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Analysis of Nitrogen Dioxide as an Air Pollutant in Office, Industrial, Residential, and Transportation Areas in Lampung Province

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ABSTRACT

Monitoring air quality can be undertaken in industrial areas, residential areas, offices, and transportation hubs to maintain public health and sustainable environmental practices in Lampung Province. The province suffers unique challenges, including a mix of emission sources (industrial activities, vehicular traffic, and domestic operations). Industrial zones have high levels of nitrogen dioxide (NO_2) due to manufacturing, transportation hubs have increased NO_2 due to vehicle emissions, and residential regions provide background pollution from household pollutants. Such complex spires must be addressed to achieve acceptable levels of air quality. This research aimed to analyze NO_2 concentrations on four stations in 15 districts of Lampung Province using the Air Pollution Index Values (ISP - Indeks Standar Pencemaran Udara). To assess the coupling relationship between the NO_2 concentrations and seasonal variations over 2 years, Statistical Analysis of Variance (ANOVA) was analyzed. The results showed that NO_2 levels had higher concentrations along transportation routes but were still safe and non-hazardous according to Regulation No. 41 of 1999. The average NO_2 concentrations in the districts were also below the regulatory threshold, reflecting good air quality management in the region. The ANOVA analysis results with the Anderson-Darling test show p-values of 0.322 (rainy season) and 0.258 (dry season), both above the 0.05 significance level. These results imply that the data follows a normal distribution and that there are no significant differences between the districts' average NO_2 concentrations by season. The study highlights the necessity of continued surveillance and targeted interventions to address air quality issues in Lampung Province.

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INTRODUCTION

Air is a mixture of gases whose proportions vary with the temperature, pressure, and environment. When it perverts from its normal composition and disrupts life for humans, animals, and plants, it is considered polluted [1]. Air pollution is a chronic problem exacerbated by population growth and the proliferation of industries and transport sectors. However, these advancements, which stimulated the economy, came at the cost of increased emissions and aggravated air pollution [2], [3]. Air pollution is contamination by harmful substances, including gases, solid particles, and liquid droplets, called pollutants [4].

Carbon monoxide, nitrogen dioxide, hydrocarbons, sulfur oxides, and particulate matter are the five groups of pollutants, among which particulate matter (dust) and nitrogen dioxide have been shown to have the highest level of toxicity [6], [7]. Nitrogen dioxide (NO_2) is a strong oxidizing, reactive gas, rendering it highly toxic when inhaled. It readily interacts with moisture and other compounds in the respiratory tract to form nitric acid and other harmful byproducts, irritating and damaging lung tissue [5]. It combines that attribute with the tendency for PM_{10} to plow deep into the lungs, which makes it a contributing factor to respiratory diseases in vulnerable people. Nitrogen dioxide (NO_2) is mainly released through different channels, particularly the transport sector, providing 69% of urban areas NO_2 pollutants, followed by industry and households [8], [9]. For example, high concentrations of NO_2 with an ISPU value greater than 100 can have detrimental effects such as coughing, acid rain, diminished visibility, and respiratory diseases. Long-term exposure to NO_2 poses the greatest threat in urban settings where pollution tends to be much higher. It can aggravate asthma, bronchitis, and chronic obstructive pulmonary disease (COPD). In addition, vulnerable populations, including children and the elderly, are at higher risk, as they possess less robust respiratory systems or pre-existing health conditions that render them particularly susceptible to the deleterious effects of NO_2 exposure. In addition, the public needs to be informed about what is considered a safe concentration of nitrogen dioxide (NO_2) in the ambient air for health [10], [11].

Nitrogen dioxide (NO_2) is one of the major air pollutants and a noxious compound with adverse respiratory effects primarily for those living near industrial or busy urbanized areas. In addition to fueling respiratory diseases such as asthma, NO_2 compounds can make people more vulnerable to infections, especially in high-risk populations like the young and old, as they are byproducts of heating emissions [12]. Many high pollution areas recording higher than average levels of NO_2 also exceed safety limits, thus highlighting the need for constant monitoring and action to safeguard against these health risks [13].

The combined effect of NO_2 on environmental and public health is particularly significant in densely populated urban areas. Well established associations exist regarding NO_2 exposure and respiratory illnesses, including asthma and chronic obstructive pulmonary disease (COPD), as well as cardiovascular disorders. Air pollution is particularly threatening in urban areas in Southeast Asia because of rapid urbanization, increased industrial activity, and seasonal haze due to forest pests and fires. NO_2 is often a pollutant that increases during the dry season, pointing to the important need for implementing air quality management policies in these populated areas to ensure public health is not threatened [14].

