NO_2 absorbent solution onto the filter for NO_2 sampling. Each filter is then sealed with a polyethylene cap, and the passive sampler is ready for use. Additional samplers should also be prepared following the same procedure and stored in a closed container to serve as field blanks. These field blanks must be sent along with the test samples but must not be exposed to the sampling environment.

Passive Sampling Method. First, determine the coordinates of the ambient air sampling points according to the locations listed in Table 1. Then, prepare the equipment as shown in Figure 2. A is the bracket, while B serves as the rain and heat protector. C indicates the minimum installation height of the protector, which should be 2 meters above ground level. D refers to the hook, and E is the support pole. Lastly, F represents the cross-section of the sampling device for the diffusion test.-and securely install the sampling pole at a height of 2.5 meters, ensuring it is stable and not easily toppled. Remove the passive samplers for NO_2 and SO_2 from their respective tubes and attach each sampler to the protective holder with the wire mesh facing

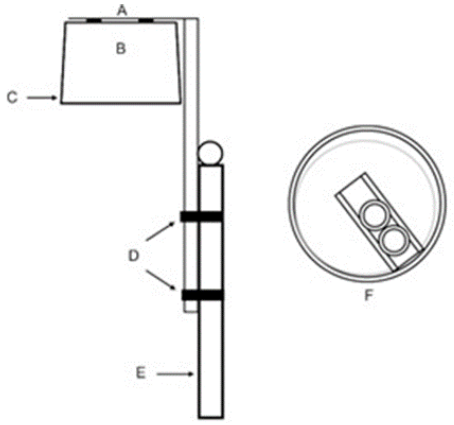

Figure 2. Illustration of the Installation of a Sampling Device for SO_2 or NO_2 Diffusion Test.

downward. Hang them on the pole, using gloves during the process to prevent contamination. Expose the sampling devices to ambient air by leaving the passive samplers in place for 14 days. After the 14-day sampling period, remove the exposed passive samplers and place them back into their original sampler tubes, seal them tightly in appropriate containers, and send them to the laboratory for analysis.

SO_2 Analysis Method. The passive samplers that have been used for sampling over 14 days will be analyzed in the laboratory to determine the SO_2 concentration in the ambient air at each sampling point. The SO_2 concentration is analyzed using HPLC-IC based on the method from SNI 7119-16:2023. The exposed filter is taken with tweezers, placed into a 10 mL test tube, and added with 5 mL of deionized water. The tube is gently shaken, sealed, and left in the refrigerator for 24 hours before being analyzed. The same procedure is followed for the field blank filter.

For calibration curve preparation, Na_2SO_4 is dried in an oven at 105°C for 1 hour, then cooled in a desiccator for 15 minutes. 147.9 mg of dry Na_2SO_4 is dissolved in a 100 mL volumetric flask with deionized water, then diluted to the mark and homogenized. This solution serves as the 1000 mg/L sulfate master standard. A series of working sulfate solutions is prepared with one blank and at least three different concentrations proportionally within the measurement range of 0.1–5 µg/mL.

The instrument is then operated according to HPLC-IC procedures, with the syringe rinsed using deionized water and injected into the device. The syringe is then rinsed with the test sample solution and injected into the device. The instrument conditions used are as follows: Column: IC Pak A-HR 4.6 x 75 mm; Mobile Phase: 0.889 g $Na_2HPO_4 \cdot 2H_2O$ in 1 L; Column temperature: 30°C; Detector: IC detector; Flow rate: 1.0 mL/min; Injection volume: 100 µL. The concentration of SO_2 in the air was first calculated by converting the concentration of sulfate ions (SO_4^{2-}) from µg/mL to µmol/L using Equation (1).

$$SO_4^{2-}(\mu mol/L) = C \text{ x } \frac{1000}{BM\ SO_4^{2-}} \quad (1)$$

where C represents the concentration of SO_4^{2-} in µg/mL, and BM SO_4^{2-} is the molecular weight of SO_4^{2-} (96.06 g/mol). The factor of 1000 is used to convert from µmol/mL to µmol/L.

Next, the SO_2 concentration in ambient air, expressed in nmol/m³, was calculated using Equation (2). In this equation, R is the total air resistance (41.2 m^{-1}), EV is the extraction volume (5 mL), $[SO_4^{2-}]$ is the sulfate concentration in µmol/L, t is the sampling time (in seconds), and D is the diffusion coefficient for SO_2 (1.32×10^{-5} m²/s).

$$SO_2(nmol/m^3) = \frac{R \text{ x } EV \text{ x } [SO_4^{2-}]}{t \text{ x } D} \quad (2)$$

Finally, to convert the SO_2 concentration from nmol/m³ to µg/m³, Equation (3) was used.

$$SO_2(\mu g/m^3) = \frac{C_a \text{ x } BM\ SO_2}{1000} \quad (3)$$

where C_a is the SO_2 concentration in nmol/m³, and BM_SO_2 is the molecular weight of SO_2 (64.06 g/mol).

NO_2 Analysis Method. The passive samplers that have been used for sampling over 14 days will be analyzed in the laboratory to determine the NO_2 concentration in the ambient air at each sampling point. The NO_2 concentration is analyzed using a spectrophotometer based on the method from SNI 7119-17:2023. The exposed filter is taken with tweezers, placed into a 10 mL test tube, and added with 5 mL of deionized water. The tube is gently shaken, sealed, and left in the refrigerator for 24 hours before being analyzed. The same procedure is followed for the field blank filter.

