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# Ecological mapping analysis of air quality factors associated with the incidence of low birth weight in Palembang city, 2019-2023

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**Abstract**

Infants with a birth weight of less than 2,500 grams, regardless of gestational age, are classified as having Low Birth Weight (LBW). LBW remains a global public health concern, including in Indonesia. As an environmental risk factor, exposure to air pollutants such as Carbon Monoxide (CO), nitrogen dioxide ($NO_2$), and Sulfur Dioxide ($SO_2$) has been empirically shown to adversely affect maternal and fetal health. This study aimed to analyze the spatial patterns of air pollution risk factors (CO, $NO_2$, and $SO_2$) in relation to the prevalence of LBW in Palembang City from 2019 to 2023. An ecological study design was employed, integrating spatial analysis and time-series analysis to examine the temporal correlation between air pollutant exposure and LBW incidence. Secondary data on LBW births were obtained from the Palembang City Health Office, while air quality monitoring data were sourced from the Palembang City Environmental Agency, resulting in seven districts being included based on environmental sampling locations. Univariate analysis showed that the highest LBW prevalence (58 cases) occurred in Ilir Timur I District. The highest mean CO concentration was recorded in Ilir Timur III District (13,568 µg/$Nm^3$/hour), while the highest mean $NO_2$ concentration (115 µg/$Nm^3$/hour) was observed in Plaju and Kertapati Districts. The highest mean $SO_2$ concentrations varied annually, with peak averages in Plaju (59 µg/$Nm^3$/hour) and Kertapati (57 µg/$Nm^3$/hour). Spatial analysis using QGIS software with overlay techniques identified a significant association between CO concentrations in 2021–2022 and LBW prevalence in 2022–2023 in Ilir Timur I District, as well as an association between LBW cases and $SO_2$ concentrations in Plaju District during 2021–2022. However, no association was found between LBW incidence and elevated $NO_2$ concentrations.

**Keywords:** Air pollution, Ecology, Low birth weight, Spatial analysis.

## Introduction

Low Birth Weight (LBW) is one of the leading contributors to neonatal mortality worldwide. UNICEF (2013) reported that approximately 2.9 million infants die within the first month of life, with more than 80% of these deaths associated with LBW. Infants born with LBW have a mortality risk up to 35 times higher than those born with normal birth weight.

In Indonesia, the prevalence of LBW declined from 11.5% in 2007 to 10.2% in 2013. In South Sumatra Province, the prevalence reached 9.3%, while Palembang City recorded 319 LBW cases (1.13%) out of 29,235 live births. The etiology of LBW is multifactorial, encompassing maternal conditions (such as hypertension, preeclampsia, and hemorrhage), fetal factors (including congenital anomalies, infections, and multiple pregnancies), as well as environmental factors, particularly exposure to air pollution and radiation. Exposure to ambient air pollutants, including carbon monoxide (CO), Nitrogen Dioxide ($NO_2$), and Sulfur Dioxide ($SO_2$), has been consistently associated with an increased risk of LBW, with differential effects observed across pregnancy trimesters.

In Palembang City, analyses of LBW data have predominantly relied on tabular and graphical methods, with limited application of detailed spatial analysis. However, the use of Geographic Information Systems (GIS) and remote sensing technologies enables the spatial mapping of LBW distribution at finer geographic scales, thereby enhancing the identification of environmental risk factors and supporting geographically targeted public health interventions.

The transformation of Palembang into a metropolitan city has been accompanied by rapid growth in motor vehicle traffic and industrial activities, contributing to elevated levels of ambient air pollutants. Exposure to air pollution is known to result in a wide range of

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adverse health outcomes, including respiratory infections, lung cancer, and pregnancy complications such as preterm birth and low birth weight. Infants born with LBW face both short-term and long-term health risks, including an increased susceptibility to degenerative diseases later in life. Despite these concerns, the spatial distribution patterns of LBW incidence in Palembang City have not been comprehensively examined. Therefore, spatial ecological analysis using GIS is required to map the distribution of LBW cases and to identify potential environmental determinants. This study aims to conduct an ecological analysis using a spatial approach to examine the relationship between air quality and the distribution of LBW incidence in Palembang City.

