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Environmental health risk analysis of nitrogen dioxide (NO_2) exposure in children around sugar factory X, Nganjuk Regency

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Abstract

Nitrogen dioxide (NO_2) gas in the air surrounding residential areas near Sugar Factory X presents a noteworthy health hazard, particularly for children. The objective of this study is to identify the sources of NO_2 pollution and perform an Environmental Health Risk Analysis (EHRA) on children's exposure. This study is a quantitative, descriptive-analytical research using secondary data from ambient air quality tests in residential areas surrounding Sugar Factory X in 2022. The data were obtained from relevant agencies. The data were analyzed using EHRA method. The analysis identified the boiler chimney emissions of Sugar Factory X as the primary source of NO_2 gas in that area. The overall risk characterization indicated that NO_2 concentrations of 0.0514 mg/m^3, 0.0528 mg/m^3, and 0.0541 mg/m^3 were unsafe for children weighing 15 kg and 20 kg, based on a 24-hour daily inhalation time and an exposure frequency of 350 days/year. The effects of exposure were projected over a period of 6 years. Children weighing 15 kg are at a higher risk than children weighing 20 kg. The NO_2 concentration limit for a 15 kg child was 0.0261 mg/m^3, while for a 20 kg child, it was 0.0348 mg/m^3. Sugar factory X is the only source of NO_2 pollution in the adjacent residential areas, which poses a threat to children living in these nearby areas, especially those weighing 15 kg. Sugar Factory X is expected to undertake several measures, including replacing the boiler chimneys, conducting regular equipment maintenance, and establishing green belts.

Keywords: EHRA; Nitrogen Dioxide (NO_2); Children; Sugar Factory

1. Introduction

East Java is one of the provinces in Indonesia that has the highest number of industrial companies in the country. There are 6,746 large and medium-scale industrial companies in East Java (1). Out of the thousands of companies, East Java has 45 operating sugar factories (2). The policy of the East Java Provincial Government regarding the rejection of refined sugar imports has led to the sugar industry becoming a potential sector for development (3). One of the growing sugar factories in East Java is Sugar Factory X, located in Nganjuk Regency and situated close to residential areas. Based on the Direct Supervision conducted by Division IV of the East Java Environmental Office, Sugar Factory X produces granulated sugar with an actual production capacity of 3,300 - 3,600 tons per day during the 2022 milling season. The sugar production process conducted by Sugar Factory X consists of six stages, namely crushing sugarcane to obtain juice, purification of the juice to remove impurities, evaporation of water from the juice, cooking the juice to crystallize, centrifugation to separate sugar crystals from the mother liquor, and finalizing the process with sugar drying and packaging.

The increase in waste and by-products during the sugar production process can create environmental issues around the Sugar Factory, particularly related to solid waste and air pollution (4). The air waste generated by the Sugar Factory originates from the chimneys of several production machines. One of the production machines with a chimney is the

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stationary emission source, namely the boiler. In the production process of granulated sugar, boilers are required for the evaporation and cooking stages as they require heat energy. There are 2 (two) boilers along with their chimneys in Sugar Factory X that use bagasse as fuel and emit gases such as carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), hydrogen sulfide (H_2S), ammonia (NH_3), hydrocarbons, particulate matter, and other substances.

Based on the Direct Supervision conducted by Division IV of the East Java Environmental Office, Sugar Factory X has implemented an air pollution control device in the form of a wet scrubber on the boiler chimney. Furthermore, regular monitoring of the emission quality from the boiler chimney and ambient air has been conducted every 6 months, particularly during the milling season. The emission quality testing results from the boiler chimney of Sugar Factory X meet the standards stated in East Java Governor Regulation No. 10 of 2009 (Appendix I/N) for Biomass-Fueled Steam Boilers using Bagasse or Dry Sugarcane Leaves. Similarly, the ambient air quality testing results at the two residential location points indicated that all parameters were below the air quality standards specified in Government Regulation No. 22 of 2021 (Appendix VII) regarding Ambient Air Quality Standards. However, the ambient air quality testing results of Sugar Factory X in June 2022 showed that the nitrogen dioxide (NO_2) parameter approached the established air quality standard of 65 $\mu g/Nm^3$. At the location point in Hamlet 1, it measured 51.4 $\mu g/Nm^3$, and at Hamlet 2, it measured 54.1 $\mu g/Nm^3$. Although the ambient air quality still meets the standards, these results indicate the presence of NO_2 exposure risks to the community around Sugar Factory X.