For calibration curve preparation, the

$NaNO_2$ 0.1 M master solution is prepared by dissolving 0.69 g of $NaNO_2$ in a 100 mL volumetric flask with deionized water, then diluted to the mark and homogenized. The $NaNO_2$ 100 µM standard solution is made by pipetting 100 µL of $NaNO_2$ 0.1 M into a 100 mL volumetric flask, then diluting with NaI diluent solution to the mark and homogenizing. A series of nitrite working solutions is prepared with one blank and at least five different concentrations proportionally within the measurement range of 1–40 µM. The standard series is prepared using NaI diluent solution.

For test sample analysis, 2 mL of the test sample is pipetted, and 2 mL of the NEDA-sulfanilamide reagent solution is added to each test tube, then left to stand for 40 minutes at room temperature to ensure the reaction is complete. The absorbance of the standard solution and the test sample is then measured using a spectrophotometer at a wavelength of 540 nm. , the concentration of NO_2 in the ambient air was calculated by first determining the nitrite concentration from the extraction volume, using Equation (4).

$$NO_2\,(\text{nmol/m}^3) = \frac{R \times EV \times [NO_2^-]}{t \times D} \quad (4)$$

where R represents the total air resistance (41.2 m^{-1}), EV is the extraction volume (2 mL), $[NO_2^-]$ is the nitrite concentration in µmol/L or µM, t is the sampling time (in seconds), and D is the diffusion coefficient for NO_2 (1.54×10^{-5} m^2/s).

The NO_2 concentration in µg/m³ was then calculated using Equation (5).

$$NO_2\,(\mu\text{g/m}^3) = \frac{C_a \times BM\ NO_2}{1000} \quad (5)$$

where C_a is the NO_2 concentration in nmol/m³, and BM-NO_2 is the molecular weight of NO_2 (46 g/mol).

Data analysis. The concentration data of SO_2 and NO_2 in ambient air at each sampling point will be used to calculate the Air Quality Index (ISPU) and map the distribution of pollutants in the city of Bogor using the Surfer 11 application.

The distribution of SO_2 and NO_2 pollutants will be visualized using Surfer 11 software. The output generated is a map showing the distribution of pollutant concentrations in the form of concentration isopleth maps. The coordinates used are three-dimensional Cartesian coordinates (XYZ). The process involves entering the sampling point coordinate data, with longitude (X-axis) and latitude (Y-axis), while the SO_2 and NO_2 concentrations are represented on the Z-axis in Surfer 11. The software will then calculate the data and transform it into a spatial pattern in the form of SO_2 concentration isopleths. The SO_2 concentration isopleth map will subsequently be overlaid on the layout of the city map of Bogor, allowing visualization of areas with the highest and lowest concentrations.

The air quality index (ISPU) calculation is carried out in accordance with the guidelines of the Ministry of Environment and Forestry Regulation No. 14 of 2020 regarding the Air Quality Index. The ISPU calculation is based on the upper and lower ISPU limits, upper and lower ambient limits, and the measured ambient concentrations. The standard values for calculating the upper and lower ISPU limits are provided in Table 2.

Table 2. Concentration Limits for SO_2 and NO_2 to Determine the Air Quality Index

Air Quality Index (ISPU)	SO_2 (µg/m³)	NO_2 (µg/m³)
0-50	52	80
51-100	180	200
101-200	400	1130
201-300	800	2260
>300	1200	3000

Source: PermenLHK No.14 Tahun 2020

The Air Quality Index (ISPU) is calculated using the Equation (6).

$$I = \frac{I_a - I_b}{X_a - X_b}(X_x - X_b) + I_b \quad (6)$$

Where I represents the calculated ISPU value. In this formula, I_a refers to the upper ISPU limit, while Ib represents the lower ISPU limit. The values X_a and Xb correspond to the upper and lower ambient concentration limits (measured in µg/m³), respectively. X_x is the measured ambient concentration, also in µg/m³. This formula is used to calculate the ISPU by considering the measured concentration of a pollutant and determining its relative position between the upper and lower concentration limits. By applying this equation, the ISPU value can be determined, providing an index that reflects the air quality based on the concentration of pollutants such as SO_2 or NO_2.

Result and Discussion

This study involves the determination of nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) concentrations in the ambient air of Bogor City using the passive sampler method. After measuring the concentrations of both pollutants, the Air Quality Index (ISPU) values are calculated and the distribution of these pollutants is mapped onto the map of Bogor City using the Surfer application.

Nitrogen Dioxide Concentration and ISPU Value. Based on the determination of nitrogen dioxide (NO_2) concentration, the data were processed to obtain the NO_2 concentration in ambient air. This concentration data was then further processed to calculate the corresponding Air Quality Index (ISPU). The results for the nitrogen dioxide (NO_2) concentration in ambient air and the associated ISPU values are presented in Table 3.