Chronic NO_2 exposure is a major contributor to the disease burden in impacted areas, measured in Disability-Adjusted Life Years (DALYs). Long-term exposure has been linked to airway inflammation, decreased lung function, and a higher risk of respiratory and cardiovascular diseases. More vulnerable populations, including people with pre-existing respiratory diseases, are at greater risk, with more frequent and severe asthma symptoms and complications. Long-term exposure to NO_2, in particular, is associated with an increased risk of premature death, and the alarming need for implementing an emission reduction program can hardly be overstressed to minimize both human health effects and environmental burdens [15].

Lampung Province is a key hub for land transportation and logistics between Java and Sumatra. Critical infrastructure such as Panjang Port, which facilitates import-export activities, and Srengsem Port, which manages coal distribution, underscores its economic importance [16]. This pivotal role necessitates comprehensive studies to establish baseline nitrogen dioxide (NO_2) data, providing essential insights for local air quality management policies. Monitoring air quality in high-traffic zones, including industrial areas, offices, residential neighborhoods, and transportation routes, is vital to raising public awareness, protecting public health, and ensuring environmental sustainability. The findings from such monitoring can also inform targeted health interventions and awareness campaigns aimed at mitigating NO_2 exposure, particularly for vulnerable populations [17].

Research has highlighted the long-term implications of NO_2 exposure on environmental and human health. For instance, long-term studies have demonstrated that despite introducing emission controls, such as particulate filters in vehicles, significant NO_2 levels persist in urban areas. These levels are directly correlated with adverse health outcomes, such as increased mortality rates and respiratory diseases. This underscores the critical role of NO_2 as a key indicator of air quality and the necessity for stringent emission controls, particularly in urban environments with high traffic density. In Indonesia, the focus on specific regional contexts, such as Lampung Province, highlights the importance of continuous monitoring and applying the Air Pollution Standard Index (ISPU) to evaluate and manage pollution in diverse zones, including rapidly developing areas [18].

Air pollution, primarily driven by urbanization and industrialization, consists of various harmful pollutants, including nitrogen dioxide (NO_2) and particulate matter, among the most hazardous to human health. NO_2 emissions, predominantly from transportation, contribute significantly to urban pollution levels. Approximately 69% of urban NO_2 emissions are attributed to vehicle exhaust, which can lead to respiratory issues and environmental problems like acid rain. Given Lampung's critical logistical role in connecting Java and Sumatra, systematic air quality monitoring is essential for ensuring public health and advancing sustainability efforts. These initiatives can also provide actionable data to guide policies and interventions for reducing pollution levels and mitigating associated risks [12].

According to prior research, NO_2 concentrations in urban environments remain a persistent challenge despite implementing emission control measures. Over three decades of longitudinal monitoring in Vienna showed little change in NO_2 levels despite introducing particulate filters to diesel cars. Indeed, as a major public health risk, a NO_2 concentration increase of 10 μg/m³ was correlated with a 0.52% increase in total mortality, according to this study. These results which measured emissions at various stations highlighted the critical role of strict emissions control in reducing health burdens, especially during high pollution periods like winter [18].

Hence, in a bid to implement sustainable air quality management, multiple measures have been discussed. An example is the production of hydroxyapatite in bioceramics from renewable resources, such as eggshell waste generated from an egg industry, and $PM_{2.5}$ variations in Jakarta shed light on how meteorological conditions shape pollution patterns. These results guide efforts to tackle pollution at the regional level. It can be used for bigger and more diverse use cases of spoiling industrial liquids, as we found extract and salts from industry waste using IONS. This NTA research will benefit from using NO_2 monitoring to target pollution in a wider range from urban communities to industrial sites to transportation hubs when applied to an area in Lampung Province. Some studies, such as water quality at historic sites, enter the realm of environmental studies and, therefore, contribute to conservation and sustainability [19-23].

Considering the importance of air quality monitoring, this study aims to identify the NO_2 level in four zones, including industrial, office, residential, and transportation, in 15 regencies in Lampung Province. The study employs Analysis of Variance (ANOVA) to assess seasonal fluctuations and geographical variation in NO_2 levels across two years (2017–2019). This study aims to improve air quality management, support local policy development, and advance the region's public health and environmental sustainability by extending monitoring outside urban centers [17].