NO_2 gas is one of the air pollutants that appears as reddish-brown in color and has a sharp odor. It is formed when nitrogen oxide (NO) and other nitrogen oxides (NO_x) react with other chemicals in the air (5). The primary source of NO_2 originates from human activities such as the combustion of fossil fuels (coal, gas, and oil), particularly gasoline used by motor vehicles, gasoline refining and metal processes, commercial processing industries, and food processing industries (6). High concentrations of NO_2 can impair lung function and cause other irritations, particularly in children. In pregnant women, it can increase the risk of birth defects such as low birth weight (LBW) in infants, prematurity, intrauterine growth restriction, congenital abnormalities, and stillbirth. Additionally, in individuals with asthma, NO_2 can irritate the nose and throat, as well as increase susceptibility to respiratory infections (7).

Children living near industrial areas have a higher risk compared to adults due to their vulnerable immune system. In children, the immune system is not fully developed, which prevents it from functioning optimally, making them more susceptible to diseases (8). This is what makes children more vulnerable to NO_2 exposure compared to other age groups. According to US EPA (9), individuals with asthma, children, and the elderly are more susceptible to NO_2 exposure. This is also consistent with Ma'rufi (10) who states that children are at a higher risk than adults and workers due to exposure to NO_2 gas in the air.

The negative impacts resulting from air pollution can be estimated for their level of risk to public health using the method of Environmental Health Risk Analysis (EHRA). EHRA is used to identify potential risk agents that can trigger health disorders. EHRA can predict the magnitude of health risks caused by exposure to a risk agent, thereby explaining whether the risk agent has an impact on public health or not (4). This research aims to identify the source of NO_2 (whether solely from the boiler chimney of Sugar Factory X or not) and conduct an environmental health risk analysis of NO_2 exposure on ambient air towards children around the vicinity of Sugar Factory X.

2. Material and methods

2.1. Research design and location

This research belongs to the quantitative research type, specifically descriptive-analytical, with a secondary data analysis approach. The data were analyzed using Environmental Health Risk Analysis (EHRA) desktop study method. The research location is in the residential around Sugar Factory X, Nganjuk Regency. Nganjuk Regency is located in East Java Province, Indonesia. This location was chosen because based on the Monitoring Report of 24 Sugar Factories in East Java conducted by Division IV of the East Java Environmental Office in 2022, NO_2 levels in the residential around Sugar Factory X were the highest compared to other sugar factories. The sample size in this study is determined using the non-probability sampling method called purposive sampling. The sample in this study is the NO_2 concentration obtained from ambient air quality testing at two residential locations. The use of purposive sampling method allows the researcher to utilize all available samples for conducting EHRA.

2.2. Data source

The secondary data that serve as the population in this study are the results of ambient air quality testing in the residential areas surrounding Sugar Factory X, as documented in the Direct Supervision Report of Sugar Factory X in

2022, owned by Division IV of the East Java Environmental Office. The ambient air quality testing was conducted on June 27, 2022, for 24-hour measurement at two different residential locations or hamlets, in accordance with Government Regulation No. 22 of 2021 (Appendix VII) regarding Ambient Air Quality Standards.

2.3. Research variables

The research variables consisted of two variables, namely the independent variable and the dependent variable. The independent variables in this study are the NO_2 concentration of each location point and the intake value according to the individual characteristics of children, while the dependent variable is the risk quotient (RQ) of NO_2 in children.

