

ENVIRONMENTAL HEALTH RISK ASSESSMENT OF NITROGEN DIOXIDE EXPOSURE TO AMBIENT AIR POLLUTION IN KUPANG CITY



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DOI: <https://doi.org/10.29121/granthaalayah.v8.i6.2020.519>

Article Type: Research Article

Article Citation: Suwari, Herry Zadrak Kotta, and Paulus Bhuja. (2020). ENVIRONMENTAL HEALTH RISK ASSESSMENT OF NITROGEN DIOXIDE EXPOSURE TO AMBIENT AIR POLLUTION IN KUPANG CITY. International Journal of Research - GRANTHAALAYAH, 8(6), 252-258. <https://doi.org/10.29121/granthaalayah.v8.i6.2020.519>

Received Date: 9 May 2020

Accepted Date: 29 June 2020

Keywords:
Environmental
Health Risk
Air Pollution

ABSTRACT

Nitrogen dioxide (NO₂) is one of the main pollutants that affecting the quality of life and human health. Mostly, the effects of NO₂ exposure depending on concentration, duration of exposure and anthropometric variables. This study aimed to analyzing the NO₂ concentration of ambient air and to assessing human health risks in real time and lifetime exposure. To achieve that goal, air samples were taken at four strategic locations in Kupang City, in which were represented by industrial, roadside, residential, and office areas. The Griess Saltzman method was used for sampling and analysis of NO₂ levels. Totally, there were 48 air samples had been analyzed for NO₂ levels. The detected NO₂ concentration showed a trend varied between sampling locations. Overall, NO₂ levels measured still met ambient air quality standards. Human health risk assessment was carried out by determining the intake (I) and Risk Quotient (RQs) in four groups of individuals exposed to NO₂. The results shown that the RQs for real time and lifetime exposures were both less than 1.0, in which implying a non-carcinogenic risk of NO₂ exposure in the study area. The results Health risk assessment also indicating that potential non-carcinogenic risks occur when NO₂ exposure is more than 39 years.

1. INTRODUCTION

Air pollution is a serious global problem because it presents a major environmental risk to health. This problem is compounded by the rapid growth of urban population, industrial development, and the increase of the transportation activities [1]. The main cause of air pollution is the burning of fossil fuels. Meanwhile, the consumption of fossil fuels continues to outweigh the use of more environmentally friendly forms of energy. This condition inadvertently has had a major effect on air quality. A study conducted by [2] indicated that transportation of motor vehicles was the main source of air pollution in urban areas. Emissions generated by motorized vehicle activities in urban areas were mainly NO₂ gas originating from the combustion process [3],[4].

The impact of the use of fossil fuels clearly will reduce air quality. Furthermore, declining air quality will cause serious impacts on human health. According to [5], air pollution is an important risk factor that can cause strokes, lung cancer, heart disease and respiratory infections such as pneumonia. It was estimated that half of the deaths that occurred were caused by heart disease, stroke and lung cancer which could be attributed to air pollution. The exposure to air pollution from both outdoor and household (indoor) resulted in the deaths of around 7 million people annually in all regions of the world, while Western Pacific and South East Asia were the most affected [5]. WHO

estimated that there were 200 thousand deaths due to outdoor pollution that mainly occur in urban areas, where about 93% of cases occurred in developing countries [6].

Air pollutants could come from anthropogenic activities including industry, transportation, offices and housing, but could also originate from natural activities. The transportation and industrial sectors were the highest contributors to the declining of air quality. It has been predicted that air pollution due to transportation and industrial activities will increase 10-fold in 2020 compared to the conditions in 1990 [7].

Kupang City as the capital of East Nusa Tenggara province in Indonesia, has experienced rapid development in various fields as marked by the emergence of new residential, shopping centers, tourist centers, transportation facilities, and other various supporting infrastructure. Certainly, this condition has a negative impact on environmental quality due to an increase in air pollutants, which could have a direct impact on the deterioration of public health.

Air pollution in the city of Kupang was more dominantly influenced by anthropogenic activities that using a lot of fossil fuels. One of the common air pollutants mainly produced through combustion, including that of fossil fuels, is nitrogen dioxide (NO₂). NO₂ is one of a group of highly reactive gases known as oxides of nitrogen (NO_x). This gas is corrosive and can irritate airways in the human respiratory system at concentrations of 1-3 ppm as well as cause lung damage if inhaled [8], [9], [10]. Studies also shown that chronic exposure to NO₂ possibly influencing individuals by the development of chronic diseases, including infections and obstructive pulmonary disease. Short-term exposure to NO₂ which caused minimum adverse effects for human was below 0.2 mg/m³ [11] and 0.9 mg/m³ [12]. Exposure to high levels of NO₂ proven had damaging the respiratory airways. In addition, contacting with the skin or eyes can cause burns. Studies also shown that longer exposures to high concentrations of NO₂ could contributed to the development of asthma and potentially increased susceptibility to respiratory infections [10], [11].