## Methods

This study employed an ecological study design as part of analytic observational epidemiology, with the unit of analysis defined as population aggregates based on geographic administrative boundaries. The study examined the relationship between ambient air pollutant concentrations (independent variables) and the incidence of Low Birth Weight (LBW) (dependent variable) in Palembang City. The analyzed data comprised all recorded live births with LBW (<2,500 g) per district per year from 2020 to 2023, along with ambient air pollutant concentration data from 2019 to 2022. A one-year lag was applied between exposure and outcome to approximate maternal exposure to air pollutants during pregnancy (approximately nine months).

The geographic units included in the analysis were determined based on the availability of air quality monitoring data collected by the Palembang City Environmental Agency. Accordingly, seven districts were included: Plaju, Alang-Alang Lebar, Kertapati, Jakabaring, Ilir Timur I, Ilir Timur III, and Bukit Kecil.

Data analysis combined spatial analysis using Geographic Information Systems (GIS) to visualize and assess the spatial distribution of LBW cases across districts, with time-series analysis to examine temporal correlations between ambient air pollutant concentrations and LBW incidence. This study design was selected due to its feasibility, relatively short implementation period, and its usefulness in evaluating population-level patterns relevant to public health planning. The study was conducted in Palembang City in 2024 over a one-year period, encompassing data processing, analysis, and interpretation.

## Results and Discussion

### Prevalence of low birth weight

Data on the prevalence of low birth weight (LBW) in Palembang City during the 2020–2023 period, recorded across 41 primary health centers in 18 districts, demonstrated a fluctuating pattern across geographic areas. The highest numbers of LBW cases were reported in Plaju District (26 cases) and Ilir Timur I District (23 cases), whereas Kertapati District consistently reported no LBW cases. These spatial variations are influenced by a combination of maternal factors, fetal factors, environmental exposures, and the effectiveness of local health programs.

According to the World Health Organization, LBW defined as a birth weight of less than 2,500 g represents a serious public health issue with long-term consequences, including increased infant mortality, impaired growth and development, and a higher risk of chronic diseases in adulthood. Spatial distribution analysis revealed significant disparities across districts, particularly in the post–COVID-19 period, which affected the prioritization and delivery of maternal and child health services. Data on the prevalence of LBW in the districts included as observation units are presented in Figure 1.

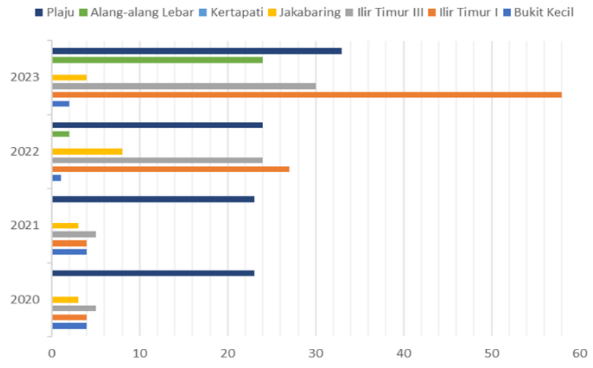


**Figure 1.** Prevalence of Low Birth Weight (LBW) Incidence in Seven Districts of Palembang City, 2020–2023

The spatial pattern of the average LBW prevalence during the 2020–2023 period across the seven districts is illustrated in Figure 2. Spatial analysis revealed that Plaju District recorded the highest average LBW prevalence over the study period, with a total of 26 cases. In contrast, Kertapati District did not report any LBW cases (zero cases) throughout the observation period.

The successful implementation of innovative health programs, such as the Ki Merogan initiative at Kertapati Primary Health Center, has been shown to effectively reduce LBW cases to zero through the prevention of maternal anemia and undernutrition during pregnancy. Identified risk determinants included extreme maternal age, anemia, preeclampsia, preterm premature rupture of membranes (PPROM), maternal undernutrition, low educational attainment, and household socioeconomic status.