2.4. Data analysis

Data analysis is conducted using the EHRA method, which involves calculating the intake to determine the level of risk of the agent or the risk quotient (RQ) on exposed individuals. The EHRA study used is a desktop study, allowing the use of secondary data as well as default values found in guidelines, recommendations, and/or assumptions from previous studies with a similar focus. Based on the EHRA Guidelines by the Ministry of Health of the Republic of Indonesia (11), the implementation of EHRA consists of four stages, namely hazard identification, dose-response analysis, exposure analysis, and risk characterization. In the exposure analysis stage, the intake of NO_2 in individuals is obtained using the following equation.

$$Intake\ (I) = \frac{C\ x\ R\ x\ tE\ x\ fE\ x\ Dt}{Wb\ x\ tavg}$$

Formulation 1

Source: Ministry of Health of the Republic of Indonesia (11)

Description:

I	=	Intake, the amount of agent concentration entering the human body each day (mg/kg/day).
C	=	Concentration, the concentration of the risk agent in the air medium (ambient air) (mg/m^3).
R	=	Rate, the inhalation rate or the amount of air volume entering each hour (m^3/hour).
t_E	=	Time of Exposure, the duration or number of hours of exposure occurring each day (hours/day).
f_E	=	Frequency of Exposure, the duration or number of days of exposure occurring each year (days/year).
D_t	=	Duration Time, the duration or number of years of exposure (years).
W_b	=	Weight of Body, Human body weight / population / population group (kg).
t_{avg}	=	Time of Average, the average time period for non-carcinogenic effects (days).

The numerical value of concentration (C) is obtained from the sample, specifically the NO_2 concentration from ambient air quality testing. On the other hand, the numerical values of R, t_E, f_E, D_t, W_b, and t_{avg} are derived from default values found in previous literature, EHRA desktop study guidelines, and assumptions based on rational logic. The default values for various variables in the EHRA desktop study, specifically for residential areas targeting the risk agents to children, are as follows: R (12 $m^3 \approx 0.5\ m^3$/hour), t_E (24 hours/day), f_E (350 days/year), D_t (6 years), W_b (15 kg), and t_{avg} (for non-carcinogenic effects, D_t x 365 days/year) (11–13).

The concentration of NO_2 obtained from the test results is expressed in units of $\mu g/Nm^3$ and needs to be converted to mg/m^3 before calculating the intake to match the units used in the default values. The following is the formula to convert $\mu g/Nm^3$ to mg/m^3.

$$\text{Concentration } mg/m^3 = \text{concentration } \mu g/Nm^3 \times 0.001$$

Formulation 2

In the risk characterization stage, the calculation of the risk quotient (RQ) is performed for non-carcinogenic effects. The following is the formula for calculating the RQ for inhalation exposure.

$$RQ = \frac{I}{RfC}$$

Formulation 3

Source: Ministry of Health of the Republic of Indonesia (11)

Description:

I = Intake, the calculated intake value obtained in the previous step.

RfC = The reference value for risk agents in inhalation exposure.

RQ is expressed as a number or decimal without units. RQ is considered safe if the intake ≤ its corresponding RfC, or expressed as RQ ≤ 1. RQ is considered unsafe if the intake > its corresponding RfC, or expressed as RQ > 1. If the risk level indicates an RQ > 1 or falls into the unsafe category, risk management measures need to be implemented. Risk management strategies that can be carried out at residential sites include establishing safe concentration limits for the risk agents. The following is the formula for its calculation.

$$C\ max = \frac{RfC\ x\ Wb\ x\ tavg}{R\ x\ tE\ x\ fE\ x\ Dt}$$

Formulation; 4

Source: Ministry of Health of the Republic of Indonesia (11)

3. Results and discussion

3.1. Identification of NO_2 pollution sources from Sugar Factory X

The ambient air sampling was conducted in hamlet 1 and hamlet 2, which are located west of Sugar Factory X. Both locations are in close proximity to the boiler chimney 1 (Yoshimine) and the boiler chimney 2 (Takuma), which emit NO_2 gas emissions. The following are the results of the distance measurement between the two hamlets and the boiler chimneys using the Google Maps application. The average distance between boiler chimney 1 and both hamlets is 60.6 meters, while the average distance between boiler chimney 2 and both hamlets is 81.6 meters.