Air quality monitoring and environmental health risk assessment are very important for the purpose of air pollution control and risk management. This study aims to determine the quality of ambient air and to predict human health risks associated with NO₂ exposure in Kupang City, Indonesia.

2. MATERIALS AND METHODS

2.1. LOCATION AND SAMPLE COLLECTION

The research was conducted at strategic locations in Kupang city from June to September 2019. Air sampling was taken from four different sampling points representing industrial areas, residential, transportation (roadside), and strategic office areas in Kupang City. Air sampling followed the guidelines and methods from The Government Regulation No. 41 of 1999 [14] and Indonesian National Standards [15].

The air quality measurement equipment, in the form of an air sampler, was installed at a predetermined location with a height of 150 cm. Basically, the procedure for air quality sampling used the wet methods. Sampling procedure used absorbent Griess Saltzman solution.

Suction of air was carried out at a flow rate, F₁, of 0.4 L/min for 1 h whereas temperature, air pressure and humidity were recorded. After 1 h, the final flow rate, F₂, (L/min) was recorded, then the suction pump was turned off while allowed to stand for 10 min to remove the intruder. The air samples were put into the icebox to maintain the temperature and reduced the release of gas due to rising temperature.

2.2. CALIBRATION CURVE FOR NO₂ ANALYSIS

Respectively put in 0.0; 0.1; 0.2; 0.4; 0.6; 0.8 and 1.0 mL, of 1640 µg/L standard nitrite solution into a 25 mL erlenmeyer. Then the absorbent solution was added to the limit mark (10 ml volume), shaken and left for 15 minutes. After color formation perfectly formed, the absorbance of each standard solution was measured at the maximum wavelength. Furthermore, a calibration curve was made between the absorbance and the concentration of NO₂ gas.

2.3. SAMPLE ANALYSIS

Analysis of NO₂ levels using the Saltzman method. The sample solution was put into a cuvette on a spectrophotometer, then measured the intensity of the pink color formed at a wavelength of 550 nm. Read the absorbance of the test sample then calculated the concentration using a calibration curve.

2.4. ENVIRONMENTAL HEALTH RISK ASSESSMENT

Health risk assessment was used to predict level risk of NO₂ exposure to humans. The applied method was Public Health Assessment [16].

The necessary data was collected through four stages, namely hazard identification, exposure assessment, dose-response assessment, and risk characterization [17], [18], [19], [20].

The data was collected in order to simulate human health risks including NO₂ concentration, anthropometric data and activity patterns consisting of duration exposure (tE), body weight (Wb), inhalation rate (R), frequency of exposure (fE) and duration of exposure (Dt). For anthropometric data and activity patterns used secondary data from several references that were relevant to local conditions. Reference data used including body weight of 15 kg and 55 kg, respectively representing the average weight of Indonesian children and adults [18],[21] inhalation rate of 20 m³/day or 0.83 m³/h [22], tE and Dt used residential default values.

To simulate environmental health risks, four risk population groups were established, namely children ≤6 years of age and housewives representing exposure of 24 h/day, street vendors to whom showed 12 h/day exposure, and employees representing 8 h/day exposure [18], [21].

2.5. DATA ANALYSIS

Analysis of NO₂ concentrations in ambient air was preceded by calculation of air sample volume. Volume of taken air samples, was calculated under normal conditions (25 °C, 760 mmHg) using the following equation:

$$V = \frac{F_1+F_2}{2} \times t \times \frac{P_a}{T_a} \times \frac{298}{760} \quad (1)$$

Where V is the volume of air absorbed (L); F₁ and F₂ are the initial and final flow rates (L/min) respectively; P_a is the average barometer pressure during sampling (mmHg); T_a is the average temperature during sampling (K); 298 and 760 are respectively the temperature and pressure (mmHg) under normal conditions.

Furthermore, the NO₂ concentration in ambient air was calculated using the following equation:

$$C = \frac{a}{V} \times 1000 \quad (2)$$

Where C is NO₂ concentration in the ambient air (µg/Nm³); a is amount of NO₂ from the sample by looking at the calibration curve (µg), v is volume of air under normal conditions (L); and 1000 is the conversion of liter to m³.

Exposure assessment aimed to identify NO₂ exposure pathways so that the amount of intake received by individuals in the population at risk could be calculated. Amount of NO₂ intake by inhalation was calculated by the following equation:

$$I = \frac{C \times R \times t_E \times f_E \times D_t}{W_b \times t_{avg}} \quad (3)$$

Where I is inhalation intake (mg NO₂/kg individual body weight /day), C is NO₂ concentration in ambient air (mg/m³), R is inhalation rate (m³/h), tE is duration exposure (h/day), fE is frequency exposure, 350 days/year for residential default values, Dt is duration exposure, 30 years for residential default values, Wb is individual weight (kg), tavg is average time period (Dt x 365 days/year).

