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Estimated CO and NO_2 Emissions Due to Conventional Brick Kilns in Sidrap Regency, South Sulawesi, Indonesia

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Abstract*—The brick industry in Indonesia utilizes conventional burning methods that significantly impact CO and NO2 emissions, posing a severe environmental threat. The brick burning in Sidenreng Rappang Regency, South Sulawesi, uses rice husks as fuel, an agricultural waste product. Therefore, it is necessary to study the impact of the emissions produced, especially since rice husks contain much carbon. This research takes a unique approach by assessing the effects of CO and NO2 emissions from conventional brick burning in Sidenreng Rappang Regency, South Sulawesi, and examining the impact of husk volume on the combustion of the emissions produced. The research method involves the innovative technique of taking samples of ambient air around the brick kiln using an Impinger and analysis using a UV-Vis spectrophotometer. Air samples were taken at four different points, located at 2m, 4m, 6m, and 8m, from the burning location for eight consecutive days. The results showed that CO and NO_2 concentrations increased significantly during the combustion process, with the highest concentrations at 2m from the combustion location. Meanwhile, the CO and NO_2 concentrations increased at 8m from the combustion location. This research reveals that using rice husks as fuel is closely related to CO and NO_2 emissions concentrations. Furthermore, this concentration is also influenced by environmental conditions, such as vegetation, which can reduce these emissions concentrations. The results of this research provide essential information for controlling air pollutant emissions from the brick industry, especially those that use rice husks as fuel, which can be used to develop air pollution mitigation strategies in the area.

***Keywords*—CO; NO_2; emissions; rice husk; conventional brick kiln.**

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I. INTRODUCTION

Human actions have a disadvantageous impact on the environment by contaminating the water, the air, and the soil [1]–[3]. Air pollution might be a severe threat to human health [4]–[6]. Ambient air pollution is undoubtedly the prime factor of environmental risk for morbidity and mortality [7][8]. Various research has found that ambient air pollutants were related to different harmful health effects, from asymptomatic effects to loss of life [9]–[11]. Ambient urban air pollution contains gaseous elements and particulate matter (PM) [12]. The former include ozone (O_3), volatile organic compounds (VOCs), carbon monoxide (CO), and nitrogen oxides (NOx), and these are settled as stimuli that cause inflammation in the airway. However, the inflammatory effects of PM have been studied to a more prominent degree [13], [14]. Air pollution is especially alarming in developing megacities, such as Beijing, where pollutants from conventional sources, such as solid fuel combustion, are blended with those from advanced vehicles, on top of territorial pollution from industrial and other activities that are anthropogenic [15]. Fossil fuel combustion creates emissions of lasting greenhouse gas carbon dioxide and temporary pollutants, including sulfur dioxide, which add to the accumulation of atmospheric aerosol [16]–[18]. Disarrangement happens throughout the combustion, and fuel that is not burned and partially burnt will remain. Within the process, pollution mainly mixes with air to create further combinations, shaping the partially burnt fuel into an assortment of gasses [19].

Brick kilns are infamous for the precarious amounts of harmful pollutants that emanate into the air, which may have a devastating effect on human health [20]. Bricks are the earliest and the most common construction substance for building Parrock. They are traditionally delivered from clay in a tunnel kiln at soaring temperatures [21]. This technique guides the extensive emission of greenhouse gases [22]. Amid the combustion, the brick is heated and baked at the most extreme temperature of 900–1200ºC, depending on the clay type. The combustion affects the brick quality and requires abundant energy [23].

The growth of the construction industry in Indonesia has triggered the development of the brick industry. The community developed this industry conventionally because the raw materials were accessible. Clay, the main ingredient for making bricks, is widely available in almost all regions of Indonesia. Apart from that, manufacturing methods that do not require special skills have become a driving force for the development of this industry. The brick industry in Indonesia generally uses traditional burning methods. The mass-printed bricks are then arranged vertically to form a furnace. The conventional stove system arranges the bricks so that the combustion can be even. Several articles explain that traditional brick stoves have fuel and air circulation chambers [24]. A previous study by [25], as discussed elsewhere [26]–[29], has shown that burning bricks has an impact on environmental quality, including damage to land quality, health problems for workers and local communities, and disruption to the productivity of domestic animals.

Sidenreng Rappang is one of the brick industry development areas in South Sulawesi. The home industry has been going on for half a century and uses rice husks as firewood. The brick industry was built conventionally, both in terms of firing techniques and workforce management. The burning method using a non-permanent type of furnace without using a chimney is thought to increase greenhouse gas emissions and can endanger human life and other natural resources.

The type of fuel used is rice husk or agricultural waste. This material can be found easily throughout the year and is available in large volumes due to intensive agricultural activities. Industry players are changing wood fuel to husk ash due to the difficulty in obtaining wood fuel with low moisture content.

A burning technique that uses an arrangement of bricks as a furnace and is not permanent. The volume of husk ash used in the firing process needs to be designed systematically according to the number of bricks processed. As a result, industry players need help to predict the burning time and how much husk volume is required in one burning cycle. Industry players also ignore the characteristics of husk, especially its water content. The amount of water in the husk affects the quality of combustion and phase changes at each combustion stage (volatile matter).

The height of the kiln is only adjusted to the volume of bricks being processed. Most industries burn with a stove size of no more than 1.8 meters and do not use a chimney. The exhaust gas discharge chamber practically does not exceed the size of an adult's height. As a result, pollutants contained in exhaust gas have an impact on human health. The risk of pollution due to the brick industry impacts people's lives. Industrial locations in residential areas indicate a risk to air quality, which can indirectly affect human health and vegetation. Thus, the industry is considered to threaten human life, and if control is not carried out, it could threaten the sustainability of the brick industry.

Based on the description of the facts, the pollutant content in brick kiln flue gas is essential to study. The risk of air pollution is increasing due to the increasing number of industries, even in densely populated areas. The findings of this study will contribute to the sustainability and development of an environmentally friendly brick industry. This sustainability means that more and more brick industries are recruiting workers simultaneously and ensuring the welfare of the population in the research area.

This study measures two types of gas: carbon monoxide and nitrogen dioxide. Several studies illustrate that NOx gas in the air disrupts wheat production due to decreased chlorophyll, ascorbic acid, and carotenoid content [30]. NOx and CO emissions have negative impacts on human health and the environment. NOx can irritate the respiratory tract and form dangerous ozone on the earth's surface. In contrast, CO can cause carbon monoxide poisoning and harm human cardiovascular and nervous systems [31]. The concentration of emission gases varies depending on the month of the year [32]. Measurements were carried out at 8 locations with a variety of 4 measurement points, namely a distance of 2 m, 4 m, 6 m, and 8 m from each location. Analysis of CO and NO_2 concentration measurements is also related to the volume of fuel (rice husks) used during the combustion process. Specific data regarding gas emissions from burning rice husks shows that rice husks have low fixed carbon and volatile matter content, producing more CO_2 and particulate emissions than other biomass with higher carbon content [33]. The results of this study can be used to control pollutant concentrations based on fuel use.

II. Materials and Method

A. Materials

The tools used in this study are as follows:

1) Impinger: A tool used to take CO and NO2 samples using the chemical reaction principle of absorbing solutions with polluting gases with a flow rate of 1L/minute - 2 L/minute (Fig. 1).

Fig. 1 Impinger

2) The Midget Impinger Adsorbent Bottle: A tool used to store absorbent solutions during measurement (Fig.2).

Fig. 2 The midget impinger adsorbent bottle

3) Silica Bottle: A tool that stores silica connected to an absorber bottle to prevent water vapor from entering the impinger (Fig. 3).

Fig. 3 Silica bottle

4) Weather Station: A tool used to determine meteorological conditions around the sampling location, such as data on air humidity, pressure, and air temperature (Fig. 4).

Fig. 4 Weather station

5) Tripod: A tool used to prop/sustain the impinger (Fig. 5).

Fig. 5 Tripod

6) Cables: Tools used to connect the impinger to a power source (Fig. 6).