Table 1 Boiler chimney emission test results

No.	**Boiler Chimney Name**	**Standard Limit/Quality Standard ***		**Test Result**	
		Value	Unit	August 2021	June 2022
1.	Boiler Chimney 1	800	mg/Nm^3	2.40	10.7
2.	Boiler Chimney 2			36.2	37.7

*) East Java Governor Regulation No. 10 of 2009 (Attachment I/N) for Biomass-Fueled Steam Boilers; Using Bagasse or Residues and/or Dried Sugarcane Leaves

Table 2 Ambient air test results for residential areas

No.	**Location Name**	**Standard Limit/Quality Standard ***		**Test Result**	
		Value	Unit	August 2021	June2022
1.	Hamlet 1	65 (24-hour measurement)	μg/Nm^3	21.7	51.4
2.	Hamlet 2			24.5	54.1

*) Government Regulation No. 22 of 2021 (Appendix VII) regarding Ambient Air Quality Standards

Table 1 shows the concentration of NO_2 in the emissions from each boiler chimney increased from 2021 to 2022. The increase in NO_2 concentration is directly proportional to the increase in NO_2 concentration in the ambient air of hamlet 1 and hamlet 2 (table 2).

3.2. Causes of increased NO_2 concentration

Damage to Air Pollution Control Devices: Based on the direct monitoring report owned by Division IV of the East Java Environmental Office, the air pollution control device on the boiler chimney of Sugar Factory X, which is a wet scrubber, has not been functioning optimally. As a result, the emissions released from the chimney still contain soot and enter the surrounding residential areas.

The Relationship Between Milling Season and Air Quality Testing Time: Based on the direct monitoring report owned by Division IV of the East Java Environmental Office, the testing of chimney emission quality and ambient air quality in residential areas around Sugar Factory X was conducted in August for the year 2021, and in the year 2022, it was conducted in June. Sugar Factory X is included in the second cluster of sugar factories that carry out the milling season in June (14). The milling season has a fixed schedule from year to year. In 2021, chimney emissions testing and ambient air quality testing were conducted nearly two months after the milling season, thus there was no chimney activity. However, in 2022, the testing was conducted during the milling season when the chimney was operational. In a study conducted by Rochmatin (15), it was found that during the milling season, Sugar Factory X causes the air to become hotter, noise due to the sounds of factory machinery, as well as smoke and dust from the chimney, spread along with the vehicle flow, thereby disrupting community activities.

The Influence of Weather and Temperature on NO_2 Accumulation: In June 2022, it should have already been the dry season, but in reality, rainfall still occurred due to the La Niña phenomenon (16). Nganjuk Regency is included in the region affected by the La Niña phenomenon, which leads to an increase in rainfall with moderate and heavy intensity (17). High rainfall leads to a decrease in temperature (low temperature) and an increase in air humidity. The highest accumulation of NO and NO_2 concentrations occurs when the air temperature is low, air humidity is high, and wind speed is low (18). High rainfall in June 2022 increased the accumulation of NO_2 in the air, as indicated by the data from Meteorology, Climatology, and Geophysics Agency Malang Climatology Station (19), In August 2021, the rainfall in Nganjuk Regency in all districts ranged from 0-20 mm, indicating low rainfall. This can be a contributing factor to the increased concentration of NO_2 in the ambient air during the tests conducted in 2022 compared to the tests conducted in 2021.

