International Journal of Applied and Advanced Multidisciplinary Research (IJAAMR)
Vol.3, No.11, 2025: 865-872

Ambient Air Quality of Sulfur Dioxide (So_2) and its Implications for Public Health: A Study in the Densely Populated Retail Area of Manado City

Natalita Camelia Rarung[1]*, Oksfriani Jufri Sumampouw[2], Sri Seprianto Maddusa[3]
Universitas Sam Ratulangi
Corresponding Author: Natalita Camelia Rarung
natalitararung121@student.unsrat.ac.id

ARTICLEINFO

Keywords: Sulfur Dioxide (SO_2), Ambient Air, Air Quality, Urban Area, Environmental Health

Received : 5 September
Revised : 23 October
Accepted: 23 November

ABSTRACT

Air pollution, particularly from vehicular emissions of Sulfur Dioxide (SO_2), poses a significant threat to public health in urban areas. Although previous studies in Manado City have reported SO_2 concentrations below quality standards, long-term exposure to low levels remains a risk for vulnerable populations such as street vendors. The Jumbo Swalayan Area is a commercial hub with high traffic density, creating potential for pollutant accumulation. This study aimed to measure ambient SO_2 concentrations in this area and analyze their implications for public health and policy. This descriptive study was conducted in the Jumbo Swalayan Area of Manado City. Ambient air sampling was carried out at three points during morning, afternoon, and evening hours, yielding a total of 9 samples. SO_2 concentration measurement followed standard procedures. The obtained data were analyzed using univariate analysis to determine mean, standard deviation, minimum, and maximum values, and compared against national ambient air quality standards (Government Regulation No. 22 of 2021). The average SO_2 concentration in the Jumbo Swalayan Area was 14.1 µg/m³ (SD=8.7), ranging from 5-32 µg/m³. The highest concentration (32 µg/m³) was detected at the exit point during morning hours. All measured values remained well below the national standard of 350 µg/m³. These findings are consistent with previous studies in Manado reporting low SO_2 levels. Quantitatively, the ambient air quality based on SO_2 parameter in the Jumbo Swalayan Area is good and meets quality standards. However, concentration variations and the potential for long-term exposure to these low levels warrant vigilance, particularly in protecting the health of vendors as a vulnerable group. Preemptive measures such as traffic management, routine monitoring, and health promotion should be intensified to prevent future concentration increases

DOI: https://doi.org/10.59890/ijaamr.v3i11.140
ISSN-E: 3026-2437
https://journal.multitechpublisher.com/index.php/ijaamr

INTRODUCTION

Air pollution has become a major environmental problem in global urban areas. Air contamination by various harmful substances or particles from vehicle emissions, industry, and fossil fuel combustion threatens the health of humans, animals, and ecosystems (Candrasari, 2023). The health impacts include respiratory disorders, cardiovascular diseases, and even climate change (Sumampouw, 2020). The World Health Organization (WHO) reported in 2016 that more than 3 million deaths annually worldwide are caused by exposure to ambient air pollution. Sulfur dioxide (SO_2), a sharp-smelling gas primarily produced from the combustion of fossil fuels, is one of the critical air pollutants. Long-term exposure to SO_2, even at concentrations below standard limits, can have adverse health effects, especially for vulnerable populations who are continuously exposed (Pinontoan et al., 2020; Sumampouw & Nelwan, 2024). In addition to directly affecting health, SO_2 also contributes to global warming and climate change (Sumampouw, 2020). Manado City, as the provincial capital, faces air pollution challenges alongside the high growth of motor vehicles, reaching 429,267 units in 2023. Although Manado's Air Quality Index (AQI) is generally considered good (score of 25), the high vehicle activity has the potential to cause pollutant accumulation in certain areas. This is suspected to contribute to the high incidence of Acute Respiratory Infections (ARI), which reached 21,865 cases according to the Manado City Statistics Agency (2024). Data from the Manado City Health Office at Wenang Community Health Center from 2020-2024 also recorded ARI as the most common disease among outpatients, indicating potential exposure to air pollutants in this city.

