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Ambient Air Quality (No_2) in Traditional Markets: Compliance With National Quality Standards Versus Health Risks Based on World Health Organization Guidelines

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A B S T R A C T

Ambient air quality, particularly the Nitrogen Dioxide (NO_2) parameter, is a crucial determinant of environmental health, especially in areas with high activity, such as traditional markets. Bersehati Market in Manado City, which is located in the city center and close to busy traffic routes, has a high potential for pollutant accumulation from motor vehicle emissions. Chronic exposure to NO_2, even at low concentrations, has been linked to respiratory and cardiovascular disorders. This study aims to measure ambient air quality based on the NO_2 parameter and analyze its potential health risk for vendors at Bersehati Market. This study used a descriptive observational design. Air sampling was conducted purposively at three points (front, middle, and rear parking areas) representing variations in vehicle activity. Measurements of NO_2 concentration and meteorological parameters (temperature, humidity, wind speed) were carried out three times a day (morning, noon, evening) for 1 hour per session, referring to the Indonesian Ministry of Health Regulation No. 2 of 2023. The collected data were analyzed descriptively by comparing the measurement results with national quality standards and WHO guidelines, and their correlation with meteorological conditions was examined. NO_2 concentrations at Bersehati Market ranged from 4–31 µg/m³ with an average of 27.33 µg/m³. All of these values are still below the national Threshold Limit Value (TLV) (200 µg/m³). However, the average concentration has already exceeded more than twice the WHO annual limit (10 µg/m³). Variations in concentration are significantly influenced by wind speed, with the highest level (31 µg/m³) recorded at the front parking area in the afternoon when wind speed was very low (0.3 m/s), indicating a pollutant stagnation phenomenon. Legally, the ambient air quality at Bersehati Market based on NO_2 parameters is considered safe as it meets the national quality standards. However, from a public health perspective, long-term exposure to NO_2 concentrations exceeding WHO guidelines, experienced by vendors with an average working duration of 13.9 years, has the potential to pose chronic health risks. Mitigation measures are needed, such as optimizing air circulation in vulnerable areas, promoting the use of masks, and conducting regular monitoring to protect the health of this vulnerable group

INTRODUCTION

Environmental health is a fundamental determinant in efforts to improve public health, with air quality being one of the critical aspects that directly affects human health (World Health Organization/ WHO, 2021). Areas with high human activity and motor vehicle traffic, such as traditional markets, are highly vulnerable to the accumulation of air pollutants. Air pollution, defined as the presence of physical, biological, or chemical substances in the atmosphere in amounts that are harmful to health, largely originates from motor vehicle emissions. This poses a real threat, especially in urban areas with high traffic density and limited natural ventilation. One of the main air pollutants of concern is Nitrogen Dioxide (NO_2). NO_2 is a reddish-brown reactive gas primarily produced from the combustion of fossil fuels in motor vehicles and industrial activities (WHO, 2021). Chronic exposure Chronic exposure to NO_2 has been linked to adverse effects on the respiratory, cardiovascular, and nervous systems. Traditional markets, as the economic centers of communities, often face air quality challenges due to a combination of dense human activities, suboptimal ventilation, and their proximity to traffic hubs. Vendors working in these environments are at risk of long-term exposure to air pollutants because they typically work 8 to 12 hours per day without adequate protection. This group of informal workers has higher health vulnerabilities compared to market visitors who are only exposed occasionally.

Previous research in various traditional markets in Indonesia has confirmed the link between air pollution and respiratory health problems among vendors. A study at Sambu Market, Medan, found that Carbon Monoxide (CO) and NO_2 concentrations exceeded safe limits and were correlated with significant respiratory complaints among street vendors (Girsang & Lumbangaol, 2021). Similar findings were reported by Sari (2014) at Sangkumpal Bonang Market, Padangsidimpuan, where high CO and NO_2 levels were correlated with increased respiratory issues. At Prawirotaman Market, Afrizal's (2024) research revealed that NO_2 levels in the market's basement area had exceeded recommended standards. Likewise, a study at 26 Ilir Market, Palembang, showed that NO_2 concentrations surpassed safe limits, thereby increasing the risk of respiratory illnesses among street vendors (Mulyawati & Sunarsih, 2019). The latest research at Sumberrejo Market also identified High concentrations of NO_2 also contribute to the overall decline in air quality (Prastian & Anggara, 2025). Specifically in Manado City, research on NO_2 exposure is still very limited. A study by Farikah et al. (2018) that measured NO_2 in the basement parking area of a shopping center showed levels ranging from 21.10-134.04 $\mu g/Nm^3$. Meanwhile, research by Tampa et al. (2019) on several main streets in Manado, including the Karombasan Market area, reported an average NO_2 concentration of 1.0529 $\mu g/Nm^3$. Although these figures are still below the Threshold Value (NAB) of 400 $\mu g/Nm^3$, the measurements were not conducted directly within the busy environment of a traditional market.