Fig. 6 Cables

7) Cool Box: A tool used to store measurement samples and blanks before analysis in the laboratory (Fig.7).

Fig. 7 Cool box

B. Study Area

This study was carried out in Watang Pulu Subdistrict, Sidrap Regency, South Sulawesi, Indonesia, at latitude 03°54'081" - 03°54’122"S and longitude 119°44'365" - 119°44'475"E. The location of this research is the local brick industry in Sidrap Regency. This industry uses conventional brick kilns. There are three sampling points (Figures 8 and 9), and the characteristics are shown in Table I.

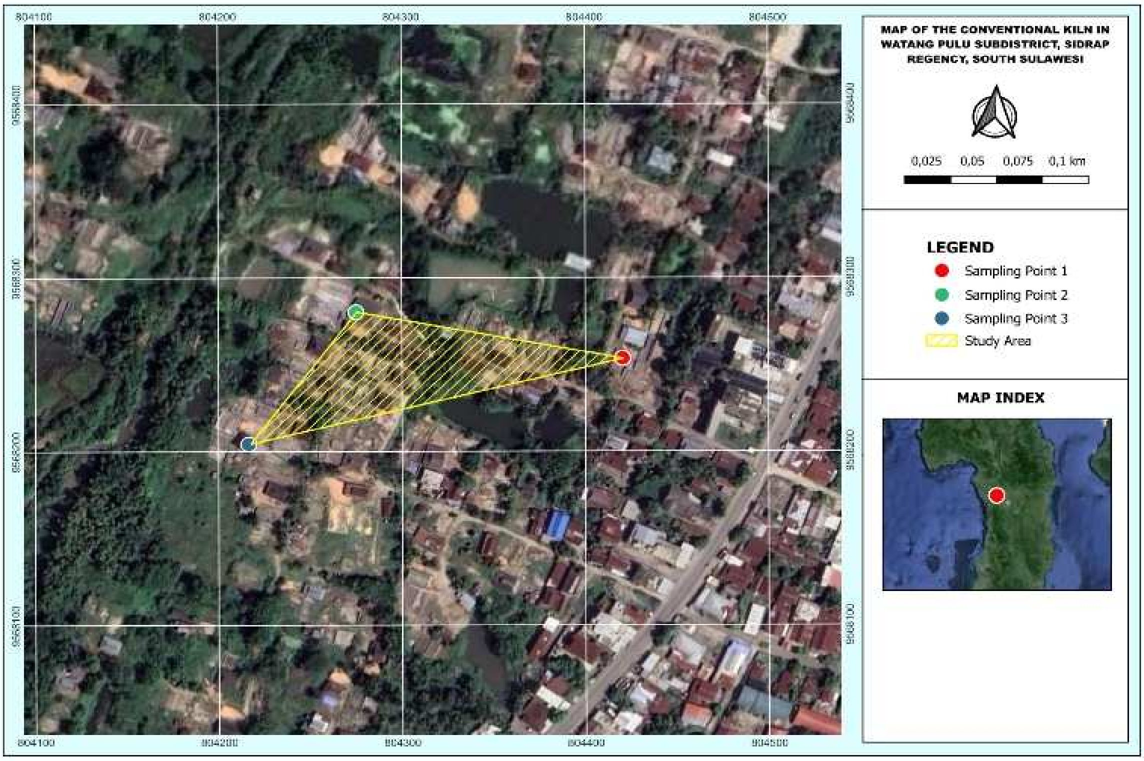

Fig. 8 Map of the conventional kiln in the sampling area

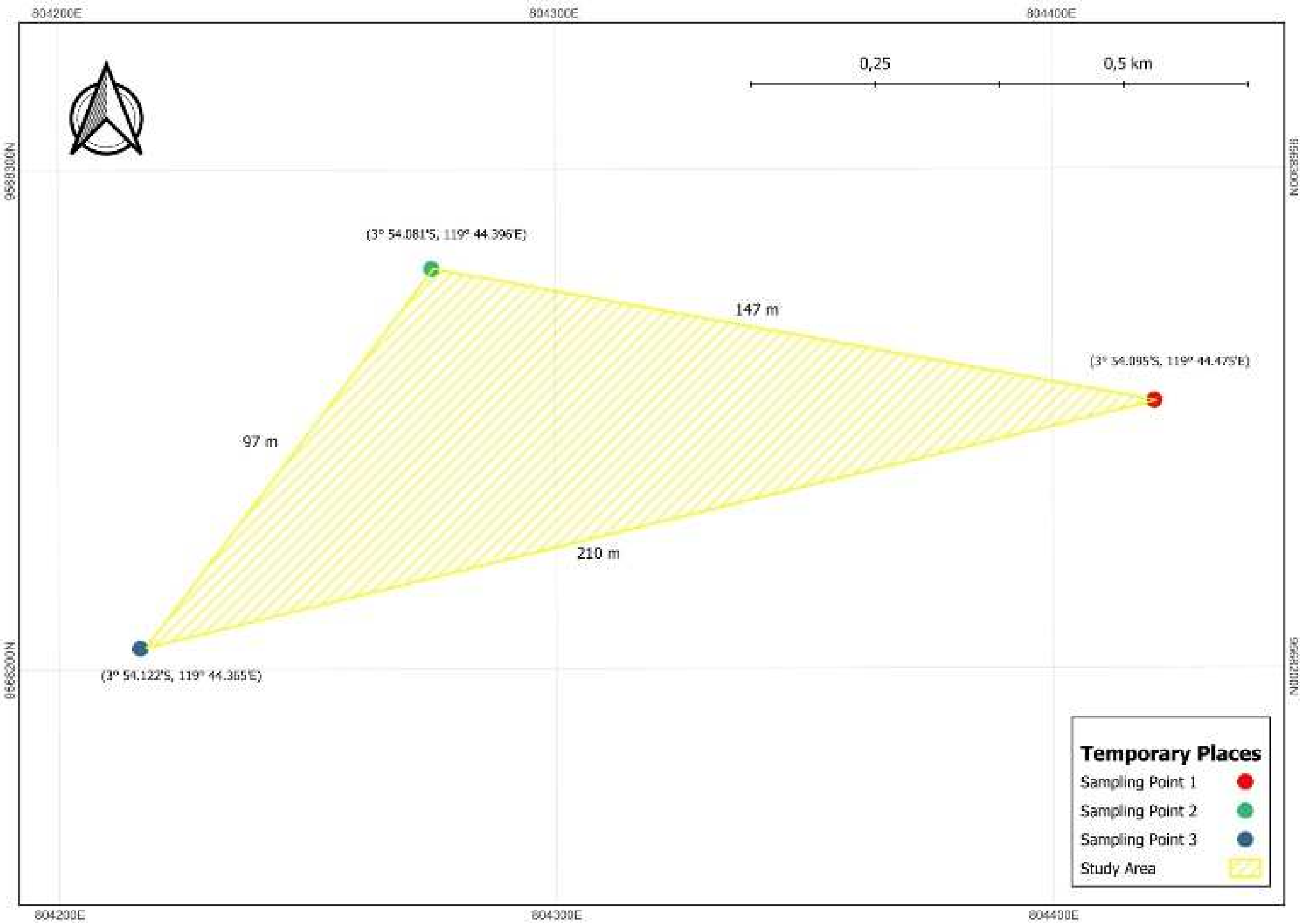

Fig. 9 The sampling area

TABLE I
THE CHARACTERISTICS OF THE SAMPLING POINTS

Sampling point	**The brick industry activity area (m^2)**	**The presence of vegetation around the kiln**	**The kiln with chimney**
1	277.5	Yes	No
2	205.9	No	No
3	198.2	Yes	No

C. Research Method

The brick combustion in the local industry is carried out in Sidrap Regency, South Sulawesi. This combustion process uses rice husk fuel (waste from rice factories) and is executed by arranging bricks, as shown in Figures 10, 11, and 12. Data CO and NO^2 are collected using an Impinger and analyzed using a UV-Vis spectrophotometer. Ambient air sampling was carried out at four points at different distances: 2 m, 4 m, 6 m, and 8 m, respectively, from the brick kiln location. The ambient air tests include CO (carbon monoxide) and NO_2 (nitrogen dioxide). Measurements were carried out daily during the brick-burning process, specifically for eight days. The pile of bricks in one burn can reach the amount of 30,000–40,000 bricks, depending on the kiln's capacity.