LITERATURE RIVIEW

Several previous studies have examined air quality in various locations in Manado. The study by Ponga, Akili, and Sumampouw (2018) in Tuminting District reported SO_2 concentrations in the range of 14.59–34.31 µg/Nm³, which are still below the quality standards. A recent study by Tiwa, Sumampouw, and Ratag (2024) at Karombasan Bus Terminal also found ambient SO_2 levels between <20–33 µg/Nm³, which still meet the standards. However, research at Karombasan Terminal has identified that although concentrations are low, merchants who work around the terminal are at risk of SO_2 exposure. Similar findings were reported by Wenas, Pinontoan, and Sumampouw (2020) in the Manado Shopping Center area, where environmental health risk analysis indicated that 24% of street vendors have a long-term health risk (RQ value > 1) due to SO_2 exposure, even though the real-time concentrations do not exceed the threshold. These findings highlight that even at concentrations that meet quality standards, chronic exposure can still pose a health risk that cannot be ignored. Nevertheless, there are still research gaps, particularly those focusing on SO_2 exposure in economic activity centers with very high human and vehicle density, such as modern shopping areas. The Jumbo Swalayan area in Manado City is one of the economic centers with heavy vehicle traffic and a high level of public visits. This condition has the potential to cause the accumulation of air pollutants, including SO_2. Vendors who work daily in this area are a population group at

risk of long-term exposure to pollutants. The aim of this study is to measure the concentration of SO_2 in ambient air in the Jumbo Swalayan area of Manado City.

METHODOLOGY

This type of research is observational with a method using an environmental health risk analysis approach. The study was conducted in the Jumbo Swalayan area of Manado City, located on Suprapto Street, Pinaesaan sub-district, Wenang district, Manado City, North Sulawesi. This location is part of an area with dense economic, social, and transportation activities, making it one of the strategic points in the city center. The research location map can be seen in Figure 1.

Figure 1. Map of the Research Location in the Jumbo Supermarket Area

The research was conducted from May to August 2025. The research subject was the air in the Jumbo Supermarket area. Ambient air quality analysis of SO2 was carried out by a team from the BLKM Manado laboratory. The variable in this study was SO2 concentration. The procedures for sampling and measurement are as follows:

1. Preparation: The impinger was filled with a specific absorbing solution according to the standard operating procedure.
2. Sample Collection: The LVAS was installed at predetermined sampling points with an inlet height of 1.5-2 meters. Air samples were drawn at a certain flow rate (e.g., 1 L/min) for 60 minutes at each time interval.
3. Storage and Transportation: After sampling, the impinger was tightly sealed, labeled, and stored in a cool box before being taken to the laboratory for analysis within a maximum of 24 hours.
4. Laboratory Analysis: Samples were analyzed in the laboratory using the spectrophotometry method to determine the concentration of SO_2. The data collected are primary data in the form of SO_2 concentration measurements from the laboratory.
5. Data Analysis: Data analysis is conducted univariately. SO_2 concentration data from all points and measurement times are summarized and presented in the form of frequency distribution tables, as well as descriptive statistical

measures such as mean, standard deviation, minimum value, and maximum value.

6. Comparison with Quality Standards: The measured average SO_2 concentration is then compared with the national ambient air quality standards listed in the Government Regulation of the Republic of Indonesia No. 22 of 2021 concerning the Implementation of Environmental Protection and Management.

RESULT

This section describes the distribution of Sulfur Dioxide (SO_2) measurements in ambient air and meteorological factors. This is shown in Table 1.