The ISPU value of NO_2 represents the concentration level of NO_2 in the air. The higher the ISPU value of NO_2, the higher the level of air pollution by NO_2 in the region. Based on the table above, it can be observed that the highest NO_2 concentration was found at the sampling point Pomad Intersection, with a concentration of 15.35 µg/m^3 and an ISPU value of 9.59, while the lowest NO_2 concentration was found at the sampling point Masjid Bogor Nirwana Residence, with a concentration of 7.46 µg/m^3 and an ISPU value of 4.66. The Pomad Intersection often experiences congestion due to the accumulation/ density of vehicles, leading to traffic jams. The Baranangsiang Bus Terminal is a place where intercity vehicles gather to pick up and drop off passengers. This terminal serves routes for intercity transportation, including Bogor-Kampung Rambutan, Bogor-Sukabumi, Bogor-Bandung, and Bogor-Pelabuhan Ratu.

The ISPU values for NO_2 at all sampling points are still within the range of 0-50, indicating that the air quality in Bogor City falls under the good category. A good air quality condition means that the air quality is excellent and does not have any negative impact on humans and other living beings.

NO_2 pollution can cause respiratory problems, increase the risk of respiratory infections, and worsen conditions for individuals with lung diseases. Nitrogen Dioxide (NO_2) is one of the pollutants emitted from several sources, particularly in the transportation and industrial sectors [11].

Table 3. Nitrogen Dioxide Concentration and ISPU Values

No	Location	NO_2 Concentration (µg/m^3)	Calculated ISPU
1	Masjid Bogor Nirwana Residence	7,46	4,66
2	Stasiun Batutulis	11,69	7,31
3	Terminal Baranangsiang	15,08	9,43
4	Depan Istana/ Balaikota	14,46	9,04
5	Depan Siloam Hospital	14,08	8,80
6	Perempatan Pomad	15,35	9,59
7	Universita Ibn Khaldun	8,00	5,00
8	SPBU BP (Perempatan Yasmin 1)	10,83	6,77
9	Mcd Semplak	11,61	7,26

Sulfur Dioxide Concentration and ISPU Value. Based on the measurements of sulfur dioxide (SO_2), the data were processed to obtain the sulfur dioxide concentration in the ambient air. This concentration data was then further processed to calculate the corresponding Air Quality Index (ISPU). The results for the sulfur dioxide (SO_2) concentration in ambient air and the associated ISPU values are presented in Table 4.

Table 4. Sulfur Dioxide Concentration and ISPU Values

No	Location	SO_2 Concentration (µg/m^3)	Calculated ISPU
1	Masjid Bogor Nirwana Residence	3,77	3,62
2	Stasiun Batutulis	9,35	8,99
3	Terminal Baranangsiang	12,69	12,20
4	Depan Istana/ Balaikota	12,32	11,85
5	Depan Siloam Hospital	12,19	11,72
6	Perempatan Pomad	13,25	12,74
7	Universita Ibn Khaldun	4,53	4,35
8	SPBU BP (Perempatan Yasmin 1)	9,68	9,31
9	Mcd Semplak	9,87	9,49

The ISPU measures the concentration of SO_2 in the air and provides information about the air quality level in a specific area. An increase in the ISPU value of SO_2 indicates an increase in the concentration of SO_2 in the air, which means a higher risk to public health in that region. Based on the table above, it can be observed that the highest SO_2 concentration was found at the sampling point Pomad Intersection, with a concentration of 13.25 µg/m³ and an ISPU value of 12.74, while the lowest SO_2 concentration was found at the sampling point Masjid Bogor Nirwana Residence, with a concentration of 3.77 µg/m³ and an ISPU value of 3.62. The ISPU values for SO_2 at all sampling points remain within the 0-50 range, indicating that the air quality in Bogor City falls under the good category. A good air quality condition signifies that the air quality is excellent and does not have any negative impact on humans and other living beings.

SO_2 is a gas produced from the combustion of fossil fuels, such as coal and oil. SO_2 pollution can cause irritation in the respiratory tract, especially in individuals with respiratory issues such as asthma. Long-term exposure to SO_2 can lead to an increased risk of chronic lung diseases and contribute to the formation of acid fog [12].

Nitrogen Dioxide Distribution Pattern. Based on the previously obtained NO_2 concentration data, as shown in Table 3, a distribution pattern of NO_2 pollutants in the ambient air of Bogor City was created by plotting the NO_2 concentrations at the coordinates of each sampling point, as listed in Table 3. This distribution pattern was then overlaid with the map of Bogor City, with the results shown in Figure 3.

Based on the distribution pattern, it can be observed that the NO_2 concentration increases from the south and west of Bogor towards the north and east of Bogor. Nitrogen Dioxide (NO_2) is a gas typically produced by combustion activities, such as from motor vehicles and industrial processes. The high NO_2 concentration in the northern areas of Bogor, Tanah Sareal, and Bogor Timur can be attributed to the high traffic density in or around these areas.

This could be caused by the presence of two different toll roads located on the northern and eastern edges of Bogor City, namely the Jagorawi Toll Road and the Bogor Outer Ring Road (BORR). The Jagorawi Toll connects Jakarta to Bogor and continues towards Ciawi, while the Bogor Outer Ring Road (BORR) is a toll road that encircles Bogor, linking various surrounding areas.