This study intends to assess NO_2 levels in four zones, industrial, office, residential, and transportation, in 15 regencies of Lampung Province. It will use an analysis of variance (ANOVA) model for multidimensional variance analysis of NO_2 variation and seasonal variations within two years. The study seeks to facilitate air quality management and protect human health and the environment by extending air quality monitoring beyond urban areas.

METHODS

1. Materials

The study utilized various materials, including sulfanilic acid crystals (≥99% purity, Sigma-Aldrich), 1% (v/v) glacial acetic acid (Merck), mineral-free distilled water, 0.1% (w/v) sodium nitrite (Sigma-Aldrich), and 0.1% (w/v) N-(1-naphthyl)ethylenediamine dihydrochloride stock solution (Sigma-Aldrich). Acetone (≥99% purity, Merck) was used for cleaning, while the Griess-Saltzman absorbent solution was prepared following standard protocols. Additionally, a 1,000 ppm nitrite stock solution was prepared using analytical-grade reagents to ensure precision.

2. Equipment

The following instruments were used in this study for collecting background NO_2: standard NO_2 sample collectors together with standard instruments for the volumetric measurement of microparticulate samples (volumetric flasks, microbursts, and graduated cylinders and beakers (Pyrex)) used for the preparation and measurement of the solutions. Absorbance measurements were performed using a Shimadzu UV-1800 UV spectrophotometer, calibrated before each measurement by verifying its wavelength accuracy. Weightings were performed with a high-precision analytical balance (Sartorius ENTRIS64-1S) with an accuracy of ±0.1 mg. Otherwise, it was the same: oven for drying glassware, dark amber bottles for light-sensitive solutions, a barometer to help set atmospheric pressure to adjust concentrations of NO_2, and a thermometer to monitor temperature. A desiccator was also used to store dry samples and materials, and a watch glass was employed for sample and reagent handling and weighing.

3. Calibration and Maintenance

They deployed equipment for ambient air quality monitoring. 10 mL of Griess-Saltzman absorbent solution was added to a bottle protected from sunlight and rain. Using a calibrated flow meter, the air suction pump was adjusted to 0.4 L/minute, and the UV spectrophotometer (Shimadzu UV-1800) was standard with standard solutions and baseline absorbance check (540 nm). The pump flow was checked every 15 minutes during sampling (over a 1-h period), the pump was checked, and the filter was cleaned regularly. The UV spectrophotometer was kept in a dust-free cabinet, and optics and cuvette holders were cleaned after each usage. The sample was taken by sealing the absorbent bottle, labeling it, and preparing it for analysis to ensure the sample's integrity.

4. Sampling Method

To avoid contamination, the NO_2 samples were collected in such a way as to minimize any potential errors. Then, 10 mL Griess-Saltzman absorbent solution was inserted into a sealed bottle, and the air suction pump was calibrated using a flow meter at a flow rate of 0.4 L/minute. Standard solutions were measured using a UV spectrophotometer (Shimadzu UV-1800) for calibration at 540 nm. The pump flow rate was assessed every 15 minutes during the 1-hour collection. After collection, the absorbent bottle was sealed, labeled, and stored in a cold, dark environment. Samples were suspended in a temperature-controlled vessel, with every effort to minimize cross-contamination and maintain sample integrity. To perform sample testing with a UV spectrophotometer [24].

5. Preparation of Reagents

Stock reagents were prepared for the NO_2 measurement, including a 0.1% (w/v) sodium nitrite solution and a 0.1% (w/v) N- (1-naphthyl) ethylenediamine dihydrochloride solution. Furthermore, the Griess-Saltzman absorbent solution was prepared per the standardized procedure to maintain consistency in reactivity. These reagents were kept in dark amber bottles to protect them from light exposure. Mineral-free distilled water was used to prepare all solutions to prevent contamination.

6. Measurement and Data Collection

Absorbance measurement was performed for a sample of 0.5 mL collected after stirring using a calibrated Shimadzu UV-1800 UV spectrophotometer at 540 nm. The measurement was calibrated against standard solutions and a blank absorbance to normalize the data. The absorbance of each sample was recorded in a controlled environment, and the optics and cuvette holders were cleaned between samples to prevent cross-contamination. To maintain their integrity, the samples will be moved to the laboratory in temperature-controlled containers.