Table 1. Measurement Results of SO_2 Air Levels and Meteorological Parameters

Sampling Point	Measurement Time	Air Temperature (°C)	Humidity (%)	Wind Speed (m/s)	SO_2 (µg/m³)
Titik 1 N: 1°29'51.9" E: 124°54'50.8"	Morning (09:00-10:00)	33,3	47,5	0,2	**5**
	Day (11:05-12:05)	37,1	46,5	0,3	**9**
	Evening (15:30-16:30)	33,1	58,1	0,3	**9**
Titik 2 N: 1°29'51.7" E: 124°50'28.1"	Morning (08.15-09.15)	33,8	49,5	0,5	**19**
	Day (11.45-12.45)	33,8	49,5	0,5	**12**
	Evening (15:05-16:05)	32,8	58,0	0,3	**16**
Titik 3 N: 1°29'53.3" E: 124°50'25.4"	Morning (08.40-09.40)	33,1	56,6	0,3	**32**
	Day (11.30-12.30)	38,2	46,8	0,5	**17**
	Evening (15:00-16:00)	32,8	60,5	0,4	**8**

1. SO_2 Concentration Frequency Distribution
   The results of this study indicate that most samples (66.6%) have SO_2 concentrations in the Low to Medium category (≤ 20 µg/m³). However, there are 2 samples (22.2%) that fall into the High category.
2. Descriptive Statistics of SO_2 Concentration
   The summary of descriptive statistics for all SO_2 measurement data shows that the average SO_2 concentration in the Jumbo Swalayan area is 14.1 µg/m³. The concentration values range from 5 µg/m³ (lowest) to 32 µg/m³ (highest) with a standard deviation of 8.7 µg/m³, indicating a considerable variation in concentration between measurement points and times.

3. Comparison with National Ambient Air Quality Standards
   Based on Appendix VI of the Government Regulation of the Republic of Indonesia No. 22 of 2021 concerning the Implementation of Environmental Protection and Management, the ambient air quality standard for the Sulfur Dioxide (SO_2) parameter for a 1-hour measurement period is 350 μg/m³. By comparing the measurement results with the standard, it can be concluded that all measured SO_2 concentration results, both individual values at each time point and the average value (14.1 μg/m³), are still far below the standard set by the government (350 μg/m³). The highest recorded concentration, 32 μg/m³ at Point 3 in the morning, only reaches 9.1% of the air quality standard value.

DISCUSSION

SO_2 Concentration Profile and Compliance with Quality Standards

The results of this study reveal that the average SO_2 concentration in the Jumbo Swalayan area of Manado City is 14.1 μg/m³, with a range between 5–32 μg/m³. The peak value of 32 μg/m³ was recorded at Point 3 (exit door) in the morning. When compared to national quality standards, which are 350 μg/m³ (Government Regulation No. 22 of 2021) and 150 μg/m³ (Ministry of Health Regulation RI No. 02 of 2023), all measurement results, including the highest value, are still far below the established limits. Therefore, quantitatively, the ambient air quality of the SO_2 parameter in this area can be considered good and safe.

These findings are consistent with patterns reported in various previous studies in the city of Manado. For example, research in the Tuminting District by Ponga et al. (2018) recorded an average SO_2 of 21.01 μg/Nm³, while a study at the Karombasan Terminal by Tiwa et al. (2024) found a concentration range of <20–33 μg/Nm³. The consistency of this data indicates that SO_2 pollution levels at various urban hotspots in Manado are still relatively low and manageable.

However, the significant variation in concentrations between points and measurement times in this study highlights the strong influence of local factors. Point 3, which is a narrow exit, showed the highest concentration. This is due to high vehicle activity in the morning, causing queues with engines running, thereby increasing exhaust emissions. Coupled with a low wind speed (0.3 m/s), pollutants tend to get trapped and accumulate at that location. In contrast, Points 1 and 2, which are more open with better air circulation, showed lower concentrations. This phenomenon aligns with research in China that found urban management, including traffic flow regulation, can significantly affect SO_2 emissions (Zhang et al., 2025).