In addition to the toll roads, this area has many arterial roads that are heavily traveled daily. The Kebun Raya Bogor Ring Road, which consists of Jl. Pajajaran, Jl. Oto Iskandar Dinata, Jl. Ir. H. Juanda, and Jl. Jalak Harupat, experiences high levels of congestion, especially during peak hours. The vehicle volume around the Kebun Raya Bogor Ring Road reaches 3,000-4,000 vehicles/hour. This road section is dominated by offices, research institutions, business centers, schools, universities, hospitals, and markets [13].

Jalan Raya Bogor is a national road connecting DKI Jakarta Province to Bogor City, passing through 3 municipalities and 1 district, namely East

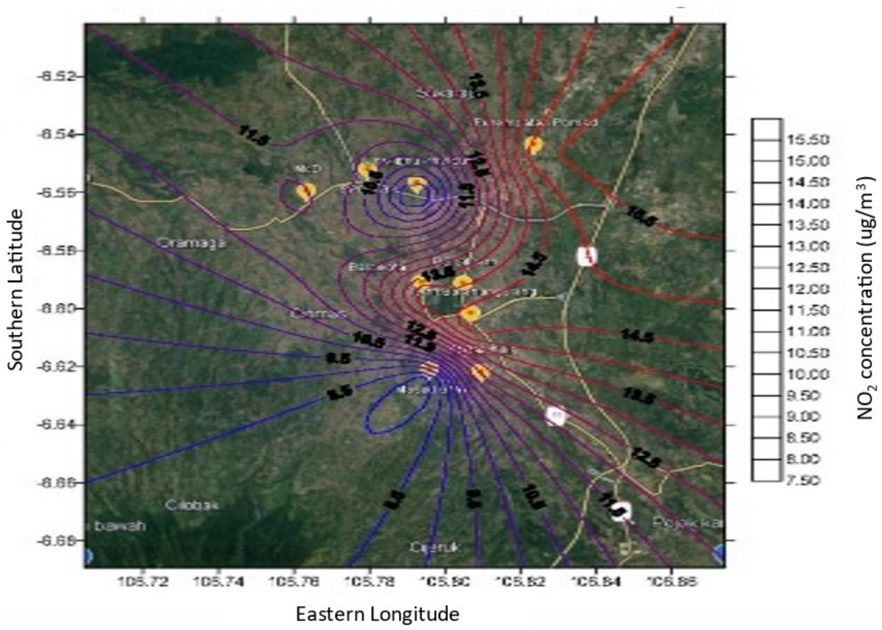

Figure 3. Nitrogen Dioxide Distribution Pattern in Bogor City

Jakarta, Depok City, Bogor Regency, and Bogor City. Congestion can occur anywhere, not just in the Jakarta Capital Region, but also in Bogor, such as at the intersection connecting Jalan Raya Bogor with Jalan Tegar Beriman, Bogor. This intersection handles between 11,000 to 15,000 vehicles/hour [14].

The traffic condition at the Pomad Intersection during peak hours on Jalan Raya Bogor shows that in Section 1 during the holiday, from 10:00-11:00, the traffic volume is 1,566 vehicles/hour, while on working days from 17:00-18:00, it rises to 2,131 vehicles/hour. For Section 2, during holidays from 10:00-11:00, the traffic volume is 1,609 vehicles/hour, and on working days, from 17:00-18:00, it is 2,112 vehicles/hour, which exceeds its actual capacity, causing traffic congestion. Meanwhile, on Jalan P. Ashogiri, the traffic volume on holidays from 08:00-09:00 is 377 vehicles/hour, and on working days from 17:00-18:00, it is 615 vehicles/hour, both below its actual capacity, allowing smooth traffic flow. On Jalan Mandala, the traffic volume on holidays from 14:00-15:00 is 456 vehicles/hour, and on working days from 12:00-13:00, it is 576 vehicles/hour, indicating smooth traffic flow [15].

Gasoline is a hydrocarbon compound with a high octane or iso-octane content. Octane compounds (C_8H_{18}) are hydrocarbons used as a benchmark for determining the quality of gasoline, known as the octane rating. The combustion reaction of gasoline is an oxidation reaction between hydrocarbons and oxygen, resulting in products such as carbon dioxide (CO_2), water vapor (H_2O), nitrogen oxides (NO_x), or other products depending on the combustion quality. If the chemical formula for gasoline is C_8H_{18} and the air used for combustion contains 78% nitrogen (N_2) and 21% oxygen (O_2) (the ratio of N_2:O_2 is 3.7:1), the general combustion reaction of gasoline as shown in Equation 1.

$$C_8H_{18} + 12.5\ O_2 + 12.5\ (3.7)\ N_2 \rightarrow 8\ CO_2 + 9\ H_2O + 12.5\ (3.7)\ N_2 \quad (1)$$

The chemical equation above shows the complete combustion of 1 mole of fuel. During the combustion process, the hydrocarbon compound reacts with oxygen to form CO_2 and H_2O. Combustion is considered complete when the mixture of fuel and oxygen (from air) is stoichiometrically correct, leaving no residue.

Nitrogen does not participate in the combustion process, but at high temperatures, it will react with oxygen to form nitrogen monoxide (NO). After combustion, this NO can further react with oxygen to form nitrogen dioxide (NO_2), as shown in the following equation 2.

$$N2(g) + O2(g) \rightarrow 2NO(g)$$

$$2NO(g) + O2(g) \rightarrow 2NO2(g) \quad (2)$$

Stoichiometrically (theoretically), based on the combustion reaction of gasoline, gasoline requires air at a ratio of 1:15 (1 kg of gasoline requires 15 kg of air) for complete combustion. Since the air used for combustion contains 78% nitrogen, every 1 kg of gasoline burned will produce 11.7 kg of nitrogen. Since every 1 mole of N_2 produces 2 moles of NO_2 according to the reaction above, each combustion of gasoline can generate a significant amount of nitrogen dioxide if the nitrogen in the combustion process reacts with leftover oxygen at high temperatures.