LITERATURE RIVIEW

Bersehati Market, as one of the largest and busiest markets in North Sulawesi, is located in the heart of the city and close to terminals and busy traffic routes. This location makes it highly susceptible to air pollution, especially from vehicle emissions. Data from Wenang Community Health Center, whose working area covers Bersehati Market, records that Acute Respiratory Infections (ARI) are the most common illness. In 2024 alone, there were 2,781 cases of ARI, and the disease consistently ranked first among the top 10 illnesses over the past five years (2020-2024). Initial interviews at the site also revealed that some traders who have been selling for 10-20 years experience respiratory problems such as ARI and asthma.

Based on the description above, this research becomes highly relevant and urgent to conduct. This article aims to measure ambient air quality based on NO_2 parameters at Bersehati Market in Manado City. By identifying the level of exposure to this main pollutant among high-risk groups, namely market traders, the results of this study are expected to provide a scientific basis for the formulation of policies and targeted environmental health interventions to protect public health, particularly informal workers in the traditional market sector.

METHODOLOGY

This research is a descriptive observational study designed to assess ambient air quality and the potential health risks from Nitrogen Dioxide (NO_2) exposure among vendors at Bersehati Market in Manado City. Air sampling was conducted purposively at three representative points, covering the front parking area (as a vehicle drop-off zone with engines running), the middle parking area (internal traffic congestion zone), and the back parking area (dense vehicle route), with repeated measurements taken at three different times of the day (morning, afternoon, and evening) to capture temporal variations. Each measurement session lasted for 1 hour, referring to the standards of the Regulation of the Minister of Health of the Republic of Indonesia No. 2 of 2023, where NO_2 concentrations were measured using nationally standardized methods (presumably with passive samplers or electrochemical devices following the Griess-Saltzman method), while supporting meteorological parameters such as air temperature, humidity, and most importantly, wind speed were also recorded Wind, measured simultaneously using a thermohygrometer and an anemometer, was analyzed for its correlation with pollutant dispersion. The collected data were analyzed quantitatively in a descriptive manner by comparing the average NO_2 concentrations obtained with national standards and the stricter WHO guidelines, and were examined qualitatively to understand the spatio-temporal distribution patterns and their relationship with meteorological conditions.

RESULT

The results of ambient air measurements based on NO2, SO2, and meteorological parameters at the car exit gate of the Mega Mas area can be seen in Table 1.

Table 1. Results of NO2 Air Level Measurements and Meteorological Parameters

Sample Point	Measurement Time	Air Temperature (°C)	Humidity (%)	Wind Speed (m/s)	NO_2 ($\mu g/m^3$)
Point 1 N: 1°29'51.9" E: 124°54'50.8"	Morning (09:00-10:00)	35.0	46.8	0.9	**17**
	Day (11:05-12:05)	35.5	47.2	0.7	**18**
	Evening (15:30-16:30)	32.2	58.7	0,3	**31**
Point 2 N: 1°29'51.7" E: 124°50'28.1"	Morning (08.15-09.15)	31.0	54.1	0.4	**26**
	Day (11.45-12.45)	33.6	51.8	1.6	**11**
	Evening (15:05-16:05)	34.7	54.6	0,6	**10**
Point 3 N: 1°29'53.3" E: 124°50'25.4"	Morning (08.40-09.40)	37.4	43,0	1.2	**12**
	Day (11.30-12.30)	34.6	49.5	2.9	**13**
	Evening (15:00-16:00)	33.0	54.3	3.0	**4**

Based on data obtained from three sampling points at Bersehati Market, an analysis can be conducted on the levels of Nitrogen Dioxide (NO_2) pollution as well as the influence of meteorological conditions on the distribution of pollutants.