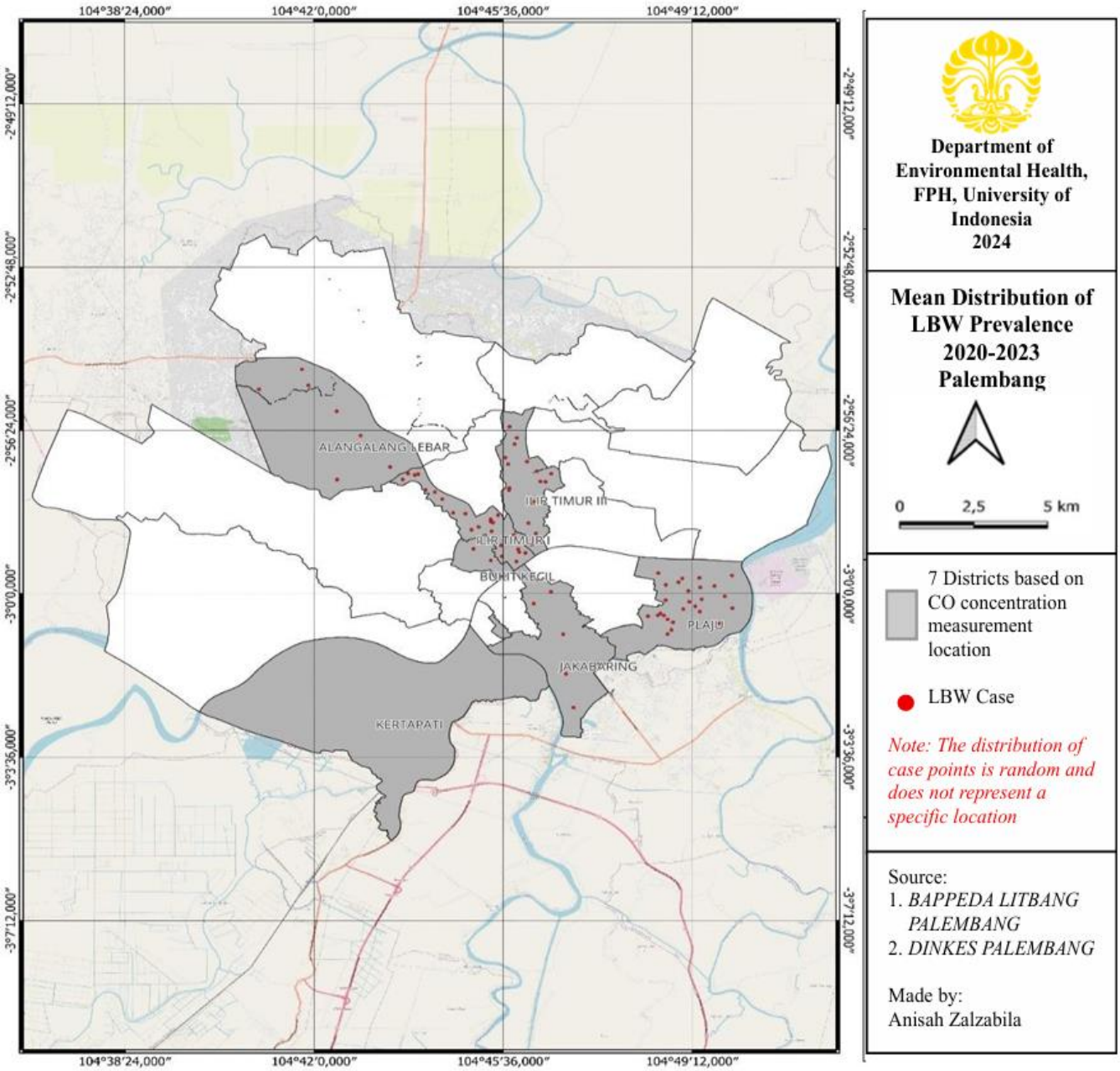


**Figure 2.** Spatial Distribution Map of Low Birth Weight (LBW) Prevalence, 2020–2023

Environmental factors, particularly exposure to air pollution arising from urban activities and industrial operations, may further exacerbate the vulnerability of pregnant women. These findings underscore the importance of improving access to primary health care services, strengthening the quality of antenatal care, enhancing maternal nutrition programs, and integrating environmental health approaches to reduce the incidence of LBW in Palembang City.