Distribution Pattern of Sulfur Dioxide. Based on the previously obtained concentration data for SO_2, as presented in Table 4, a distribution pattern of SO_2 pollutants in the ambient air of Bogor City was created by plotting the SO_2 concentrations at each sampling point's coordinates, as shown in Table 4. This distribution pattern was then overlaid on the map of Bogor City, with the resulting output shown in figure 4.

Based on the distribution pattern, it is observed that the concentration of SO_2 increases from the southern and western parts of Bogor towards the northern and eastern areas. Sulfur dioxide (SO_2) is a gas produced from the combustion of fossil fuels, such as coal and oil containing sulfur. The high concentration of SO_2 in the northern, Tanah Sareal, and eastern areas of Bogor could be attributed to the high traffic density in and around these areas.

Previous research has shown that SO_2 concentrations are often associated with traffic density. For example, a study in Jakarta revealed that SO_2 concentrations increased with the rising volume of vehicles in densely trafficked areas, especially in the city center [16]. Additionally, it was found that industrial areas and places with heavy traffic tend to have higher SO_2 concentrations, indicating a significant impact from transportation activities and the burning of fossil fuels on air quality [17]. On the oth-

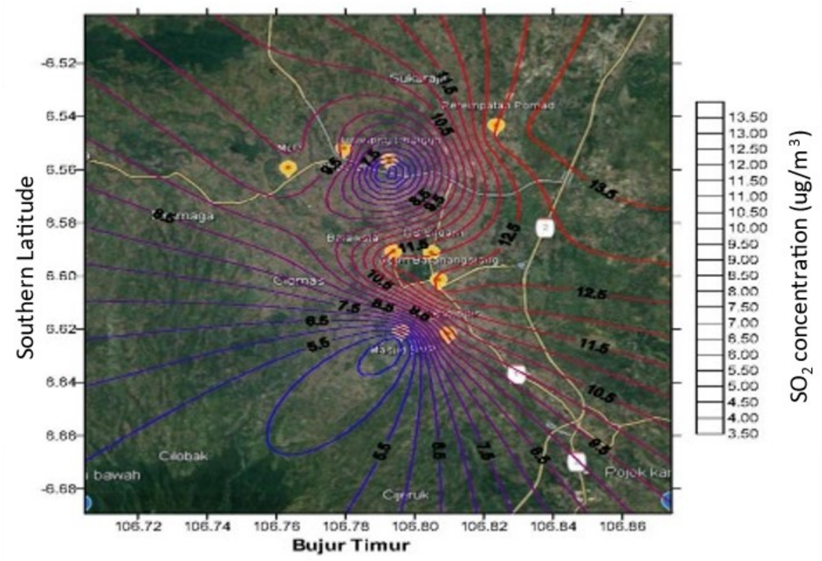

Figure 4. Sulfur Dioxide Distribution Pattern in Bogor City

er hand, geographical factors also play a crucial role in the distribution of SO_2 concentrations. Low-lying areas with unfavorable wind conditions can lead to higher concentrations of pollutants, including SO_2, which become trapped in these regions [18]. Another study showed that areas near industrial locations and high-traffic zones, such as North and East Bogor, exhibit higher pollutant concentrations [19]. These findings support the hypothesis that traffic density and the presence of industries play a crucial role in increasing SO_2 concentrations in these areas.

Transportation, such as motorcycles, cars, trucks, buses, and other commercial vehicles, rely on fuel oil (BBM) for operation. This fuel generally contains a small amount of sulfur, which is regulated in the specifications of each type of fuel. The sulfur content in the fuel can generate sulfur dioxide gas during combustion, as sulfur reacts with oxygen according to the following equation 3.

$$S_{(l)} + O_{2(g)} \rightarrow SO_{2(g)} \quad (3)$$

Gasoline consists of various types, such as Pertamax, Pertalite, and Premium. The maximum sulfur content specification for these types of gasoline from Pertamina is 0.05% or 500 ppm. Diesel fuel (solar) contains sulfur, as regulated by the Decree of the Director General of Oil and Gas No. 3675 K/24/DJM/2006 dated March 17, 2006, which defines the specifications for two types of diesel fuel: Solar 48 and Solar 51. The specification for Solar 48 allows a maximum sulfur content of 0.35% by mass (3500 ppm), while Solar 51 allows a maximum sulfur content of 0.05% by mass (500 ppm).

Studies have shown that the sulfur content in 17 diesel samples from various regions in Indonesia varies significantly, ranging from 0.11% to 0.30% by mass, exceeding the maximum sulfur content allowed in Solar 51 regulations (0.05% by mass or 500 ppm) [3]. This finding indicates a discrepancy between the quality of diesel available in the market and the specifications set by the government. Another study analyzing the quality of diesel fuel in West Java found an average sulfur content of around 0.22% by mass, which, although lower than the findings of Semar, still exceeds the allowed limit for Solar 51 [20]. These findings highlight the need for improved implementation and supervision of fuel quality in the field, despite government regulations imposing strict sulfur content limits.