Spatial Analysis (Based on Sampling Points)

Overall, NO_2 concentrations at all points and measurement times are still well below the Threshold Value (NAB) set in Government Regulation No. 22 of 2021 concerning the Implementation of Environmental Protection and Management, which is 225 $\mu g/m^3$ (1-hour average). Nevertheless, the distribution pattern shows interesting variations related to the characteristics of each location.

a. Point 1 (Front Market Parking): This point records the highest absolute NO_2 concentration, which is 31 $\mu g/m^3$ in the afternoon. This is consistent with the location description as a drop-off and parking area with engines running. Vehicle activity entering and exiting, combined with engines often still running while waiting, is the primary source of emissions at this point. Exposure for vendors around this point needs more attention, considering the relatively higher NO_2 levels.

b. Point 2 (Middle Market Parking) and Point 3 (Back Market Parking): These two points show lower NO_2 concentrations. The highest value at Point 2 is 26 μg/m³ (in the morning), while at Point 3 it is only 13 μg/m³ (at midday). This difference is most likely influenced by meteorological factors, particularly wind speed, which will be discussed further. Although suspected as congestion points, pollutant dispersion in the more open areas (middle and back) seems to be more open areas (middle and rear) seem to be diluted more quickly. 2. Temporal Analysis (Based on Measurement Time) The temporal pattern of NO_2 concentration at each point shows different dynamics, which are strongly influenced by the combination of vehicle activity patterns and weather conditions. a. Point 1: NO_2 concentration increases from morning (17 μg/m³) to noon (18 μg/m³) and peaks in the afternoon (31 μg/m³). This pattern can be explained by the accumulation of pollutants throughout the day. In the afternoon, very low wind speed (0.3 m/s) causes pollution stagnation, where vehicle emissions accumulate at the location due to minimal dispersion.
c. Point 2: The pattern observed is actually the opposite. The highest concentration occurs in the morning (26 μg/m³) and drops sharply in the afternoon (11 μg/m³) and evening (10 μg/m³). This decrease is closely related to a significant increase in wind speed, from 0.4 m/s (morning) to 1.6 m/s (afternoon) and 0.6 m/s (evening). Stronger winds play an effective role in dispersing NO_2 concentrations, so pollutant levels decrease even though vehicle activity might still be high.
d. Point 3: This point shows a pattern similar to Point 2, where NO_2 concentrations are lowest in the evening (4 μg/m³). This again demonstrates the dominant influence of wind speed. In the evening, wind speed reaches 3.0 m/s, the highest value recorded, making the pollutant dispersion process very effective.

Analysis of the Influence of Meteorological Parameters

Meteorological parameters, especially wind speed, have proven to be key factors controlling NO_2 concentrations at Bersehati Market. Wind Speed: There is a clear negative correlation between wind speed and NO_2 concentration. Under calm wind conditions (< 1 m/s) such as at Point 1 in the afternoon, pollutants tend to accumulate. Conversely, under strong wind conditions (> 2 m/s) such as at Point 3 in the late morning and afternoon, pollutants disperse rapidly, resulting in very low concentrations. Temperature and humidity within the measured range did not show a consistent or direct influence on NO_2 levels.

DISCUSSION

This study revealed that the ambient air quality at Bersehati Market in Manado City, based on Nitrogen Dioxide (NO_2) parameters, is legally still within safe limits. Measured NO_2 concentrations ranged from 4–31 μg/m³ with an average of 27.33 μg/m³, which is still well below the Threshold Limit Value (TLV) according to the Regulation of the Minister of Health of the Republic of Indonesia No. 2 of 2023, which is 200 μg/m³ (1-hour average), and also below the annual quality standard in Government Regulation No. 22 of 2021, which is 40 μg/m³.

The finding of relatively low NO_2 concentrations is consistent with several previous studies in Manado City. For example, a study in the basement parking area of Jumbo Supermarket reported NO_2 levels ranging from 21.10–134.04 µg/m³ (Farikah et al., 2018), as well as research on several main roads in Manado City that recorded an average NO_2 level of 1.0529 µg/m³ (Tampa et al., 2019, in background). However, an interesting pattern emerges when compared to studies in other commercial areas in Manado. Wenas et al. (2020) found higher NO_2 concentrations, ranging from 130.69–205.10 µg/m³ around Manado Shopping Center, with 56% of traders having a lifetime Risk Quotient (RQ) considered at risk (RQ > 1) from NO_2 exposure. This difference indicates variations in the level of air pollution vulnerability across commercial locations in the same city, which are strongly influenced by topography, building design, and traffic patterns.