Fig. 10 Rice husks

Fig. 11 Conventional brick kiln

Fig. 12 Impinger tools

D. Research Variables

The variables in this study are the parameter values of ambient air pollutants CO (carbon monoxide) and NO_2 (nitrogen dioxide) with variations in sampling points, days, and distance of the combustion process. The CO parameters were obtained using an adsorbing solution of $AgNO_3$ 0.1 M and NH_4OH 0.1 M spectrophotometrically. Carbon monoxide gas is adsorbed in the adsorbing solution to form a dark yellowish color. The solution concentration was determined spectrophotometrically at a wavelength of 550 nm (µg m^{-3}). The NO_2 parameters were obtained spectrophotometrically using the Griess-Saltzman method [34]. Nitrogen dioxide gas is absorbed in the Griess Saltzman solution to a red-violet azo-dye-forming, which is stable after 15 minutes. The solution concentration was determined spectrophotometrically at a wavelength of 550 nm (µg m^{-3}). Another variable from this research is the weight of rice husks used in the burning process. This variable is measured by weighing the amount of rice husks put into the furnace and measured in kg.

E. Data Analysis

This research uses three analysis stages: emission concentration analysis, emission increase analysis, and polynomial regression analysis. Emission concentration analysis aims to describe air quality in the brick kiln area. The data analysis used in this research is descriptive analysis, which provides an overview of the data obtained from the results of air quality measurements at local industrial brick kilns in Sidrap District. The CO gas concentration is calculated by converting the absorbance value obtained from laboratory analysis into µg m^{-3} units using equation 1 for each sample, namely:

$$CO = \frac{[y]\times Final\ Solution\ Vol.\ (L)\ Temp.(K)\times 760\ mmHg \times Molecular\ Weight\ \left(\frac{gr}{mol}\right)\times 10\hat{}6}{\text{Flow rate}\left(\frac{\text{L}}{\text{Min.}}\right)\times Sampling\ time\ (60\ min.)\times P\ (mmHg)298K\ \times 24{,}45\ \left(\frac{L}{mol}\right)} \quad (1)$$

whereas Y is absorbance concentration based on linear regression.

The amount of NO_2 (µg) in 1 ml of standard solution used in the calibration curve (b) can be calculated using equation 2 (SNI 7119.2-2017). SNI is the Indonesian National Standard.

$$NO_2 = \frac{a}{100} \times \frac{46}{69} \times \frac{1}{l} \times \frac{10}{1000} \times 10^6 \quad (2)$$

whereas NO_2 is the amount of NO_2 in the standard $NaNO_2$ solution (µg ml^{-1}), a is the weight of the $NaNO_2$ weighed (g), 46/69 is molecular weight of $NaNO_2$, is factor that shows the number of moles of $NaNO_2$ (f value = 0.82), 10/100 is dilution factor of $NaNO_2$ stock solution and 10^6 is grams to µg conversion.

The total volume of air taken under normal conditions of 25ºC 760 mmHg (Nm3) (v) can be calculated using equation 3 (SNI 7119.2-2017).

$$V = \frac{\sum_{i=1}^{n} Qi}{n} \times t \times \frac{pa}{ta} \times \frac{298}{760} \quad (3)$$

whereas V is air volume (Nm^3), Qi is i-th flow rate (Nm^3/minute) records, n is number of flow rate records, t is duration of test sampling (minutes), Pa is average barometric pressure during test sampling (mmHg), Ta is average temperature during test sampling in Kelvin (K), 298 is the temperature under normal conditions (25ºC) into Kelvin (K) conversion, and 760 is standard air pressure (mmHg).Based on equations 2 and 3, the total NO_2 concentration in the ambient air can be calculated using equation 4 (SNI 7119.2-2017).

$$C = \frac{b}{v} \times \frac{10}{25} \times 1000 \quad (4)$$

whereas C is NO_2 concentration in the air (µg m^{-3}), b is the amount of NO_2 from the test sample calculated (used calibration curve) (µg), v is corrected air volume under standard conditions 25ºC 760 mmHg (Nm^3), 10/25 is dilution factor, and 1000 is liter to m^3 conversion.

Analysis of increased emissions shows the comparison of CO and NO_2 concentrations on the last day of burning with the first day. This analysis uses the percentage method to see changes in emission concentrations. Polynomial regression analysis determines the trend of increasing emissions due to the amount of husk used in the combustion process. This analysis produces a better R^2 value and shows the level of determination between the two variables. The data obtained is analyzed using regression analysis to estimate the relationship between the rice husk and CO and NO_2 variables. It can be utilized to assess the strength of the relationship between variables and for modeling the future relationship between them [35].

III. Results and Discussion

A. Results

1) CO Concentration due to Burning Duration Figure 13 shows the CO (Carbon Monoxide) concentration measured at sampling point 1 at a distance of 2 meters, 4 meters, 6 meters, and 8 meters from the emission source during the burning duration from day 1 to day 8. The highest CO concentration was recorded at a distance of 2 meters and tends to decrease with increasing distance. At a distance of 2 meters, concentrations ranged from 5.733 to 6.658 µg m^{-3}. At a distance of 4 meters, the concentration decreased to between 3.932 to 4.876 µg m^{-3}, and further away at 6 meters and 8 meters, it ranged from 2.225 to 3.291 µg m^{-3} and 1.108 to 2.262 µg m^{-3}, respectively. The general trend shows increased CO concentration with increasing burning time, with the highest concentration on day eight at all measurement distances. The significant decrease at longer distances indicates that dispersion occurs in the air as the distance from the emission source increases.

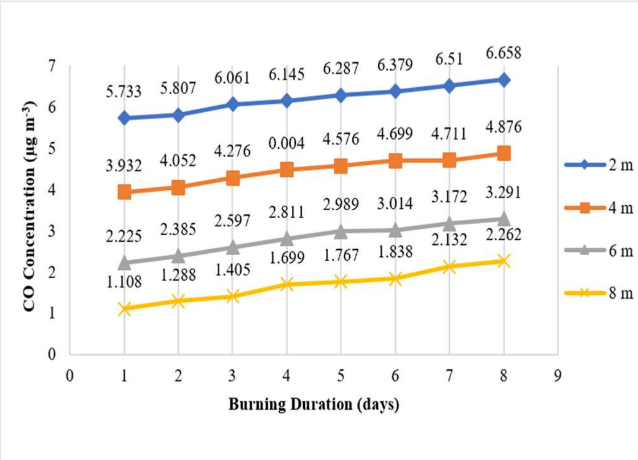

Fig. 13 Relation between burning duration and CO concentration at various measurement distances (sampling point 1)

Figure 14 depicts the CO concentration at sampling point 2, measured at a distance of 2 meters, 4 meters, 6 meters, and 8 meters for eight days of burning. Just like at sampling point 1, the highest CO concentration was measured at a distance of 2 meters and decreased with increasing distance. However, the CO concentration at sampling point 2 was slightly lower than at sampling point 1. At a distance of 2 meters, the concentration ranged from 5.672 to 6.974 μg m^{-3}. At a distance of 4 meters, the concentration decreased to between 3.791 to 4.968 μg m^{-3}, and further away at 6 meters and 8 meters, it ranged from 2.199 to 3.077 μg m^{-3} and 1.007 to 2.502 μg m^{-3}, respectively. The increase in CO concentration from day 1 to day 8 was also clearly visible, with a significant decrease at longer distances.