3.3. Sources of NO_2 pollution around Sugar Factory X

In locations of hamlet 1 and hamlet 2, only Sugar Factory X is the business/industry that produces NO_2, but there is a highway located to the east of hamlet 1 and hamlet 2 (Figure 1). The highway can become a source of NO_2 pollution. According to Br. Tarigan (20), motorized vehicles are the main factor causing air pollution in urban areas by contributing 70% of NO_x (nitrogen oxides) emissions to the environment. This is supported by the statement of Rosyid (21) that the increase in traffic activity is the cause of the increased levels of NO_x (nitrogen oxides) and CO (carbon monoxide) concentrations. Exhaust emissions will increase along with the increase in the number of motorized vehicles passing through highways, thus resulting in a decrease in environmental quality (22,23). Based on the aforementioned statements, it is necessary to pay attention to the traffic conditions of the Sugar Factory X Highway in order to clearly identify the source of NO_2 pollution entering Hamlet 1 and Hamlet 2. The traffic conditions of the highway can be observed on the following map.

The digital map above was obtained from the Google Maps application. The application also performs an analysis of the daily traffic density on the Sugar Factory X highway. The results of the Google Maps analysis indicate that the traffic on the highway is generally light (not congested or with a low volume of vehicles passing through). This serves as evidence that the largest source of NO_2 pollution comes from the boiler chimney of Sugar Factory X. The following table provides a detailed summary of the hazard identification findings.

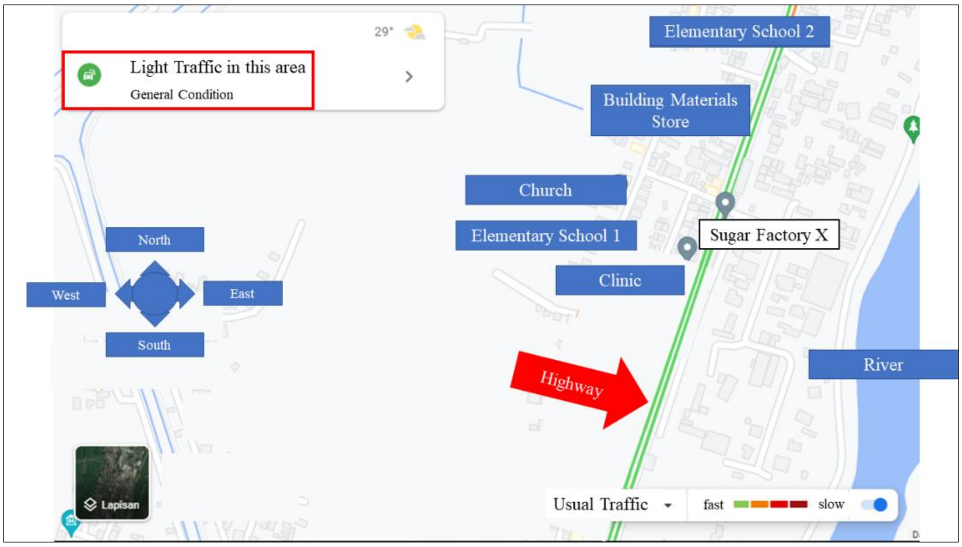

Figure 1 Traffic conditions of Sugar Factory X highway

Table 3 Sources of nitrogen dioxide pollution

Source	**Environmental media**	**Risk agent**	**Measured concentration**		
			Minimal	Average	Maximal
Emissions from the Boiler Chimney of Sugar Factory X	Ambient air	Nitrogen Dioxide (NO_2)	51.4 µg/Nm³ (0.0514 mg/m³)	52.8 µg/Nm³ (0.0528 mg/m³)	54.1 µg/Nm³ (0.0541 mg/m³)