Health Implications: Beyond Legal Limits Towards Chronic Risk

Although all measured SO_2 concentrations were within regulatory safe limits, this finding does not necessarily negate the potential health risks. Global health agencies have long warned that there is no level of air pollution exposure that is completely safe. A multicountry study by O'Brien et al. (2023) analyzing data from 399 cities found that short-term exposure to SO_2 at an average

concentration of 11.7 µg/m³ (lower than the average in this study) still contributed to increased mortality. These findings reinforce the argument that chronic exposure, even at low levels, remains a serious concern.

The most vulnerable group in this context is the traders who spend more than 8 hours a day in the Jumbo Supermarket area. SO_2 gas is highly irritating and can react with water vapor to form sulfurous acid, which damages the mucous membranes of the respiratory tract (Ma'rufi, 2017). Repeated and long-term exposure can increase respiratory tract sensitivity, triggering symptoms such as irritation, dry cough, and mild shortness of breath. This is supported by research by Wenas et al. (2020) in the Manado Shopping Center area, which found that although the real-time SO_2 concentration is still below the quality standard, the long-term (lifetime) risk analysis revealed that 24% of traders had a Risk Quotient (RQ) > 1, indicating an unacceptable health risk.

More concerningly, recent evidence is beginning to link long-term exposure to low levels of SO_2 with more systemic health effects. Yuan et al. (2025) reported that exposure to low concentrations of SO_2 (<8 µg/m³) is associated with an increased risk of mental disorders, including depression and anxiety, in urban adult and elderly populations. These findings broaden the perspective on the health impacts of SO_2 beyond respiratory disorders.

Environmental Impacts and Policy Recommendations

In addition to health effects, SO_2 also plays a role in the formation of smog, which reduces visibility and can potentially cause acid rain. Acid rain can damage plants in open green areas around the region and disrupt the balance of aquatic ecosystems (Kunak Air, 2025). Therefore, maintaining SO_2 concentrations as low as possible is not only a public health goal but also an environmental protection measure.

Based on research findings and literature reviews, comprehensive prevention and control efforts are absolutely necessary: a. Control of Emission Sources: Encourage regular maintenance of motor vehicles and periodic emission testing, as well as optimize traffic flow management to minimize congestion at critical points such as entry/exit gates. b. Individual Protection: Health education and promotion about the importance of wearing masks for vendors and outdoor workers to reduce direct exposure. c. Continuous Monitoring: The implementation of a routine and real-time air quality monitoring system, as recommended by Marini et al. (2021), is crucial to early detect any rising pollution trends and evaluate the effectiveness of control policies..

CONCLUSION

Overall, the ambient air quality based on SO_2 parameters in the Jumbo Swalayan area of Manado City is still in good condition and meets all applicable national quality standards. However, the presence of points with higher concentrations and the potential for long-term exposure to low concentrations require caution. A precautionary principle approach should be implemented, focusing on protecting vulnerable groups and enforcing sustainable pollution control policies to ensure public health and environmental preservation in this continuously developing urban area.

ACKNOWLEDGEMENT

The author would like to thank Jumbo Supermarket in Manado City for granting permission to conduct this research, as well as the respondents who participated voluntarily, allowing this study to be completed. Gratitude is also extended to the Faculty of Public Health at Sam Ratulangi University Manado for their support in carrying out this research.

REFERENCES

Cahyono, R. T., & Sunarsih, E. (2024). Environmental Health Risk Analysis of Sulfur Dioxide (SO2) Exposure in Ambient Air on Lung Function of Officers and Communities Around Public Fuel Filling Stations (SPBU). Indonesian Journal of Global Health Research, 6(S6), 293-300. https://doi.org/10.37287/ijghr.v6iS6.4868

Candrasari, P. (2023). Dampak pencemaran udara terhadap kesehatan dan lingkungan. Deepublish.