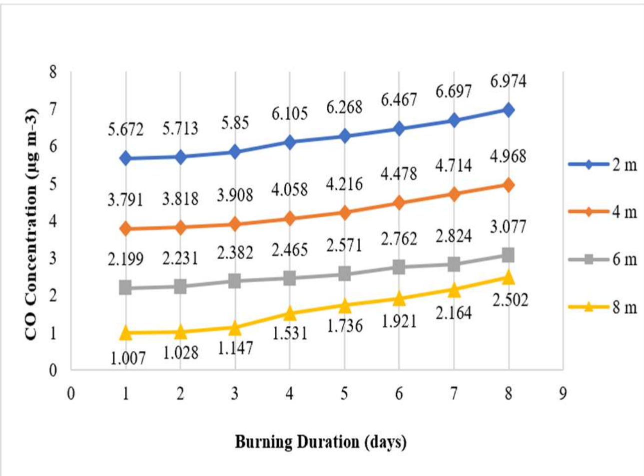

Fig. 14 Relation between burning duration and CO concentration at various measurement distances (sampling point 2)

Figure 15 displays the CO concentration at sampling point 3. The observed pattern is similar to sampling points 1 and 2, where the highest CO concentration was recorded at a distance of 2 meters and decreased at a distance of 4 meters, 6 meters, and 8 meters. The increase in concentration from day 1 to day 8 was also consistently seen at sampling point 3. However, the CO concentration at sampling point 3 was slightly higher than at sampling point 2, but it was similar to sampling point 1. At a distance of 2 meters, with a range of 5.105 to 6.203 μg m^{-3}. At a distance of 4 meters, concentrations ranged from 4.337 to 5.516 μg m^{-3}. At 6 and 8 meters, it ranges from 2.988 to 4.135 μg m^{-3} and 1.677 to 2.877 μg m^{-3}, respectively.

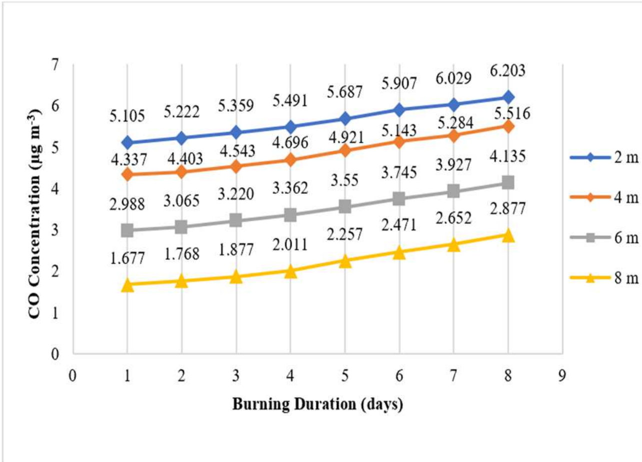

Fig. 15 Relation between burning duration and CO concentration at various measurement distances (sampling point 3)

2) NO_2 Concentration due to Burning Duration: Figure 16 shows the concentration of NO_2 (Nitrogen Dioxide) at sampling point 1 at the same distance as the CO measurement. The highest NO_2 concentration was detected at a distance of 2 meters from the emission source and decreased with increasing distance. As the burning time progressed from day 1 to day 8, the NO_2 concentration also increased significantly, especially at a distance of 2 meters and 4 meters. At a distance of 2 meters, the circumferential concentration is between 14.527 to 18.501 μg m^{-3}, while at a distance of 4 meters, the concentration decreases to 11.536 to 15.638 μg m^{-3}. The decrease in concentration at a greater distance shows the dispersion effect in the air.

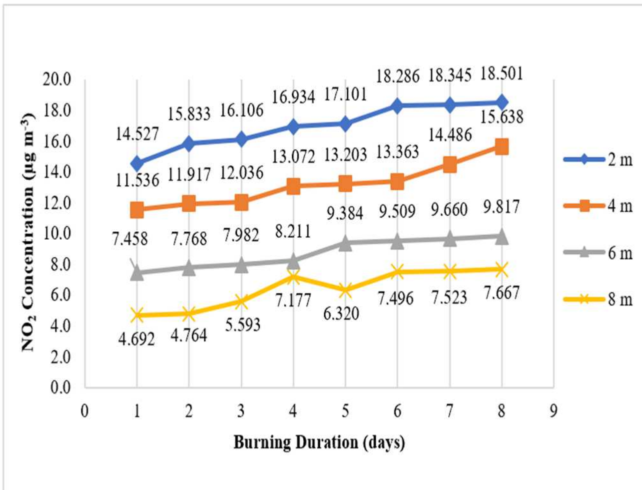

Fig. 16 Relation between burning duration and NO_2 concentration at various measurement distances (sampling point 1)

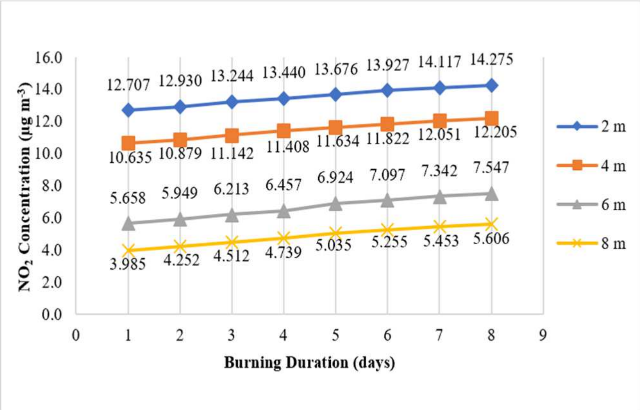

Fig. 17 Relation between burning duration and NO_2 concentration at various measurement distances (sampling point 2)

Figure 17 depicts the NO_2 concentration at sampling point 2, following a similar pattern to sampling point 1. The highest concentration was recorded at a distance of 2 meters, with a significant decrease at distances of 4 meters, 6 meters, and 8 meters. At a distance of 2 meters, the concentration ranges from 12.707 to 14.275 µg m^{-3}, while at a distance of 4 meters, it ranges from 10.635 to 12.205 µg m^{-3}. An increase in concentration from day 1 to day eight was also seen at sampling point 2, although with a slightly lower value than sampling point 1.

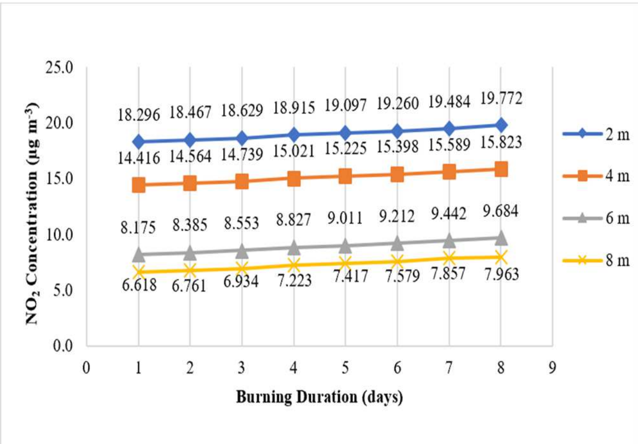

Fig. 18 Relation between burning duration and NO_2 concentration at various measurement distances (sampling point 3)

Figure 18 displays the NO_2 concentration at sampling point 3, which follows the same pattern as the previous two locations. The highest NO_2 concentration was found at a distance of 2 meters and decreased with increasing distance. At a distance of 2 meters, with a range of 18.296 to 19.772 µg m^{-3}. At a distance of 4 meters, concentrations ranged from 14.416 to 15.823 µg m^{-3}. The increase in concentration from day 1 to day 8 was evident at sampling point 3, with concentrations slightly higher than at sampling point 2 but similar to sampling point 1.

3) The volume of Rice Husk during the Burning Process: Conventional kilns for burning bricks use rice husks as fuel. The study of emissions due to combustion cannot be separated from the type of fuel and its volume. Therefore, researchers calculated the fuel volume for eight days of burning at three observation locations (Table II).