Nationally, the average finding of 27.33 µg/m³ at Bersehati Market is within a lower range compared to other densely populated areas. Syahriyah's study (2024) at Mandala Terminal, Rangkasbitung found an average NO_2 of 44.0551 µg/m³, while Utami et al. (2020) reported NO_2 concentrations in Jakarta ranging from 23–60 µg/m³. In fact, research at Mardika Terminal Ambon showed NO_2 levels consistently below 5.22 µg/m³ (Rumselly et al., 2024), which is lower than the findings in Manado. These differences strengthen the evidence that local characteristics, including vehicle volume and meteorological conditions, greatly determine air pollution levels. Despite the concentrations still meeting national standards, these findings should be interpreted cautiously in the context of public health. The WHO Air Quality Guidelines (2021) set a much stricter annual NO_2 limit of 10 µg/m³. With an average concentration of 27.33 µg/m³ at Bersehati Market, it can It is concluded that the NO_2 levels at the research site have exceeded more than twice the recommended WHO limits. The implications are very significant considering the exposure characteristics of the trader population. Research data show that the duration of traders' exposure ranges from 1–22 years with an average of 13.9 years. Chronic exposure at this level, even though below the national ambient air quality standard, still has the potential to cause serious health impacts. The health impact mechanisms of NO_2 have been well documented. As an irritant gas, NO_2 can cause inflammation in the respiratory tract, trigger acute symptoms such as coughing and shortness of breath, and play a role in asthma exacerbation (Resti Putri, 2018). Long-term exposure is associated with reduced lung function, chronic bronchitis, and increased risk of cardiovascular disease through mechanisms of oxidative stress and systemic inflammation (Syaiful & Sembiring, 2024). Market traders' vulnerability is further heightened as they are also exposed to a mixture of other pollutants (*cocktail effect*) originating from emissions of the same vehicles, such as PM2.5 and CO, whose synergistic effects can worsen health impacts (Sumampouw & Nelwan, 2024).

Findings on concentration variations based on time and location provide valuable insights for interventions. The highest concentration (31 $\mu g/m^3$) was recorded at Point 1 (front parking area) in the afternoon, combined with very low wind speed (0.3 m/s). This confirms the phenomenon of pollutant stagnation in enclosed or semi-enclosed areas with high vehicle activity, as also observed in a market basement by Afrizal (2024). Conversely, the lowest concentration (4 $\mu g/m^3$) at Point 3 in the afternoon correlated with the highest wind speed (3.0 m/s), demonstrating the crucial role of atmospheric dispersion in controlling local air pollution levels (Pinontoan et al., 2020).

Based on this discussion, it can be concluded that although, from the perspective of national regulations, the air at Pasar Bersehati is declared safe, from a public health and vulnerable group protection standpoint, this condition requires caution. Traders exposed to NO_2 concentrations above the WHO threshold for years are at high risk of developing respiratory and cardiovascular health problems in the future. The high incidence of ARI cases at Wenang Health Center, which covers the Pasar Bersehati area, provides an indirect indication of this health burden. Therefore, the precautionary principle needs to be applied by recommending mitigation and protection measures, whether through market environmental management policies, traffic engineering, or increasing awareness and use of personal protective equipment among traders.

1. Although all measurement results are still below the quality standards, these findings do not automatically rule out health risks for vendors. Several points need to be considered:
2. Chronic Exposure: Vendors are continuously exposed to these low concentrations for 8-12 hours each day, over many years. Chronic NO_2 exposure at levels below the quality standards is still associated with respiratory tract irritation, reduced lung function, and exacerbation in asthma patients (WHO, 2021). 2. Other Pollutants: NO_2 is just one of many pollutants present. Vendors are highly likely to be exposed to a mixture of other pollutants such as PM2.5, PM10, CO, and Volatile Organic Compounds (VOCs) originating from the same vehicles. The synergistic effects (cocktail effect) of these various pollutants can worsen health impacts.
3. Local Health Data: The high number of ARI cases, which is the most common illness at Wenang Health Center (covering Bersehati Market), strongly indicates that environmental conditions, including air quality, plays a role in the community's disease burden, including market vendors.

CONCLUSION AND RECCOMENDATION

Based on the research results, the concentration of Nitrogen Dioxide (NO2) from three research points measured in the morning, afternoon, and evening has an overall average value of 27.33 µg/m³, which is still below the quality standard as referred to in (Government Regulation No. 22 of 2021) that sets the annual NO_2 limit at 40 µg/m³. Wind speed is the main determining factor in NO_2 concentration variation, where weak winds cause pollutant accumulation, while strong winds promote dispersion. Health risks for traders still exist due to long-term and chronic exposure to air pollution, including NO_2, which is worsened by potential exposure to a mix of other pollutants. Therefore, mitigation efforts and health protection for this vulnerable group remain highly necessary. Therefore, the implementation of an integrated approach involving all stakeholders (government, market managers, traders, and the community) is key to creating a Harmonious Market that is not only economically vibrant but also environmentally healthy for its workers. Although NO_2 levels are still below the threshold, proactive preventive measures and efforts to improve air quality will be highly meaningful in protecting the health of traders from chronic exposure to air pollution.

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