7. Data Analysis

Variable: the Air Quality Index (ISPU) is calculated based on data for particulate matter with a diameter of 10 µm (PM_{10}), sulfur dioxide (SO_2), carbon monoxide (CO), oxidants, which include ozone (O_3), and nitrogen dioxide (NO_2) [25]. According to KEP-45/MENLH/10/1997, and KEP-107/KABAPEDAL/11/1997.

Air quality assessment is performed regarding pollution parameter concentration based on national ambient air quality standards with Government Regulation No. 41 of 1999 as the standard. ANOVA, particularly multivariate correlation tests [26], to analyze monitoring locations, sampling, and NO_2 concentrations. Data for the ISPU NO_2 at four monitoring points (e.g., industrial, office, residential, and transportation) across fifteen Lampung Province regencies were collected from the Lampung Provincial Environmental Monitoring Agency (BPLHD) for 2019–2020. Two monitoring phases were carried out during the rainy and dry seasons. The data were used to classify air quality at each monitoring point. Table 1 presents the qualifications for air quality conditions.

The ISPU value can be calculated using the following formula:

$$I = \frac{(Ia-Ib)}{(Xa-Xb)}(Xx-Xb)+IbI = \frac{Ia-Ib}{Xa-Xb}(Xx-Xb)+Ib$$

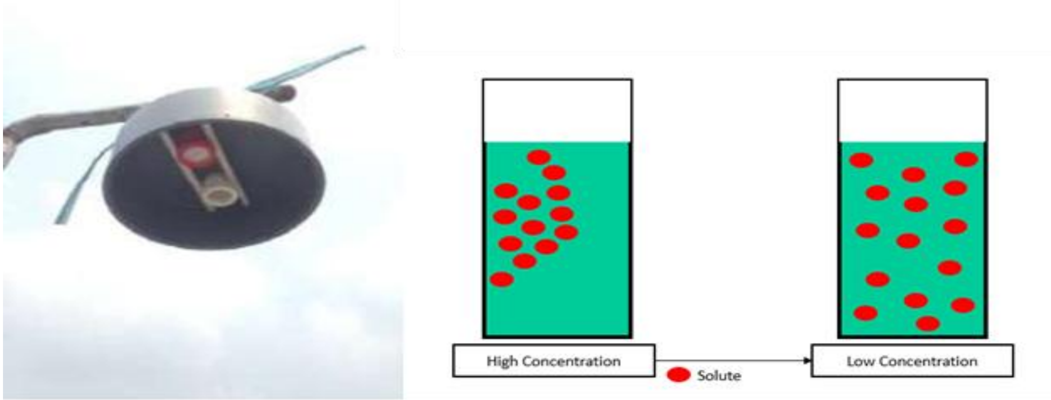
Explanation:
I : Calculated Air Quality Index (ISPU)
Xa : Upper limit of ambient concentration (µg/m^3)
Ia : Upper limit of ISPU
Xb : Lower limit of ambient concentration (µg/m^3)
Ib : Lower limit of ISPU
Xx : Actual ambient concentration resulting from measurements (µg/m^3)

Table 1. Air quality categories based on ISPU values according to the annex of Chief Bapedal Decision Number 107 of 1997 [14]

No.	ISPU Value	Category
1.	0-50	Good
2.	51-100	Currently
3.	101-199	Not healthy
4.	200-299	Very unhealthy
5.	> 300	Dangerous

A seasonal factor was included in a statistical analysis with Analysis of Variance (ANOVA) with multivariate correlation to analyze the influence of season on NO_2 concentrations collected using passive samplers. It is understood that seasonal changes can influence gas diffusion to passive samplers [27]. The concentration analysis of NO_2 by the Lampung Provincial

Environmental Monitoring Agency (BPLHD) used the Passive Sampler method (Figure 1a). This method is economical, easy to use, and can be implemented in urban, rural, or remote areas without electricity [28]. The Passive Sampler absorbs gases from the surrounding air through diffusion or molecular permeation through a membrane filter, enabling temporal and spatial evaluation of pollutant distribution [29].



(a) (b)

Figure 1. (a). Passive sampler device; (b) Diffusion process

RESULTS AND DISCUSSION

1. NO_2 Concentration Levels

As can be seen in Table 2 and Table 3, the NO_2 parameter of four monitoring points in 15 regencies in Lampung Province can be used as a reference for ISPU values. Then, the data in the two tables above were compared with Chief Bapedal Decision Number 107 of 1997 about ISPU to determine the ISPU category in each monitoring. These results show that in the 15 regencies of Lampung Province, the NO_2 concentration at each monitoring point is included in the safe and non-hazardous category.