TABLE II
VOLUME OF RICE HUSK DURING THE BURNING PROCESS

Burning Duration (days)	Rice Husk (kg)		
	Sampling Point 1	Sampling Point 2	Sampling Point 3
1	5148.42	3615.20	4395.78
2	8752.31	6145.84	7472.83
3	12098.78	8495.73	10330.08
4	15084.86	10592.54	12879.64
5	16886.80	12175.09	14489.53
6	18534.30	13331.96	15896.18
7	20181.79	14488.82	17302.83
8	21468.89	15356.47	18357.81

The process of burning bricks requires that all the stones arranged in a furnace must receive heat. The volume of rice husks is crucial to ensure the fire stays lit and spreads heat throughout the furnace area. Table 2 explains the accumulated value of rice husks from day one to day eight. The volume of rice husks on day 8 showed four times the initial combustion volume. Apart from that, the combustion process in the furnace is also influenced by the air conditions in the furnace. If the furnace space is mainly filled with husks, the combustion process will be slow due to the lack of air. On the other hand, if the fuel volume is small, it can also prevent the fire in the furnace from spreading evenly.

B. Discussion

1) The Increase of CO Concentration: Figure 19 shows data on the increase in CO concentration at three different sampling points measured at various distances from the source of burning rice husks, namely at a distance of 2, 4, 6, and 8 meters. At Sampling Point 1, the CO concentration increased from 16.13% at a distance of 2 meters to 104.15% at 8 meters. At Sampling Point 2, the CO concentration increased from 22.95% at 2 meters to 148.46% at 8 meters. Meanwhile, at Sampling Point 3, an increase was seen from 21.51% at 2 meters to 71.56% at 8 meters.

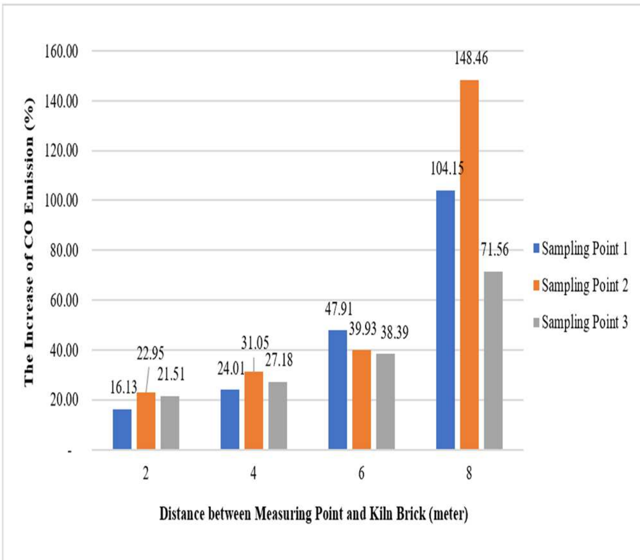

Fig. 19 The increase in CO concentration at the three sampling points

This data shows that the increase in CO concentration tends to be more significant at a greater distance from the combustion source for most sampling points, especially at Sampling Point 2, which shows the sharpest increase. Variations between measurement locations suggest that local environmental factors, such as wind direction and topography, may influence the distribution and concentration of CO emissions in the area surrounding the combustion source. These findings emphasize the importance of considering distance and location in managing and monitoring air quality to reduce the negative impact of harmful gas emissions.

CO concentrations from the brick-burning process generally result from incomplete solid fuel combustion. In other words, most of the heat produced is released into the air and encourages the release of CO gas into the air [36]. Specifically, the phenomenon at Sampling Point 2 showed the sharpest increase. The phenomenon of increasing CO emissions at this location can be related to the condition of the vegetation around the brick industry. At Sampling Point 1 and Sampling Point 3, the location survey showed the presence of tree vegetation. This allows the absorption of emissions by the vegetation. In contrast to Sampling Point 2, researchers found no trees that caused higher CO emissions. This is in line with Velasco's and Kafy's description [37], [38] that the characteristics of trees and permeable surfaces influence the level of carbon absorption in the air. Vegetation and landscape are very effective in reducing carbon emissions from burning biomass.

However, variations between measurement locations indicate that local environmental factors, such as wind direction and topography, influence the distribution and concentration of CO emissions around the combustion source. These findings emphasize the importance of considering distance and location in managing and monitoring air quality to reduce the negative impact of harmful gas emissions.

2) The Increase of NO_2 Concentration: Based on the graph in Figure 20, it can be seen that the increase in NO_2 concentration varies depending on the distance from the emission source and the specific measurement point. At Sampling Point 1, NO_2 concentration increased from 27.36% at a distance of 2 meters to 63.41% at a distance of 8 meters, showing a clear pattern of increase. At Sampling Point 2, the NO_2 concentration increased from 12.34% at 2 meters to 40.68% at 8 meters, with a sharper increase at greater distances. Meanwhile, at Sampling Point 3, the increase in NO_2 concentration was more moderate, from 8.07% at a distance of 2 meters to 20.32% at a distance of 8 meters. This analysis shows that the increase in NO_2 concentrations tends to be more significant at greater distances from the emission source, especially at Sampling Points 1 and 2. Sampling Point 1 shows the most consistent and significant increase with distance, while Sampling Point 3 shows a more stable and less sharp. The increase in NO_2 emissions due to burning rice husks is in line with the results of Yerizam's research [39], which found that biomass fuel produces NO_2 emissions. Furthermore, in another study, the distribution of NO_2 emissions was greatly influenced by the distance of the sampling point to the emission source and the stability of the air in the atmosphere [40]–[42].

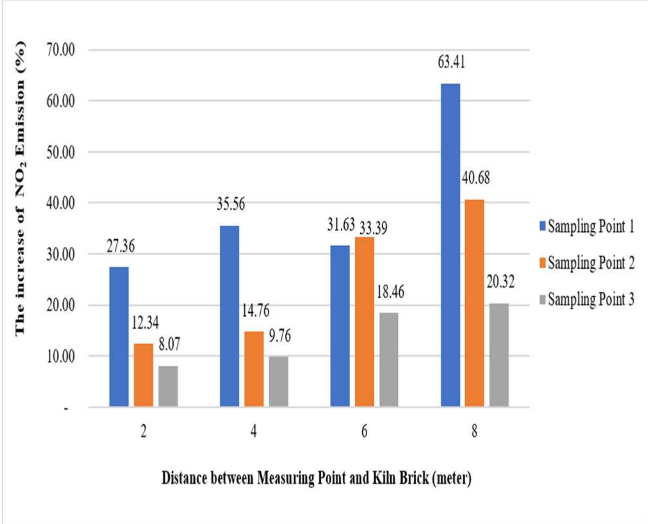

Fig. 20 The increase in NO_2 concentration at the three sampling points

3) The Increase of CO Concentration due to Rice Husk Volume: Burning bricks using rice husks as fuel affects the concentration of CO emissions. Tables III, IV, V, and VI describe the equation of relation between rice husk volume (x) and CO concentration at the ordinate value.

TABLE III
EQUATION OF THE RELATION BETWEEN CO CONCENTRATION AND RICE HUSK VOLUME (2 M DISTANCE)

Sampling Point	CO Concentration (µg m^{-3})	
	Regression	R Square
1	$y = 2E\text{-}09x^2 + 1E\text{-}05x + 5.6353$	0.9900
2	$y = 1E\text{-}08x^2 - 1E\text{-}04x + 5.8913$	0.9951
3	$y = 8E\text{-}09x^2 - 4E\text{-}05x + 5.1738$	0.9950

TABLE IV
EQUATION OF THE RELATION BETWEEN CO CONCENTRATION AND RICE HUSK VOLUME (4 M DISTANCE)

Sampling Point	CO Concentration (µg m^{-3})	
	Regression	R Square
1	$y = 7E\text{-}10x^2 + 5E\text{-}05x + 3.6675$	0.9894
2	$y = 1E\text{-}08x^2 - 0.0001x + 4.1769$	0.9906
3	$y = 1E\text{-}08x^2 - 8E\text{-}05x + 4.4988$	0.9963

TABLE V
EQUATION OF THE RELATION BETWEEN CO CONCENTRATION AND RICE HUSK VOLUME (6 M DISTANCE)