The high sulfur content in both diesel and gasoline contributes to increased emissions, leading to air pollution and potential damage to vehicle engines. To reduce sulfur dioxide emissions in the future, the government should focus on reducing the use of fossil fuels. It could also tighten sulfur content limits for various types of fossil fuels to minimize sulfur dioxide pollution moving forward.

Based on the wind speed graph shown in the Figure 5, it is evident that the wind speed during the sampling period using passive samplers varied considerably across different locations. On some days, the wind speed was relatively low, around 1-4 km/h, while on other days, it reached higher speeds of 13-19 km/h. The passive sampler method adsorbs SO_2 and NO_2 gases through diffusion, meaning that

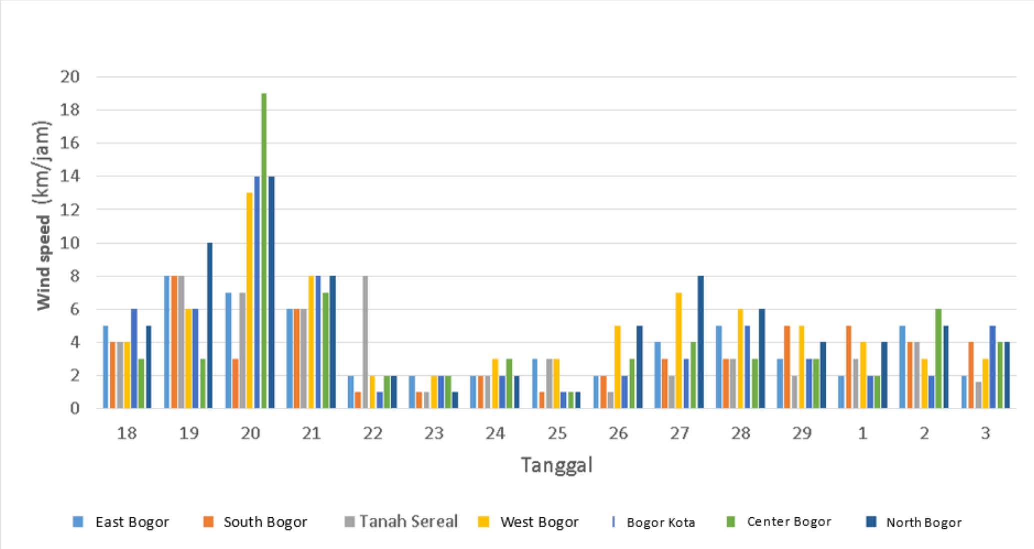

Figure 5. Wind Speed Data in Bogor City

wind speed can influence the concentration of pollutants in the surrounding air. Strong winds can reduce local accumulation of pollutants, while weak winds can create stagnant conditions that enhance the buildup of pollutants around the sampler [2].

These findings are consistent with other studies that have shown that low wind speeds lead to reduced atmospheric ventilation, which in turn results in higher pollutant concentrations in certain areas. Additionally, it has been noted that passive samplers are effective in monitoring changes in pollutant concentrations in response to variations in wind speed [21]. Furthermore, other research has highlighted that weak wind conditions are linked to the accumulation of pollutants in the air, further supporting the understanding that air stagnation caused by weak winds can exacerbate pollution levels, particularly for harmful gases such as SO_2 and NO_2 [22]. Therefore, the results of this study align with existing literature, emphasizing the crucial role of wind speed in influencing pollutant accumulation and its subsequent impact on air quality in the surrounding environment.

Based on the wind direction frequency graph in Figure 6, it can be observed that the wind direction during the sampling period using passive samplers was quite variable across different locations. In general, the wind predominantly blew from the south (43 occurrences) at several sampling points over multiple days. This pattern can influence the distribution of pollutants, with lower concentrations on the southern side and higher concentra-

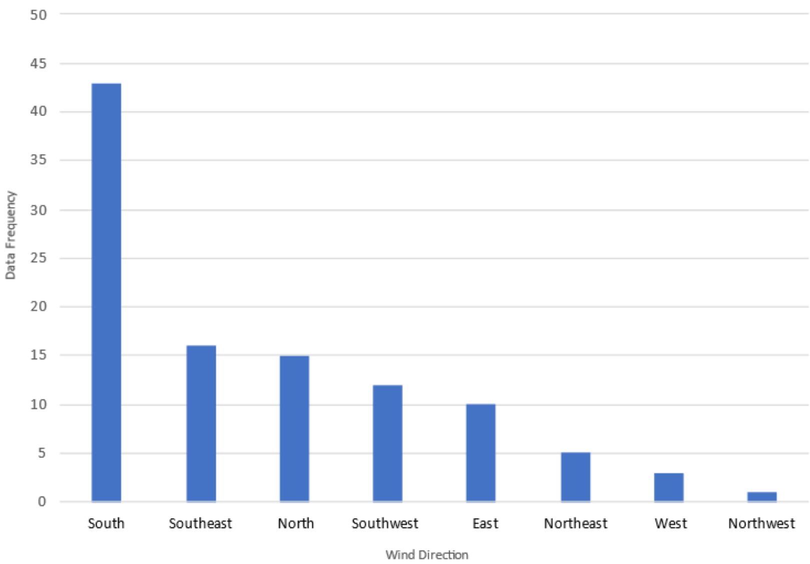

Figure 6. Wind Direction Frequency Data in Bogor

tions on the northern side, as seen in Figure 4 (NO_2 concentration distribution) and Figure 5 (SO_2 concentration distribution).