The Air Pollution Index (ISPU) values describe the ambient air quality at the sampling site, according to their health concern, aesthetic and environmental aspects [30]. While ISPU values are more appropriate at the urban scale, they can be extended to all regions.

The average NO_2 concentrations across the monitoring points were calculated for 2019 and 2020 based on the acquired NO_2 concentration data. Table 4 and Table 5 show the average results of NO_2 concentration.

Table 4 and Table 5 indicate that the highest average concentrations of NO_2 in 2019 and 2020 were found along the transportation route. At the same time, the office, residential, and industrial monitoring points followed with the next highest average NO_2 concentrations. As indicated in phase 1 (rainy season) and phase 2 (dry season) in 2019 monitoring, the average NO_2 concentration along the transit route is 13.62 $\mu g/m^3$ and 15.59 $\mu g/m^3$, respectively. NO_2 concentration in phase 1 monitoring (rainy season) is 14.27 $\mu g/m^3$ and 13.86 $\mu g/m^3$ in phase 2 monitoring (dry season) in 2020.

Table 2. Data from calculating ISPU values for the NO_2 parameter (µg/m^3) at phase 1 (rainy season) in Industrial and Residential Areas in Lampung.

Year	Regency	Transportation	Industry	Residential	Office
2019	Tanggamus	18.40	0.50	1.80	2.50
	Lampung Selatan	5.70	0.41	6.20	0.41
	Lampung Timur	22.30	7.20	7.30	10.50
	Lampung Tengah	13.80	2.90	12.30	7.90
	Lampung Utara	28.14	14.70	8.90	9.20
	Way Kanan	21.80	16.30	3.60	3.70
	Tulang Bawang	0	0	17.30	15.40
	Mesuji	13.10	10.90	3.30	3.20
	Pringsewu	19.60	9.40	8.40	5.40
	Pesawaran	12.80	6.00	6.20	2.10
	Tulang Bawang Barat	8.90	3.50	5.80	4.70
	Kota Bandar Lampung	13.80	6.80	12.50	7.30
	Kota Metro	8.90	7.10	5.80	15.70
	Lampung Barat	5.30	5.00	5.20	12.40
	Pesisir Barat	11.80	2.30	3.80	12.80
2020	Tanggamus	15.31	1.87	3.36	3.24
	Lampung Selatan	13.00	8.17	7.43	7.78
	Lampung Timur	1579	6.62	8.16	11.50
	Lampung Tengah	2307	3.34	12.51	11.15
	Lampung Utara	12.55	14.03	10.97	9.63
	Way Kanan	21.15	18.72	5.19	8.01
	Tulang Bawang	842	6.66	7.94	12.38
	Mesuji	10.06	6.92	3.40	2.98
	Pringsewu	26.31	14.22	11.20	7.70
	Pesawaran	18.54	1.33	5.80	0.73
	Tulang Bawang Barat	8.48	11.44	7.40	4.91
	Kota Bandar Lampung	15.91	6.85	12.21	8.08
	Kota Metro	12.96	10.15	14.80	12.85
	Lampung Barat	4.37	4.11	4.79	10.36
	Pesisir Barat	8.15	3.24	3.13	9.05

Table 3. Data from calculating ISPU values for the NO_2 parameter (µg/m^3) at phase 2 (dry season) in Industrial and Residential Areas in Lampung.

Year	Regency	Transportation	Industry	Residential	Office
2019	Tanggamus	19.80	2.30	3.10	3.50
	Lampung Selatan	6.87	7.88	10.70	8.60
	Lampung Timur	22.62	7.00	9.65	10.30
	Lampung Tengah	12.50	3.27	18.90	7.90
	Lampung Utara	28.60	9.90	11.70	12.30
	Way Kanan	19.70	11.20	3.60	4.17
	Tulang Bawang	30.50	19.20	17.70	10.90
	Mesuji	9.70	10.80	3.80	4.90
	Pringsewu	23.80	11.50	8.10	5.20
	Pesawaran	16.65	5.00	7.10	3.30
	Tulang Bawang Barat	6.00	1.90	0.41	2.10
	Kota Bandar Lampung	9.80	8.75	10.60	9.90
	Kota Metro	8.40	11.60	5.90	20.80
	Lampung Barat	5.20	6.90	4.70	10.50
	Pesisir Barat	13.70	2.70	5.00	9.50
2020	Tanggamus	12.72	2.57	2.73	2.42
	Lampung Selatan	12.51	7.40	7.65	6.26
	Lampung Timur	17.70	8.15	8.88	12.20
	Lampung Tengah	28.85	5.83	10.99	10.68
	Lampung Utara	11.61	19.80	8.30	10.43
	Way Kanan	14.80	19.80	3.57	7.52
	Tulang Bawang	12.73	5.80	8.95	11.98
	Mesuji	9.44	5.39	4.54	4.68
	Pringsewu	23.51	10.25	9.68	4.31
	Pesawaran	17.70	3.37	8.83	1.02
	Tulang Bawang Barat	9.21	10.62	7.57	4.20
	Kota Bandar Lampung	13.44	7.68	9.76	0.00
	Kota Metro	11.08	12.83	12.29	13.45
	Lampung Barat	4.43	4.92	5.76	9.60
	Pesisir Barat	8.12	2.79	2.23	6.67