Sampling Point	CO Concentration (µg m^{-3})	
	Regression	R Square
1	$y = 1E\text{-}09x^2 + 5E\text{-}05x + 1.9795$	0.9943
2	$y = 7E\text{-}09x^2 - 6E\text{-}05x + 2.3271$	0.9778
3	$y = 9E\text{-}09x^2 - 7E\text{-}05x + 3.1269$	0.9960

TABLE VI
EQUATION OF THE RELATION BETWEEN CO CONCENTRATION AND RICE HUSK VOLUME (8 M DISTANCE)

Sampling Point	CO Concentration (µg m^{-3})	
	Regression	R Square
1	$y = 4E\text{-}09x^2 - 2E\text{-}06x + 1.0676$	0.9846
2	$y = 1E\text{-}08x^2 - 0.0001x + 1.2367$	0.9923
3	$y = 1E\text{-}08x^2 - 9E\text{-}05x + 1.8947$	0.9947

The results of calculating the relationship between two variables focus on the R Square value and the constant value in the polynomial regression equation. The R Square value for the three observation locations at four observation distances is more significant than 0.98. These results indicate that the CO concentration is strongly influenced by the volume of rice husks used in the combustion process. The R Square value decreases as the sampling distance from the furnace increases. These data illustrate that the level of accuracy in CO emission estimates is getting smaller due to the location being further away from the furnace. This is caused by the dispersion of pollutants, pollutant accompanying substances, and the risk of other pollutant sources. The constant value in the equation also varies between 1.0676 μg m^{-3} and 5.8913 μg m^{-3}. This value indicates the concentration of CO emissions originating from the brick-burning process. The most significant constant value was obtained at a distance of 2 meters and decreased as the distance between the sampling point and the furnace increased. This value decreases as the distance from the observation point rises.

The first CO emission measurement was carried out 24 hours after the fire spread evenly in the furnace. The equation constant at Sampling Point 1 and a distance of 2 meters shows 5.8913 μg m^{-3}, indicating the CO concentration after 24 hours of brick burning. This figure shows 5.8913 μg CO in the air with a volume of one cubic meter. This figure decreases 8 meters from the sampling point; there is 1.0676 μg CO in the same air volume. This phenomenon indicates that CO emissions are dispersed.

Previous studies revealed that pollutant dispersion occurs vertically and horizontally and is influenced by temperature and wind speed [43]. Horizontally, the air coming out of the furnace is at a height of between 1.2 meters and 1.8 meters, which causes the air to spread more slowly. This happens because the wind speed above 2 meters is higher than at a lower location. The results of this study are in accordance with the results of Gianfelice's and Huang's studies [44][45], which show that wind speeds vary at each altitude interval. The higher you are from the ground, the higher the wind speed at that point. Wind speed causes the spread of pollutants into urban areas, affecting residents' health conditions and the quality of surrounding vegetation [46].

4) The Increase of NO_2 Concentration due to Rice Husk Volume: The increase in NO_2 emissions due to the volume of husk used is presented in Tables VII, VIII, IX, and X. The polynomial regression equation is to see the close relationship between two variables and the constant value as the basic concentration of NO_2 emissions.

TABLE VII
EQUATION OF THE RELATION BETWEEN NO2 CONCENTRATION AND RICE HUSK VOLUME (2 M DISTANCE)

Sampling Point	NO_2 Concentration (μg m^{-3})	
	Regression	R Square
1	$y = 1E\text{-}09x^2 + 0.0002x + 13.534$	0.9651
2	$y = 5E\text{-}09x^2 + 4E\text{-}05x + 12.515$	0.9974
3	$y = 9E\text{-}09x^2 - 3E\text{-}05x + 18.325$	0.9929

TABLE VIII
EQUATION OF THE RELATION BETWEEN NO2 CONCENTRATION AND RICE HUSK VOLUME (4 M DISTANCE)

Sampling Point	NO_2 Concentration (μg m^{-3})	
	Regression	R Square
1	$y = 2E\text{-}08x^2 - 0.0003x + 12.499$	0.9489
2	$y = 5E\text{-}09x^2 + 4E\text{-}05x + 10.429$	0.9996
3	$y = 1E\text{-}08x^2 - 7E\text{-}05x + 14.674$	0.9965

TABLE IX
EQUATION OF THE RELATION BETWEEN NO2 CONCENTRATION AND RICE HUSK VOLUME (6 M DISTANCE)

Sampling Point	NO_2 Concentration (μg m^{-3})	
	Regression	R Square
1	$y = 8E\text{-}09x^2 - 7E\text{-}06x + 7.2953$	0.9306
2	$y = 7E\text{-}09x^2 + 2E\text{-}05x + 5.4956$	0.9951
3	$y = 8E\text{-}09x^2 - 2E\text{-}05x + 8.1695$	0.9954

TABLE X
EQUATION OF THE RELATION BETWEEN NO2 CONCENTRATION AND RICE HUSK VOLUME (8 M DISTANCE)

Sampling Point	NO_2 Concentration (μg m^{-3})	
	Regression	R Square
1	$y = 2E\text{-}09x^2 + 0.0002x + 3.5389$	0.8920
2	$y = 5E\text{-}09x^2 + 4E\text{-}05x + 3.7879$	0.9984
3	$y = 8E\text{-}09x^2 - 1E\text{-}05x + 6.5812$	0.9974

The level of closeness of the relationship between rice husk volume and NO_2 concentration ranges from 0.9626 – 0.9851. In other words, the weight of rice husks used in the combustion process is closely related to NO_2 emissions. The level of closeness decreases as the observation distance from the furnace increases. The constant value at an observation distance of 2 meters ranges from 12.515 to 18.325. This indicates that NO_2 emissions that do not originate from rice husks are worth 12.515 μg m^{-3}. If we look at the highest NO_2 emission figure at 2 meter observation at sampling point 1, it appears that the constant value is 18.501, while the NO_2 emission at the same sampling point is 13.534 μg m^{-3}, then it can be concluded that the NO_2 emission value due to burning rice husks is only around 4.967 μg m^{-3}. In other words, NO_2 emissions in the brick-burning process do not originate from burning husks but come from burning clay as the primary material for bricks.

As a ceramic industry, the brick industry is a NO gas producer. Nitrogen dioxide gas is formed at high temperatures due to combustion. The formation of NO_x concentrations in the air is caused by the oxidation process in the atmosphere with the air released from burning bricks [47]. The increase in NO emissions in the air due to burning bricks must be a concern [48]. The NO_x oxidation process in the atmosphere produces nitric acid, the main component of acid rain. Decomposed NO_x will easily combine with organic compounds, evaporating and forming O_3 [49]. In addition, NO_x gas is a particulate pollutant that affects plant morphology due to limitations in photosynthetic pigments. This influence will result in a decrease in crop production [50]. Therefore, many studies offer various emission control technologies from the brick industry [51].

The description of the research results shows that industrial bricks with traditional kiln models can impact the risk of air pollution. Industrial locations combined with residential locations and rice fields have an impact on reducing environmental quality and human health [52]. Additionally, crop production in rice fields is at risk due to increased pollutant emissions. The emission control method of the brick industry can be overcome by controlling the number of bricks produced in one cycle to prevent the accumulation of pollutants in the air [53].

IV. Conclusion

This study describes the CO and NO2 emission concentrations resulting from 8 days of red brick burning in Sidenreng Rappang District, South Sulawesi, Indonesia. The CO concentration decreases with increasing distance from the combustion source. However, the further the distance from the source, the more significant the increase in CO concentration produced. This can be seen from the increase in CO concentration at a distance of 2 meters from the combustion source, which is 16.12-22.95%. Meanwhile, the increase at a distance of 8 meters was 71.56-148.48%.

The NO_2 concentration decreases with increasing distance from the combustion source, as happens with the CO concentration. However, although there is an increase in NO_2 concentration with increasing distance, the magnitude is smaller than the increase in CO concentration. This is proven by the increase in NO_2 concentration at a distance of 2 meters from the combustion source of 8.07-27.36%. Meanwhile, the increase at a distance of 8 meters is only 20.32-63.41%.