This finding aligns with studies conducted in other cities, such as Banda Aceh, where the dominant southerly wind direction led to higher pollutant concentrations on the northern side [23]. Similarly, a study in Kupang showed that the use of passive samplers revealed a pollutant distribution pattern highly dependent on wind direction, with the southerly wind carrying pollutants to the northern side of the city [24]. Thus, the observations in this study are consistent with existing literature, which highlights the significant role of wind direction in pollutant distribution within urban areas.

Conclusion

Based on the research results, it can be concluded that the concentration of Nitrogen Dioxide (NO_2) in the ambient air of Bogor City, measured using the passive sampler method at 9 sampling points, ranges from 7.46 to 13.53 µg/m³, while the concentration of Sulfur Dioxide (SO_2) ranges from 3.77 to 13.25 µg/m³. When compared to the air quality standards set by the Government Regulation of the Republic of Indonesia No. 22 of 2021, the standard limit for SO_2 is 45 µg/m³, and for NO_2 is 50 µg/m³, meaning that the concentrations of both pollutants are still below the established standard limits. Furthermore, the Air Pollution Standard Index (ISPU) values for Nitrogen Dioxide range from 4.66 to 9.59, while the ISPU for Sulfur Dioxide ranges from 3.62 to 12.74. These ISPU values are still within the range of 0-50, which falls under the "good" category according to the Ministry of Environment and Forestry Regulation No. 14 of 2020. This indicates that the air quality in Bogor City is very good and does not have a negative impact on humans or other living organisms.

The distribution pattern of Nitrogen Dioxide concentrations in Bogor City shows that NO_2 concentration tends to increase from the southern and western parts of Bogor towards the northern and eastern parts. Nitrogen Dioxide (NO_2) is primarily produced from motor vehicle activities and industrial processes, and the high concentration of NO_2 in the northern, Tanah Sareal, and eastern areas of Bogor may be caused by high traffic density in or around these areas. The distribution pattern of Sulfur Dioxide shows a similar trend, with higher SO_2 concentrations in the same areas, particularly in northern Bogor, Tanah Sareal, and East Bogor. Sulfur Dioxide (SO_2) is a gas produced from the combustion of fossil fuels such as coal and oil, which contain sulfur. Therefore, the high concentration of SO_2 in these areas may be linked to the high volume of traffic, which contributes to air pollution due to fossil fuel combustion.

Acknowledgements

I extend my deepest gratitude to my supervisor, Dr. Sutanto, M.Si and Uswatun Hasanah, S.Si, M.Si., for her unwavering support and insightful critiques throughout my research journey. Her deep commitment to academic excellence and meticulous attention to detail have significantly shaped this undergraduate thesis. My appreciation also goes to the faculty and staff in the Department of Chemistry at Universitas Pakuan, whose resources and assistance have been invaluable. I would also like to acknowledge my peers for their camaraderie and the stimulating discussions that inspired me throughout my academic journey. Their collective wisdom and encouragement have been a cornerstone of my research experience. Finally, my sincere thanks to the staff of PT Anugrah Analisis Sempurna (AAS Laboratory), whose expertise in managing laboratory equipment was crucial for my experiments. Their patience and readiness to assist at all times have left a profound impact on the completion of my project.

Author Contributions

Herlina Febbiyanti designed and conducted the research as part of her undergraduate thesis and drafted the initial manuscript. Dr. Sutanto, M.Si and Uswatun Hasanah, S.Si, M.Si supervised the research process and provided substantial input on data analysis and manuscript preparation.

References

[1] Open Data Jabar, "Jumlah Kendaraan Bermotor Berdasarkan Cabang Pelayanan di Provinsi Jawa Barat," 2023. https://opendata.jabarprov.go.id/id/dataset/jumlah-kendaraan-bermotor-berdasarkan-cabang-pelayanan-di-jawa-barat (diakses 5 November 2023).

[2] J. H. Seinfeld dan S. N. Pandis, Atmospheric chemistry and physics: From air pollution to climate change, 3rd ed. New York: New York: John Wiley & Sons, 2016.

[3] D. Semar, "Pengaruh Viskositas dan kandungan Sulfur dalam Minyak Solar terhadap Sifat Lubrisitas Minyak Solar Indonesia," J. Lemigas ESDM, vol. 41, no. 1, hal. 20–28, 2007.

[4] [World Health Organization, WHO global air quality guidelines: Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Geneva, 2021.

[5] B. Rahadi, E. Kurniati, dan A. T. Imaya, "Analisis Sebaran Polutan SO 2 , NO x dan PM 10 dari Sumber Bergerak pada Jalan Arteri Kota Malang," Sumberd. Alam dan Lingkung., vol. 6, no. 3, hal. 40–51, 2019, [Daring]. Tersedia pada: https://jsal.ub.ac.id/index.php/jsal/article/view/323/314

[6] A. Pradifan, W. Widayat, dan A. Suprihanto, "Pemantauan Kualitas Udara Kota Tegal (Studi Kasus : Kecamatan Tegal Selatan, Kecamatan Tegal Barat, Kecamatan Tegal Timur)," J. Ilmu Lingkung., vol. 19, no. 1, hal. 73–82, 2021, doi: 10.14710/jil.19.1.73-82.