Table 4. Average NO_2 concentrations (µg/m^3) at phase 1 (rainy season) in Industrial and Residential Areas in Lampung

Monitoring Point	2019	2020
Transportation	13.62	14.27
Industry	6.20	7.84
Residential	7.23	7.89
Office	7.55	8.02

Table 5. Average NO_2 concentrations (µg/m^3) at phase 2 (dry season) in Industrial and Residential Areas in Lampung

Monitoring Point	2019	2020
Transportation	15.59	13.86
Industry	7.99	8.48
Residential	8.06	7.45
Office	8.26	7.03

2. Comparison with Air Quality Standards

.Concentrations of nitrogen dioxide (NO_2) have different effects on humans and living organisms based on the level of exposure according to the Air Pollution Index Standard (ISPU) [31], [32]. Individuals may sense a slight specific odor if NO_2 exposure is within the "Good" category (ISPU 0–50). The odor becomes detectable when moving to the "Moderate" range of 51–100. ISPU 101–199 (Unhealthy), the smell becomes stronger, and the gas loses its visible coloration, which could induce an increase in the airways with asthma reactivity. The "Very Unhealthy" category (ISPU 200–299) In persons with asthma and bronchitis, this category renders an elevated sensitivity. The "Hazardous" category for NO_2 is characterized by ISPU values above 300, which means that exposure risk affects all citizens.

The assessment of air quality indicators is typically determined by comparison with the concentration of air pollution parameters at the national level. As for Lampung Province, statistical analysis utilizing ANOVA and the Anderson-Darling test revealed no seasonal effect with $p = 0.322$ for the rainy season (Phase 1) and $p = 0.258$ for the dry season (Phase 2) of NO_2. These results indicate that NO_2 levels on transportation routes in the province are within exposure limits.

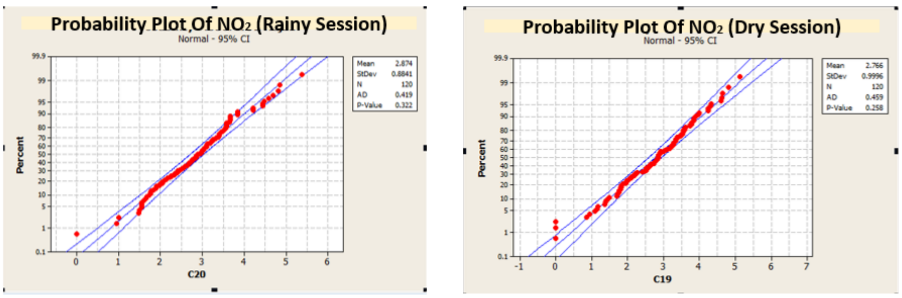
By Government Regulation 41 of 1999, national ambient air quality standards were set so the public would be safe and comfortable. It sets the permissible limits of pollutants to avoid harmful health effects and ecological consequences on the health and well-being of the community. Table 6 specifies threshold values for various parameters to protect the air quality, including NO_2.

Table 6. National ambient air quality standards according to Government Regulation Number 41 of 1999

No.	Quality Standard	Time	Parameters (µg/m^3)
1.	Particulates (PM_{10})	24 hours	150
2.	Carbon monoxide (CO)	1 hour	30000
		24 hours	10000
3.	Ozone (O_3)	1 hour	235
		1 year	50
4.	Sulfur dioxide (SO_2)	24 hours	365
		1 year	80
5.	Nitrogen dioxide (NO_2)	1 hour	0.25
		1 year	100

Based on measurements of average NO_2 concentrations in Phase 1 and Phase 2, these values were still under the threshold at 100 µg/m^3 annually based on Government Regulation 41 of 1999. As per meteorological data, there is a phenomenon of escape of gases and air particles on the surface due to heating due to increased air temperature. Hence, a rise in air temperature has a propensity to enhance gases and particle concentrations such as NO_2. Humidity in the air, however, increases the temperature of the air, which in turn decreases the observed concentration of NO_2.