The volume of rice husks used in the brick-burning process influences increasing CO concentrations. Larger husk volumes allow for more prolonged and more intense burning, which can result in more CO emissions. As with CO, increasing the volume of rice husks used in brick kilns can also cause an increase in NO_2 emissions. Large volumes of husk cause more intense combustion and produce more NO_2 as a byproduct of burning organic matter.

Nomenclature

Y	absorbance concentration based on linear regression	
a	The weight of the $NaNO_2$ weighed	g
V	Air volume	Nm^3
Qi	i-th flow rate records	
Nm^3/minute n	Number of flow rate records	
t	Duration of test sampling	minutes
Pa	Average barometric pressure during test sampling	mmHg
Ta	Average temperature during test sampling	Kelvin (K)
C	NO_2 concentration in the air	$\mu g\ m^{-3}$
b	The amount of NO_2 from the test sample calculated (used calibration curve)	µg
v	corrected air volume under standard conditions 25ºC 760 mmHg	Nm^3

References

[1] I. Manisalidis, E. Stavropoulou, A. Stavropoulos, and E. Bezirtzoglou, "Environmental and Health Impacts of Air Pollution: A Review," *Frontiers in Public Health*, vol. 8, Feb. 2020, doi:10.3389/fpubh.2020.00014.

[2] S. F. Ahmed et al., "Heavy metal toxicity, sources, and remediation techniques for contaminated water and soil," *Environmental Technology & Innovation*, vol. 25, p. 102114, Feb. 2022, doi:10.1016/j.eti.2021.102114.

[3] L. Wang et al., "Remediation of mercury contaminated soil, water, and air: A review of emerging materials and innovative technologies," *Environment International*, vol. 134, p. 105281, Jan. 2020, doi:10.1016/j.envint.2019.105281.

[4] W. H. Organization, "Ambient (outdoor) air quality and health. 2018," *Retrieved from World Heal. Organ. Available from http//www. who. int/mediacentre/factsheets/fs313/en/*, 2016.

[5] A. A. Almetwally, M. Bin-Jumah, and A. A. Allam, "Ambient air pollution and its influence on human health and welfare: an overview," *Environmental Science and Pollution Research*, vol. 27, no. 20, pp. 24815–24830, May 2020, doi: 10.1007/s11356-020-09042-2.

[6] V. V. Tran, D. Park, and Y.-C. Lee, "Indoor Air Pollution, Related Human Diseases, and Recent Trends in the Control and Improvement of Indoor Air Quality," *International Journal of Environmental Research and Public Health*, vol. 17, no. 8, p. 2927, Apr. 2020, doi:10.3390/ijerph17082927.

[7] A. J. Cohen et al., "Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015," *The Lancet*, vol. 389, no. 10082, pp. 1907–1918, May 2017, doi: 10.1016/s0140-6736(17)30505-6.

[8] N. Singh, S. Singh, and R. K. Mall, "Urban ecology and human health: implications of urban heat island, air pollution and climate change nexus," *Urban Ecology*, pp. 317–334, 2020, doi:10.1016/b978-0-12-820730-7.00017-3.

[9] J. Wang et al., "Associations between ambient air pollution and mortality from all causes, pneumonia, and congenital heart diseases among children aged under 5 years in Beijing, China: A population-based time series study," *Environmental Research*, vol. 176, p. 108531, Sep. 2019, doi: 10.1016/j.envres.2019.108531.

[10] H. Xu et al., "Environmental pollution, a hidden culprit for health issues," *Eco-Environment & Health*, vol. 1, no. 1, pp. 31–45, Mar. 2022, doi: 10.1016/j.eehl.2022.04.003.

[11] P. Kumar, A. B. Singh, T. Arora, S. Singh, and R. Singh, "Critical review on emerging health effects associated with the indoor air quality and its sustainable management," S*cience of The Total Environment*, vol. 872, p. 162163, May 2023, doi:10.1016/j.scitotenv.2023.162163.

[12] J. A. Flood-Garibay, A. Angulo-Molina, and M. Á. Méndez-Rojas, "Particulate matter and ultrafine particles in urban air pollution and their effect on the nervous system," *Environmental Science: Processes & Impacts*, vol. 25, no. 4, pp. 704–726, 2023, doi:10.1039/d2em00276k.

[13] D. A. Glencross, T.-R. Ho, N. Camiña, C. M. Hawrylowicz, and P. E. Pfeffer, "Air pollution and its effects on the immune system," *Free Radical Biology and Medicine*, vol. 151, pp. 56–68, May 2020, doi:10.1016/j.freeradbiomed.2020.01.179.

[14] I. M. Dijkhoff et al., "Impact of airborne particulate matter on skin: a systematic review from epidemiology to in vitro studies," *Particle and Fibre Toxicology*, vol. 17, no. 1, Jul. 2020, doi: 10.1186/s12989-020-00366-y.

[15] K. R. Daellenbach et al., "Sources of particulate-matter air pollution and its oxidative potential in Europe," *Nature*, vol. 587, no. 7834, pp. 414–419, Nov. 2020, doi: 10.1038/s41586-020-2902-8.

[16] D. Shindell and C. J. Smith, "Climate and air-quality benefits of a realistic phase-out of fossil fuels," *Nature*, vol. 573, no. 7774, pp. 408–411, Sep. 2019, doi: 10.1038/s41586-019-1554-z.

[17] V. Fagorite, A. Anifowose, and N. Chiokwe, "Air Pollution; Causes, Effects and Remediation in Nigeria," *International Journal of Advanced Academic Research*, pp. 13–30, Jan. 2021, doi:10.46654/ij.24889849.e7114.

[18] S. Fadnavis et al., "Atmospheric Aerosols and Trace Gases," *Assessment of Climate Change over the Indian Region*, pp. 93–116, 2020, doi: 10.1007/978-981-15-4327-2_5.

[19] A. Azhari, N. D. A. Halim, A. A. A. Mohtar, K. Aiyub, M. T. Latif, and M. Ketzel, "Evaluation and Prediction of PM10 and PM2.5 from Road Source Emissions in Kuala Lumpur City Centre," *Sustainability*, vol. 13, no. 10, p. 5402, May 2021, doi:10.3390/su13105402.

[20] P. Padmalosan et al., "An investigation on the use of waste materials from industrial processes in clay brick production," *Materials Today: Proceedings*, Feb. 2023, doi: 10.1016/j.matpr.2023.01.238.

[21] A. Almssad, A. Almusaed, and R. Z. Homod, "Masonry in the Context of Sustainable Buildings: A Review of the Brick Role in Architecture," *Sustainability*, vol. 14, no. 22, p. 14734, Nov. 2022, doi: 10.3390/su142214734.

[22] N. Fouladi, S. Hamidpour, M. A. Sedghamiz, and M. R. Rahimpour, "Application of biomass ash for brick manufacturing," *Advances in Bioenergy and Microfluidic Applications*, pp. 407–429, 2021, doi:10.1016/b978-0-12-821601-9.00017-0.

[23] M. Ngom, A. Thiam, A. Balhamri, V. Sambou, T. Raffak, and H. A. Refaey, "Transient study during clay bricks cooking in the traditional kiln; CFD numerical study," *Case Studies in Thermal Engineering*, vol. 28, p. 101672, Dec. 2021, doi: 10.1016/j.csite.2021.101672.

[24] J. L. Amboro, N. Wahyuningsih, and D. Nurcahyanti, "Traditional ceramic kiln development model," in *Proceedings of the 2nd*

International Conference on Creative Media, Design & Technology (REKA2016), Penang, Malaysia, 2016, pp. 26–27.

[25] M. A. Parvez, I. A. Rana, A. Nawaz, and H. S. H. Arshad, “The impact of brick kilns on environment and society: a bibliometric and thematic review,” *Environmental Science and Pollution Research*, vol. 30, no. 17, pp. 48628–48653, Feb. 2023, doi: 10.1007/s11356-023-26011-7.

[26] I. B. Priyambada, F. Meilasari, H. S. Huboyo, and A. D. Setyaningsih, “Preliminary study on biomass burning emission characteristics from brick industry area (Case Study: Mranggen, Demak),” *IOP Conference Series: Earth and Environmental Science*, vol. 1268, no. 1, p. 012024, Dec. 2023, doi: 10.1088/1755-1315/1268/1/012024.