European Environment Agency. (2025). Air quality status report 2025. https://www.eea.europa.eu/en/analysis/publications/air-quality-status-report-2025

Kan, H., Wong, C. M., Vichit-Vadakan, N., Qian, Z., & PAPA Project Teams (2010). Short-term association between sulfur dioxide and daily mortality: the Public Health and Air Pollution in Asia (PAPA) study. Environmental research, 110(3), 258–264. https://doi.org/10.1016/j.envres.2010.01.006

Kunak Air. (2025). Sulphur dioxide: Key to air quality and environmental health. https://kunakair.com/sulphur-dioxide/

Marini, A., Mariani, P., Garinei, A., Proietti, S., Sdringola, P., Proietti, M., ... & Marconi, M. (2021). Design of an Urban Monitoring System for Air Quality in Smart Cities. In Smartgreens (pp. 94-101).

Musfirah, M., Rangkuti, A. F., Primasari, I. A., Nurullita, I., Santri, B. J., & Lana, A. T. U. (2024). ENVIRONMENTAL HEALTH RISK ANALYSIS OF SULFUR DIOXIDE (SO. Journal of Environmental Health, 16(1).

O'Brien, E., Masselot, P., Sera, F., Roye, D., Breitner, S., Ng, C. F. S., de Sousa Zanotti Stagliorio Coelho, M., Madureira, J., Tobias, A., Vicedo-Cabrera, A. M., Bell, M. L., Lavigne, E., Kan, H., Gasparrini, A., & MCC Collaborative Research Network (2023). Short-Term Association between Sulfur Dioxide and Mortality: A Multicountry Analysis in 399 Cities. Environmental health perspectives, 131(3), 37002. https://doi.org/10.1289/EHP11112

Pinontoan, O. R., Sumampouw, O. J., & Nelwan, J. E. (2020). Epidemiologi kesehatan lingkungan. Deepublish.

Ponga, F. C., Akili, R. H., & Sumampouw, O. J. (2018). Gambaran kualitas udara ambien sulfur dioksida di Kecamatan Tuminting Kota Manado Tahun 2018. KESMAS: Jurnal Kesehatan Masyarakat Universitas Sam Ratulangi, 7(4).

Sumampouw, O. J. (2020). Perubahan iklim dan kesehatan masyarakat. Deepublish.

Sumampouw, O. J., & Nelwan, J. E. (2024). Dasar kesehatan lingkungan konsep dasar dan pencemaran lingkungan. Deepublish.

Tiwa, S. M., Sumampouw, O. J., & Ratag, B. T. (2024). Kualitas udara ambien sulfur dioksida (SO2) Terminal Bus di Kota Manado: Studi ekologi. Sam Ratulangi Journal of Public Health, 5(2), 8-15. https://doi.org/10.35801/srjoph.v5i2.57142

U.S. Environmental Protection Agency. (2022). Integrated Risk Information System (IRIS).

Wenas, R. A., Pinontoan, O. R., & Sumampouw, O. J. (2020). Analisis risiko kesehatan lingkungan pajanan sulfur dioksida (SO2) dan nitrogen dioksida (NO2) di sekitar kawasan Shopping Center Manado tahun 2020. Indonesian Journal of Public Health and Community Medicine, 1(2), 053-058. https://doi.org/10.35801/ijphcm.1.2.2020.29431

World Health Organization (WHO), 2016. Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease [Internet]. WHO Available from: https://www.who.int/phe/publications/airpollution-global-assessment/en/

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

Yuan, S., Bao, Y., Li, Y., Ran, Q., Zhou, Y., Xu, Y., Zhang, X., Han, L., Zhao, S., Zhang, Y., Deng, X., & Ran, J. (2025). Long-term exposure to low-concentration sulfur dioxide and mental disorders in middle-aged and older urban adults. Environmental pollution (Barking, Essex : 1987), 366, 125402. https://doi.org/10.1016/j.envpol.2024.125402

Zhang, Z., Hua, C., Chen, X. L., & Song, M. (2025). The spatial impact of population semi-urbanization on sulfur dioxide emissions: Empirical evidence from China. Journal of Environmental Management, 375, 124257.