From this concentration data, further statistical tests were performed using two-way ANOVA based on normality data (Figure 2), which is data normally distributed. Thus, additional testing with two-way ANOVA was performed. A repeated two-way ANOVA statistical test showed a p-value>0.05. It proved that the average NO_2 concentration in each regency was not significantly different (based on season impact) between phase 1 and 2 measurements.



(a) (b)

Figure 2. Probability plots of ambient air NO_2 measurements (a) Phase 1 rainy season; (b) Phase 2 dry season

Figure 2 Probability plots for NO_2 concentrations for rainy and dry seasons. The p-values resulted in 0.322 and 0.258 (larger than 0.05) in the Anderson-Darling test (indicating normal distribution). No season difference was observed in the NO_2 indices across different regencies, indicating that the population's activities produce a medium NO_2 pollutant. However, monitoring points on the network presented different concentrations of particulate matter due to differences in local activity (transportation, industry, residential, and office areas).

The by product of gasoline combustion, the NO_2 gas, comprises nitrogen compounds such as pyridine and quinoline. NO_2 concentrations in the exhaust–where vehicles are stationary are low, but at elevated temperatures in engine combustion, the reaction of nitrogen with oxygen produces much higher concentrations [26]. In high concentrations, nitrogen dioxide (NO_2) may cause eye irritations (redness) and injuries. Also, NO_2 is a greenhouse gas, contributing to global warming. Due to its strong correlation with traffic-related variations, nitrogen dioxide (NO_2) is a useful tracer of traffic emissions [32], [33]. In Lampung, where most people use motorcycles for transportation, NO_2 levels are higher in urban centers, especially near main roads. NO_2 is mainly generated from the combustion of fuels and vehicles [27].

The data on NO_2 concentration showed high concentrations in transportation areas, but they are still safe and non-hazardous, based on Government Regulation No. 41 of 1999. The average concentrations per 15 regencies are lower than the allowable threshold for Lampung province. Again, ANOVA ($p = 0.322$ in the rainy season and $p = 0.258$ in the dry season) and Anderson-Darling test showed that the p-value was higher than the significance level of 0.05, suggesting that season will not lead to a difference of NO_2 concentration in each regency. I suggest extending the air quality monitoring to ISPU parameters and elements other than a seasonal occupation.

Analysis of Variance (ANOVA) was used to examine the relationship between NO_2 concentrations and seasonal variation over observed monitoring locations. Before the implementation of ANOVA, core assumptions were checked, namely the normality of data for the rainy season ($p = 0.322$) and dry season ($p = 0.258$, both $p > 0.05$ by the Anderson-Darling test), confirming that data were normally distributed. To indicate valid results, the homogeneity of variance was also tested. Thus, statistical analyses were implemented using SPSS version 25 to obtain precise calculations. To avoid confusion, the analysis presented was divided into two parts: "ANOVA for Seasonal Differences" referring to how the data was divided into seasons, and "Correlation Analysis," focusing on the correlation of NO_2 to factors such as traffic density, explaining methods and results; These components offer additional elaboration concerning the statistical approaches and findings of the analysis [1].

The study's results, published in the journal Environmental Health Perspectives, have important implications for public health, particularly in regions where NO_2 concentrations are high, such as urban centers adjacent to major roadways. NO_2 concentrations overall in Lampung Province are lower than the dangerous level referred to in Government Rule No. 41 of 1999. Still, elevated concentrations in crowded and high-traffic areas may adversely affect health, especially for those with respiratory illnesses, including asthma or chronic bronchitis. Chronic exposure to even moderate levels of NO_2 has been associated with respiratory problems, increased infections, and diminished lung function. These results call for tailored public health interventions in high-emission enclaves, such as awareness-raising and health screening for vulnerable individuals [2].

These results highlight the importance of periodic air quality surveillance and regulation in areas of heavy congestion from a policy perspective. The steady levels of NO_2 from one season to another indicate that non-seasonal influences (traffic/industrial emissions) are responsible for NO_2 build-up as opposed to seasonal effects. This finding could be a valuable reference for local governments in Lampung Province to encourage the development of public transportation, cleaner fuels, and stricter emissions standards. Moreover, more research is needed to assess the effect of other environmental variables on NO_2 rates and the joint health effects of pollutants. Long time-series studies may reveal trends in NO_2 and associations with respiratory and cardiovascular health [17].