3.4. Dose-response analysis

Nitrogen dioxide (NO_2) enters the bodies of children around industrial areas through the inhalation pathway. The dose-response analysis utilizes the Reference Concentration (RfC) for inhalation exposure. The RfC for NO_2 inhalation pathway is 2E-2 (0.02 mg/kg/day) with the critical effect being respiratory system impairment (12). The RfC values mentioned are sourced from the Integrated Risk Information System (IRIS), which can be accessed through the website www.epa.gov/iris. IRIS is a guideline developed by the United States Environmental Protection Agency (US EPA). According to the study conducted by Darmawan (24), it is mentioned that RfC for NO_2 can refer to the US EPA. This is in line with the statement by the Ministry of Health of the Republic of Indonesia (11) which states that in the dose-response analysis phase, it is not necessary to conduct one's own research or experiments, but it is sufficient to rely on existing literature.

3.5. Exposure analysis

Intake for each weight category will be calculated using formula 1. The recapitulation of NO_2 exposure intake calculations for children based on concentration and weight variations can be seen in the following table.

Table 4 Recapitulation of intake calculation

Weight (W_b)	**Consentration NO_2**		
	Minimal	Average	Maximal
15 kg	0.0394	0.0405	0.0415
20 kg	0.0296	0.0303	0.0311

The exposure analysis results in Table 4 are obtained by inputting the values of each calculation variable into formula 1. The non-carcinogenic inhalation pathway intake for the children age group in residential areas will be calculated based on the numerical values of concentration (C) obtained from the minimum, mean, and maximum NO_2 parameter concentrations derived from the ambient air testing results of Hamlet 1 and Hamlet 2 around Sugar Factory X in June 2022 (Table 3). The values of R, t_E, f_E, D_t, and t_{avg} are obtained from the available default values in the "Exposure Factors Handbook" published by the US EPA (12). Additionally, Wb (15 kg) is obtained from the default values of the Nukman (13) study, and an additional category of 20 kg weight is included to analyze in a more specific manner.

According to Rahman (25), if national default values (based on local, regional, or national surveys) for exposure anthropometric factors are not available, then exposure duration, frequency, and body weight can be derived from the air pollution study conducted in nine cities by Nukman (13) and for other numerical values, they can be obtained from the "Exposure Factors Handbook" published by the US EPA (12). The default values for various variables in the EHRA desktop study, particularly for residential areas targeting children as the risk receptors, are as follows: R (12 $m^3 \approx 0.5$ m^3/hour), t_E (24 hours/day), f_E (350 days/year), D_t (6 years), W_b (15 kg and 20 kg), and t_{avg} (for non-carcinogenic effects, D_t x 365 days/year).

3.6. Risk characterization

Table 5 Recapitulation of risk characterization results

Weight (W_b)	**Consentration NO_2**		
	Minimal	Average	Max
15 kg	1.9715	2.0233	2.0751
20 kg	1.4786	1.51747	1.5563

In the risk characterization phase, the intake values obtained from the calculations in the previous step are compared to the Nitrogen Dioxide (NO_2) Reference Concentration (RfC), which is 0.02 mg/kg/day. The risk characterization is calculated using formula 3. In Table 5, it can be observed that RQ > 1 for all variations of concentrations and children's body weights. These RQ values greater than 1 indicate that the NO_2 exposure concentrations of 0.0514 mg/m^3, 0.0528 mg/m^3, and 0.0541 mg/m^3 are considered unsafe for children weighing 15 kg and 20 kg, with a 24-hour/day inhalation time, exposure frequency of 350 days/year. The effects will be experienced over a period of 6 years of exposure.