Dose-response assessment was conducted for determining the relationship between level exposure of a chemical and the response in the form of events related to adverse effects or harmful effects [19]. Dose-response of

NO₂ exposure was expressed by reference concentration (RfC) as non-carcinogenic quantitative toxicity for inhalation. The RfC value for NO₂ had been determined by WHO and European Environmental Agency's (EEA's) at 0.01 mg/kg/day, based on the air quality standard of NO₂ for the protection of human health that is 40 µg/m³, exposure time 24 h/day, frequency of exposure 350 days/year, body weight of 70 kg, and an average time period of 365 days/year [23], [24].

Risk characterization was expressed as non-carcinogenic risk level (Risk Quotient, RQs) due to NO₂ exposure, calculated by dividing the intake (I) with RfC:

$$Risk\ Quotient\ (RQs) = \frac{I}{RfC} \tag{4}$$

RQs < 1 presumably that daily exposure to NO₂ does not have a negative effect on human health, whereas RQs > 1 indicating a potential non-carcinogenic effect.

3. RESULTS AND DISCUSSION

3.1. NO₂ CONCENTRATION IN AMBIENT AIR

NO₂ measurements were carried out in the dry season, so that gas deposition due to rainwater was very minimal. Air sampling was carried out from June to September 2019. During this period precipitation occurred only twice about 8 mm [25]. The setting of this condition was intended to estimate the potential health of the environment that was most at risk, according to the precautionary principle. The measurement results of NO₂ concentration from four strategic areas in Kupang City as presented in Table 1.

Table 1: Concentration of NO₂ from ambient air in Kupang City, 2019.

Location	Concentration of NO ₂ [*] , µg/m ³				Average
	June	July	August	September	
Industrial area	15.12	21.00	14.09	17.46	16.92
Roadside	16.95	23.96	16.28	31.44	22.16
Residential area	12.00	9.89	8.22	10.80	10.23
Office area	5.20	11.23	12.12	6.19	8.69

*Average NO₂ levels from three measurements. 1 µg/m³ NO₂ level is equal to 0.53 ppb

As Indicated in Table 1, it shown that the NO₂ concentration varied between measurement times. This case could be caused by meteorological factors (such as temperature, humidity, wind, and sunlight) that occurred between measurement times and/or differences in the intensity of anthropogenic activity. As primary pollutant emitted by an emission source NO₂ will experience various physical and chemical reactions in the presence of meteorological factors. In this case, various reactions that occurring in the air could also cause NO₂ to change into several types of secondary pollutants, for example HNO₃ and dissociation of NO₂ into oxygen radicals. Due to the push of the wind, NO₂ gas will be dispersed (scattered) in the direction of the wind. Some NO₂ on their way could be deposited on the surface of land, water, buildings, and plants. Others will remain suspended in the air. Certainly, all of these events will affect the concentration of NO₂ in ambient air.

The lowest NO₂ concentration was found in the office area. In this area, NO₂ concentrations ranged from 5.20 to 12.12 µg/m³ with an average of 8.69 µg/m³. NO₂ is an indicator for road traffic. The average of NO₂ concentration at the roadside was higher than that from other three locations. The results shown that NO₂ concentrations measured at Roadside ranged from 16.28 to 31.44 µg/m³. High NO₂ concentration at that location indicated that air pollution in urban areas was mainly originated from motorized vehicles emissions. According to [26], motor vehicle exhaust gas contributed to total NO₂ emissions of 185 pounds/1000 gallons. NO₂ levels increased along with the increase in traffic activity. In conclusion, transportation sector, especially motor vehicles that use premium fuel contributed major source of air pollution in Kupang City [1], [4].

3.2. PROJECTION OF HUMAN HEALTH RISKS

This study simulated potential health risks to humans exposed to NO₂ in ambient air by calculating the NO₂ daily intake (I) and comparing it to the maximum dose allowed for humans through daily exposure. The intake calculated results was based on NO₂ concentration data as a risk agent as shown in Table 2 and Table 3. Meanwhile, the characteristics of health risks due to NO₂ exposure in the form of numerical values of Risk Quotient (RQs) presented in Table 4 and Table 5.