Based on the analysis of ISPU parameters NO_2 for four monitoring points (015-A, 015-A1, 015-A2, and 015-A3) in 15 regencies of Lampung Province, NO_2 concentrations at each of the four monitoring points were not in the medium and low category on Chief Bapedal Decision Number 107 of 1997. Within this context, transportation routes had the highest average NO_2 concentrations, followed by office, residential, and industrial areas in 2019 and 2020. The differences in NO_2 concentrations during the rainy and dry seasons were still lower than the national ambient air quality standard of 100 µg/m³, according to Government Regulation 41 of 1999.

Based on comparing the NO_2 concentrations in Lampung Province against the air quality standard, the WHO imposed a guideline limit of 40 µg/m³ for the annual mean concentration and 200 µg/m³ for the hourly mean. For annual averages, the U.S. Environmental Protection Agency (EPA) has a National Ambient Air Quality Standard (NAAQS) of 53 ppb (roughly 100 µg/ m³). NO_2 levels in Lampung should be compared with the established limits to see if they are exceeded; this is crucial in industrial zones as emissions in these areas are expected to be higher than in residential zones. Standards apply to different sectors, and stricter standards for urban residential areas to protect public health are indicated, indicating that air quality management should be performed [34], [35].

Statistical analyses revealed no significant differences in NO_2 concentrations between seasons and regencies by the two-way ANOVA test, demonstrating that anthropogenic activities consistently drove levels of NO_2 pollution. Meteorological data also indicated that higher air temperatures can increase NO_2 concentrations, and increased humidity reduces NO_2 concentrations. The probability plots showed the data distributed around the normal function, reinforcing that seasonal changes did not affect NO_2 in the regencies.

3. Sources Factors and Health Implications

Nitrogen Dioxide (NO_2) Is Harmful to Public Health, Particularly for Vulnerable Groups such as Children and the Elderly. Short-term exposure can lead to respiratory problems, including coughing and wheezing, and long-term exposure is associated with chronic illnesses like asthma and cardiovascular disease. Because its levels can trigger heart and lung diseases, an especially dangerous threat for older adults and children with developing respiratory systems, elevated NO_2 levels can be dangerous. NO_2 is often concentrated in urban centers near major transportation corridors and industrialized areas, emphasizing the need for targeted public health interventions to minimize exposures, particularly to vulnerable populations [4].

Lampung Province's main sources of nitrogen dioxide (NO_2) include emissions from motor vehicles, industrial activities, and burning fossil fuels, increasing pollutant levels in areas. NO_2 levels are affected by high traffic density and fuel type, whereas seasonality, geography, and meteorology also come into play. For example, elevated NO_2 concentrations can be observed in the dry season, when there is more vehicular traffic and stagnant air, while rain helps to wash away pollutants. Geographical factors such as elevation can also affect dispersion patterns as temperature inversions can trap emissions at low altitudes. Chronic exposure to NO_2 causes serious health problems, particularly respiratory and cardiovascular diseases. Hence, it is important to understand these sources and influencing factors for efficient air pollution controls and public health protection in Lampung Province [34].

CONCLUSION

According to the results of this study, based on the average concentration of NO_2 along transportation routes in the 15 regencies, Lampung Province is still below the regulatory limits specified in Government Regulation No. 41 of 1999. The Anderson-Darling test and analysis of variance (ANOVA) for statistical modeling validated that there was no season-based variation concerning NO_2 levels, which showed stable air quality for all seasons. It, therefore, justifies continuing air quality monitoring as the transport network in Lampung grows. It recommends that the ISPU include additional pollutants to better reflect the risks to health due to the environment. It should also include policy recommendations to broaden low-emission transport options and uphold air quality standards that protect public health. Among them, the study's limitation is only considering NO_2 and seasonal effects, but not other factors such as traffic density or meteorological conditions. Future comprehensive studies should investigate these variables, examine more pollutants, and include sampling in urban and industrial locations. Alternative air quality measuring approaches could leverage continuous monitoring systems, while advanced technologies like remote sensing could also provide more comprehensive spatial coverage of air pollutants. Therefore, it can be concluded that Lampung Province is safe with NO_2 concentrations along transportation routes.

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