Table 5 also indicates that children weighing 15 kg are at a higher risk compared to children weighing 20 kg. This is consistent with Rahman (13) which state that individual characteristics and exposure patterns greatly influence the magnitude of risk an individual. Rahman (13) is exposed to further explains that one of these individual characteristics is body weight, where a higher body weight corresponds to a lower internal dose received. According to the US EPA (26), inhaling air with high concentrations of NO_2 can irritate the airways in the human respiratory system. Such exposure, even for a short period, can worsen respiratory diseases, especially asthma, leading to respiratory symptoms (such as coughing, wheezing, or difficulty breathing), hospitalizations, and emergency room visits. Prolonged exposure to increased NO_2 concentrations can contribute to the development of asthma and potentially increase vulnerability to respiratory infections. People with asthma, children, and the elderly are at a greater risk of health effects from NO_2 exposure. Signs and symptoms of chronic or long-term NO_2 exposure include headaches, difficulty sleeping, sores in the nose and mouth, decreased appetite, tooth erosion, weakened body, chronic bronchitis, and emphysema (27).

3.7. Risk management

The following are the calculations of safe nitrogen dioxide (NO_2) concentrations for children with body weights of 15 kg and 20 kg, calculated using formula 4.

Table 6 Recapitulation of risk management results

Body Weight (W_b)	**Safe concentration of NO_2 (mg/m^3)**
15 kg	0.0261
20 kg	0.0348

The results of risk characteristics in Table 5 indicate RQ > 1 for all variations of concentration and children's body weight. Risk agents that show RQ > 1 or fall into the unsafe category require risk management. According to Rahman (13), risk management that can be conducted under unsafe exposure to pollutants includes: 1) reducing their concentration to safe limits, 2) minimizing contact time, and 3) relocating potential risks to safe areas.

The first method can be implemented for this case of NO_2 exposure in children. The second method is difficult to execute as the children reside in the residential, inevitably being exposed through inhalation pathways for approximately 24 hours. Meanwhile, the third method is challenging and requires substantial financial resources to be carried out. Therefore, the risk management that can be implemented is the first method. As previously indicated in table 2, it is known that the concentration of NO_2 in the ambient air of hamlet 1 and hamlet 2 is actually below the established standard limit. However, the risk characteristic results in table 5 indicate that the concentration of exposure is unsafe for children. By using the formula 4, the safe concentration limit for NO_2 exposure in children around the location of Sugar Factory X can be determined.

From Table 6, it can be observed that the safe concentration for children weighing 15 kg is 0.0261 mg/m^3, and for those weighing 20 kg, it is 0.0348 mg/m^3. Efforts to reduce the concentration of NO_2 can be carried out by replacing the boiler's chimney and the air pollution control equipment installed on the boiler's chimney. Additionally, regular maintenance of the air pollution control equipment is necessary to ensure its proper functionality. Another effort that can be undertaken is the construction of a green belt, which serves as a separation between industrial areas and residential areas to anticipate air pollution originating from industrial zones towards residential zones (28). The types of plants that can be utilized as a green belt to reduce NO_2 pollution include Mahogany (*Swietenia mahagoni*), Tamarind (*Tamarindus indica*), Inocarpus (*Inocarpus vagiferus*), Agathis (*Agathis alba*), and Coral Tree (*Erythrina variegata*).

4. Conclusion

The concentration level of NO_2 produced by Sugar Factory X is unsafe for children living around the factory, especially those weighing 15 kg. Sugar Factory X is expected to reduce the concentration of NO_2 produced by boiler. With the results obtained from this study, it is hoped that the local government and Sugar Factory X can immediately handle this situation and further research can be carried out using EHRA on-site to get valid results in real-time.

Compliance with ethical standards

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Disclosure of conflict of interest

The data used in this study have received permission to be used to publish scientific articles. This article has also never been issued by other publishers. So, this article has no potential conflict of interest.

Statement of ethical approval

This research has obtained approval from the Health Research Ethical Clearance Commission of the Faculty of Dental Medicine, Airlangga University, with certificate number 898/HRECC.FODM/VII/2023.

Statement of informed consent

This research is related to human health but does not directly use humans as research subjects. Secondary data is used as the unit to be analyzed in this study. The relevant agencies have authorized the data used. So, this research does not require informed consent.

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