Table 2: Intake of NO₂ (x 10⁻³ mg/kg/day) from ambient air for real time exposure

Location	Children	Housewives	Street Vendors	Employees
Industrial area	3.59	0.98	0.49	0.33
Roadside	4.70	1.28	0.64	0.43
Residential	2.17	0.59	0.30	0.20
Office area	1.84	0.50	0.25	0.17

Table 3: Intake of NO₂ (x 10⁻³ mg/kg/day) from ambient air for lifetime exposure

Location	Housewives	Street Vendors	Employees
Industrial area	5.88	2.94	1.47
Roadside	7.70	3.85	1.92
Residential	3.55	1.78	0.89
Office area	3.02	1.51	0.75

Table 4: Risk level (RQs) of NO₂ exposure at 4 locations for real time exposure

Location	Children	Housewives	Street Vendors	Employees
Industrial area	0.36	0.10	0.05	0.03
Roadside	0.47	0.13	0.06	0.04
Residential	0.22	0.06	0.03	0.02
Office area	0.18	0.05	0.03	0.02

Table 5: Risk level (RQs) of NO₂ exposure at 4 locations for lifetime exposure

Location	Housewives	Street Vendors	Employees
Industrial area	0.59	0.29	0.15
Roadside	0.77	0.38	0.19
Residential	0.36	0.18	0.09
Office area	0.30	0.15	0.08

The intake values of NO₂ presented in Table 2 and Table 3, mainly influenced by anthropometric variables and the actual dose of the risk agent received as well as inhalation rate by the individual. The results also strongly proved that body weight, frequency exposure, and duration exposure were the anthropometric variables that affecting pollutant intake. The greater the weight of individual, the smaller the intake received by individuals exposed to risk agents. Consequently the smaller the health risk affected by NO₂ exposure in ambient air. Based on these considerations, WHO and EEA's used body weight of 70 kg and an inhalation rate of 20 m³/day to set NO₂ quality standards, ie the annual mean value should not exceed 40 µg/m³ and for an average hourly maximum value of 200 µg/m³ to protect human health [23], [24]. Meanwhile, air quality standards in Indonesia according to [14] for NO₂ with a measurement time of 1 year and 1 hour, respectively, were 100 µg/m³ and 400 µg/m³. The setting of these air quality standards should be consider the average adult body weight and maximum duration of exposure as a substitution for the length of measurement.

In this study, the calculation of NO₂ intake was applied in real time using body weight of 15 kg (for children) and 55 kg (for adults) with duration exposure of 5 years, while the intake value of NO₂ for lifetime uses the duration of exposure of 30 years. Whereas other variables were fixed. The measurement results shown that the intake value of NO₂ for lifetime exposure ranges from 0.17x10⁻³ to 4.70x10⁻³ mg/kg /day. The highest NO₂ intake occurred in the group of children, while the lowest intake occurred in the group of employees. The difference value of NO₂ intake

from four study groups was due to differences in body weight and length contact time of individuals to risk agents. The same results transformed in the value of NO₂ intake for lifetime exposure, although the intake value was greater than those for real time exposure.

The highest RQs at real time exposure for 4 exposed population groups ranged from 0.04 to 0.47 (Table 4), the index had increased 0.19 to 0.77 on lifetime exposure (Table 5). The RQs (real time) and RQs (lifetime) were all less than 1.0, indicating that a long term NO₂ exposure from ambient air in Kupang City did not pose a health risk and chronic toxicity for local residents, but control efforts were needed so that NO₂ concentration did not increase significantly.

Estimated duration of exposure in which NO₂ exposure begins to pose a health risk or chronic effect, can be done by rearranging equation (3) and substituting I (intake) with RfC. As a result, local people exposed to NO₂ with concentration of 22.16 µg/m³ for 38.98 years had a high non-carcinogenic health risks and needed risk management. The assumption is that NO₂ concentration in ambient air does not increase significantly. Additionally, increasing NO₂ concentration from real time to lifetime will increase potential health risks. Scientific evidence shown that long-term exposure to high NO₂ concentrations could contribute to the development of asthma and potentially increasing susceptibility to respiratory infections. Children and older adults had greater health risks [10]. NO₂ could also reduce lung function. Individuals who were exposed to NO₂ continuously will increase symptoms of bronchitis and emphysema, and can even worsen heart disease upto early death.

4. CONCLUSION

Nitrogen dioxide, NO₂, concentration in four strategic locations in Kupang City, Indonesia, had not exceeded ambient air quality standards in accordance with Government Regulation No. 41 of 1999 and WHO standards. Environmental health risk analysis provided a numerical value of estimated risk due to NO₂ exposure both real time and lifetime based on NO₂ levels and anthropometric variables. NO₂ exposure both in real time and lifetime did not pose a potential risk to human health because the RQs were all less than 1.0, but the duration of NO₂ exposure to more than 39 years presumably pose a significant non-carcinogenic risk to local residents, especially individuals who live near the roadside.

DATA AVAILABILITY

Data used to support the findings of this study are included in the article.

SOURCES OF FUNDING

None.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest regarding the publication of this article.

ACKNOWLEDGMENT

The authors would like to thank to the Research institutions and community service, Nusa Cendana University, which provided funding for this research.

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