[7] KLHK, "Indeks Standar Pencemar Udara Kota Bogor," 2024. https://ispu.menlhk.go.id/webv4/#/peta/BOGOR/-6.572700023651123/106.79199981689453 (diakses 20 Januari 2024).

[8] U.S. Environmental Protection Agency, "Passive Samplers for Investigations of Air Quality: Method Description, Implementation, and Comparison to Alternative Sampling Methods," U.S. Environ. Prot. Agency Eng. Issue Pap., 2015.

[9] A. Indrawati, D. A. Tanti, N. Cholianawati, A. Sofyan, dan W. Ek. Cahyono, "Perbandingan Tingkat Kadar Gas SO2 dan NO2 di Udara Ambien Antara Metode Pasif dan Metode Aktif (Studi Kasus: Kota Jakarta)," J. Teknol. Lingkung., vol. 22, no. 1, hal. 111–120, 2021, doi: 10.29122/jtl.v22i1.4182.

[10] A. F. Widyani, "Aplikasi Model Gauss Termodifikasi Terhadap Dispersi Pencemaran Udara Dari Sumber Majemuk (Studi Kasus Industri Semen Di Kabupaten Bogor)," Skripsi, no. Institut Teknologi Sepuluh Nopember, 2018.

[11] E. Reezqiana Sihayuardhi, "Pemetaan Sebaran Kualitas Udara Ambien Kawasan Perkotaan Yogyakarta Dengan Parameter SO2, CO Dan NO2 Metode Inverse Distance Weighting (IDW)," Skripsi, no. Universitas Islam Indonesia, 2021.

[12] European Environment Agency (EEA), "Air quality in Europe - 2019 report," Copenhagen, 2019.

[13] I. . Husodo dan P. R. . Naibaho, "Optimalisasi kinerja lalu lintas sistem satu arah (Studi kasus jalan lingkar Kebun Raya Bogor)," J. Sains dan Teknol. Tek. Utama, vol. 2, hal. 107–124, 2020.

[14] A. P. Septiyani, N. A. Tara, E. Wiyono, dan R. S. Rizal, "Analisis Simpang Bersinyal Pada Jalan Raya Bogor – Jalan Tegar Beriman, Bogor," J. Ilm. Teknol. Infomasi Terap., vol. 9, no. 2, hal. 241–248, 2023, doi: 10.33197/jitter.vol9.iss2.2023.1025.

[15] S. Trigunantoro, "Identifikasi Permasalahan Kemacetan lalu Lintas Di Simpang Pomad Kota Bogor," Universitas Pakuan, 2008.

[16] S. T. Wibowo dan D. Susanto, "Hubungan antara volume kendaraan dan konsentrasi SO2 di pusat kota Jakarta," J. Tek. Lingkung., vol. 1, no. 19, hal. 103–112, 2018.

[17] M. A. Siregar, F. Rahman, dan M. Nasution, "Konsentrasi sulfur dioksida (SO2) dan dampaknya terhadap kesehatan di kawasan industri dan padat lalu lintas," J. Kesehat. Lingkung. Indones., vol. 2, no. 8, hal. 45–59, 2020.

[18] N. I. Yulian dan A. Turyanti, "Fluktuasi Konsentrasi SO2 di Wilayah Puncak (Bogor) dan Hubungannya dengan Kecepatan Angin Rata-rata serta Simpangannya," IPB Repos., 2022.

[19] D. Pratama, E. Nurhayati, dan I. Setiawan, "Pengaruh polusi udara terhadap kualitas hidup di daerah Bogor Utara dan Bogor Timur," J. Ilmu Lingkung., vol. 3, no. 16, hal. 211–223, 2021.

[20] D. Laksana, E. Prasetyo, dan M. Hadi, "Studi Kualitas Bahan Bakar Solar di Jawa Barat," J. Teknol. Energi, vol. 2, no. 8, hal. 115–125, 2014.

[21] Dai, Y., X. Zhang, dan X. Liu, "Effects of wind speed on air pollution concentrations in urban environments," J. Environ. Manage., hal. 59–67, 2018.

[22] J. Zhou, W., Li, L., & Li, "Impact of wind speed on the accumulation of air pollutants: A study of SO2 and NO2 levels in urban areas," Environ. Sci. Technol., vol. 4, no. 53, hal. 2180–2188, 2019.

[23] K. NAUVAL, "Analisis Pencemaran Udara Di Kota Banda Aceh Pada Tahun 2019-2022 Dengan Menggunakan Alat Passive Sampler," Fak. SAINS DAN Teknol. Univ. Islam NEGERI AR-RANIRY, 2023.

[24] [24] E. Korbafo, J. K. Mere, F. Kefi, dan Y. Telnoni, "Pemantauan Kualitas Udara (SO2 dan NO2) Dengan Metode Passive Sampler Di Kota Kupang," J. Saintek Lahan Kering, vol. 6, no. 1, hal. 24–25, 2023, doi: 10.32938/slk.v6i1.2191.