[27] L. Nicolaou et al., “Brick kiln pollution and its impact on health: A systematic review and meta-analysis,” Nov. 2023, doi:10.1101/2023.11.16.23298642.

[28] M. K. Saha, S. J. Ahmed, A. H. Sheikh, and M. G. Mostafa, “Impacts of Brick Kilns on Environment around Kiln areas of Bangladesh.,” *Jordan J. Earth Environ. Sci.*, vol. 12, no. 3, 2021.

[29] A. Abbas et al., “Assessment of long-term energy and environmental impacts of the cleaner technologies for brick production,” *Energy Reports*, vol. 7, pp. 7157–7169, Nov. 2021, doi:10.1016/j.egyr.2021.10.072.

[30] M. Asif, S. Saleem, A. Tariq, M. Usman, and R. A. U. Haq, “Pollutant Emissions from Brick Kilns and Their Effects on Climate Change and Agriculture,” *ASEAN Journal of Science and Engineering*, vol. 1, no. 2, pp. 135–140, May 2021, doi:10.17509/ajse.v1i2.38925.

[31] Z. Qu et al., “Sector-Based Top-Down Estimates of NOx, SO2, and CO Emissions in East Asia,” *Geophysical Research Letters*, vol. 49, no. 2, Jan. 2022, doi: 10.1029/2021gl096009.

[32] T. A. Mukta, M. M. M. Hoque, M. E. Sarker, M. N. Hossain, and G. K. Biswas, “Seasonal variations of gaseous air pollutants (SO2, NO2, O3, CO) and particulates (PM2. 5, PM10) in Gazipur: an industrial city in Bangladesh,” *Adv. Environ. Technol.*, vol. 6, no. 4, pp. 195–209, 2020.

[33] T. de Paula Protásio, L. Bufalino, G. H. D. Tonoli, M. G. Junior, P. F. Trugilho, and L. M. Mendes, “Brazilian lignocellulosic wastes for bioenergy production: characterization and comparison with fossil fuels,” *BioResources*, vol. 8, no. 1, pp. 1166–1185, 2013.

[34] B. E. Saltzman, “Colorimetric microdetermination of nitrogen dioxide in atmosphere,” *Anal. Chem.*, vol. 26, no. 12, pp. 1949–1955, 1954.

[35] R. B. Darlington and A. F. Hayes, *Regression analysis and linear models: Concepts, applications, and implementation*. New York: Guilford Press, 2017.

[36] Z. Bashir, M. Amjad, S. F. Raza, S. Ahmad, M. Abdollahian, and M. Farooq, “Investigating the Impact of Shifting the Brick Kiln Industry from Conventional to Zigzag Technology for a Sustainable Environment,” *Sustainability*, vol. 15, no. 10, p. 8291, May 2023, doi:10.3390/su15108291.

[37] E. Velasco, M. Roth, L. Norford, and L. T. Molina, “Does urban vegetation enhance carbon sequestration?,” *Landscape and Urban Planning*, vol. 148, pp. 99–107, Apr. 2016, doi:10.1016/j.landurbplan.2015.12.003.

[38] A.-A. Kafy, A.-A.- Faisal, A. Al Rakib, Md. A. Fattah, Z. A. Rahaman, and G. S. Sattar, “Impact of vegetation cover loss on surface temperature and carbon emission in a fastest-growing city, Cumilla, Bangladesh,” *Building and Environment*, vol. 208, p. 108573, Jan. 2022, doi: 10.1016/j.buildenv.2021.108573.

[39] M. Yerizam and M. Faizal, “Composition Variation Effect of Rice Straw and Coconut Shell to Biobriquette Characteristics as Alternative Fuel,” in *International Conference of Chemical Engineering on Science and Applications*, 2013, pp. 253–259.

[40] A. B. Tabinda, Z. Anjum, A. Yasar, R. Rasheed, A. Mahmood, and A. Iqbal, “Determination and dispersion of pollutants from different fuel types used in brick kilns by using Gaussian’s plume model,” *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, vol. 41, no. 8, pp. 1022–1028, Oct. 2018, doi:10.1080/15567036.2018.1539135.

[41] R. Arévalo, A. Rezeau, and C. Herce, “CFD Analysis of Co-firing of Coke and Biomass in a Parallel Flow Regenerative Lime Kiln,” *Waste and Biomass Valorization*, vol. 13, no. 12, pp. 4925–4949, Jun. 2022, doi: 10.1007/s12649-022-01833-7.

[42] Y. Zhang et al., “Rotary kilns coprocessing hazardous wastes,” *Low Carbon Stabilization and Solidification of Hazardous Wastes*, pp. 259–289, 2022, doi: 10.1016/b978-0-12-824004-5.00010-4.

[43] G. F. C. Lama, T. Sadeghifar, M. T. Azad, P. Sihag, and O. Kisi, “On the Indirect Estimation of Wind Wave Heights over the Southern Coasts of Caspian Sea: A Comparative Analysis,” *Water*, vol. 14, no. 6, p. 843, Mar. 2022, doi: 10.3390/w14060843.

[44] M. Gianfelice, H. Aboshosha, and T. Ghazal, “Real-time Wind Predictions for Safe Drone Flights in Toronto,” *Results in Engineering*, vol. 15, p. 100534, Sep. 2022, doi:10.1016/j.rineng.2022.100534.

[45] Y.-D. Huang, N. Xu, S.-Q. Ren, L.-B. Qian, and P.-Y. Cui, “Numerical investigation of the thermal effect on flow and dispersion of rooftop stack emissions with wind tunnel experimental validations,” *Environmental Science and Pollution Research*, vol. 28, no. 9, pp. 11618–11636, Oct. 2020, doi: 10.1007/s11356-020-11304-y.

[46] J. Yang, B. Shi, Y. Zheng, Y. Shi, and G. Xia, “Urban form and air pollution disperse: Key indexes and mitigation strategies,” *Sustainable Cities and Society*, vol. 57, p. 101955, Jun. 2020, doi:10.1016/j.scs.2019.101955.

[47] A. Hussain *et al.*, “Brick kilns air pollution and its impact on the peshawar city,” *Pollution*, vol. 8, no. 4, pp. 1266–1273, 2022.

[48] M. A. Bhat and E. O. Gaga, “Air Pollutant Emissions in the Pristine Kashmir Valley from the Brick Kilns,” *Biodiversity, Conservation and Sustainability in Asia*, pp. 959–979, 2022, doi: 10.1007/978-3-030-73943-0_53.

[49] J. Figueroa et al., “Comparative Analysis of Gas Emissions from Ecokiln and Artisanal Brick Kiln during the Artisanal Firing of Bricks,” Sustainability, vol. 16, no. 3, p. 1302, Feb. 2024, doi:10.3390/su16031302.

[50] M. K. Saha, S. J. Ahmed, A. H. Sheikh, N. U. Ahsan, and M. G. Mostafa, “Impacts of brick kiln emissions on air quality around kiln areas,” *Int. J. Nat. Hum. Sci.*, vol. 1, no. 1, pp. 60–70, 2020.

[51] J. Ryan, M. Bussmann, and N. DeMartini, “CFD Modelling of Calcination in a Rotary Lime Kiln,” *Processes*, vol. 10, no. 8, p. 1516, Aug. 2022, doi: 10.3390/pr10081516.

[52] H. R. Ahmad, Z. U. R. Farooqi, M. Sabir, and M. F. Sardar, “Brick Kilns: Types, Emissions, Environmental Impacts, and their Remedial Measures,” *Biodiversity, Conservation and Sustainability in Asia*, pp. 945–958, 2022, doi: 10.1007/978-3-030-73943-0_52.

[53] Z. Getahun et al., “Towards sustainable charcoal production: Designing an economical brick kiln with enhanced emission control technology,” *Heliyon*, vol. 10, no. 6, p. e27797, Mar. 2024, doi:10.1016/j.heliyon.2024.e27797.