## Ambient air pollutant concentrations

This study analyzed the concentrations of ambient air pollutants Carbon Monoxide (CO), Nitrogen Dioxide ($NO_2$), and Sulfur Dioxide ($SO_2$) in Palembang City during the 2019–2022 period, based on air quality monitoring data collected across seven districts by the Palembang City Environmental Agency. The results revealed considerable spatial and temporal variability in pollutant concentrations across districts and years. Data on ambient air pollutant concentrations, particularly CO, are presented in Table 1.

**Table 1.** CO Concentration in 2019 – 2022

| Year | With. | Min. | Max. | Mean | SD |
|---|---|---|---|---|---|
| 2019 | 5278,2 | 2899 | 7801 | 5278,2 | 1678,2 |
| 2020 | 6010 | 1984 | 10112 | 5631,5 | 2581,6 |
| 2021 | 8431 | 5563 | 12994 | 9157,1 | 3078,1 |
| 2022 | 8312 | 6542 | 13568 | 8798,5 | 2503,9 |
| 2019 – 2022 | 7277 | 5396 | 9298 | 7223 | 1463,4 |

**Source:** Palembang city environment agency

The highest mean CO concentration reached 9,288 µg/Nm$^3$/hour, which remains below the national ambient air quality standard stipulated in Government Regulation of the Republic of Indonesia No. 22 of 2021 (10,000 µg/Nm$^3$/hour). The spatial distribution of CO concentrations was influenced by traffic volume, wind speed, elevation, and the presence of green spaces. A marked decline in CO concentrations was observed in 2020, attributable to large-scale social restriction policies implemented during the COVID-19 pandemic. The CO concentration data are further illustrated graphically in Figure 3.

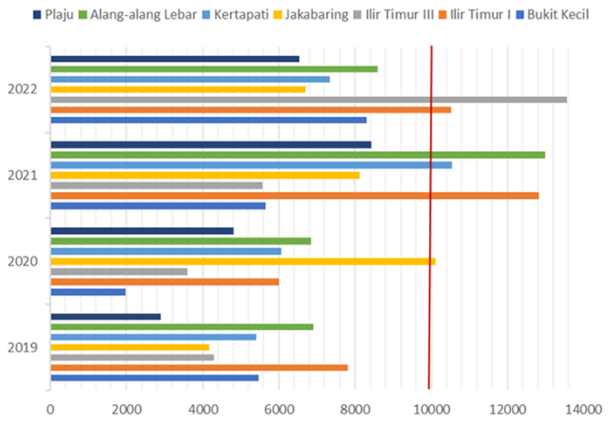


**Figure 3.** Carbon Monoxide (CO) concentrations in seven districts of Palembang city, 2019–2022

CO concentration levels are also presented graphically to facilitate visualization of spatial patterns across districts and temporal trends over the measurement years. The red vertical reference line in Figure 3 indicates that CO concentrations exceeded the ambient air quality standard (≥10,000 µg/Nm$^3$/hour) in 2021 and 2022, corresponding to the resumption of transportation activities and increased human mobility following the COVID-19 pandemic. Data on ambient air pollutant concentrations, particularly nitrogen dioxide ($NO_2$), are presented in Table 2.

**Table 2.** $NO_2$ Concentration in 2019 – 2022

| Year | With. | Min. | Max. | Mean | SD |
|---|---|---|---|---|---|
| 2019 | 59 | 37 | 92 | 61 | 18 |
| 2020 | 131 | 113 | 266 | 158 | 53 |
| 2021 | 96 | 20 | 122 | 88 | 33 |
| 2022 | 59 | 11 | 127 | 56 | 40 |
| 2019 – 2022 | 91 | 65 | 115 | 91 | 19 |

**Source:** Palembang city environment agency

As shown in Table 2, the highest $NO_2$ concentration was recorded in 2020, reaching 266 µg/Nm$^3$/hour. Based on the mean $NO_2$ concentrations over the 2019–2022 period, Kertapati and Plaju Districts consistently exhibited the highest average $NO_2$ levels across the four years. In contrast, Jakabaring and Ilir Timur I Districts consistently recorded lower average $NO_2$ concentrations during the same period.

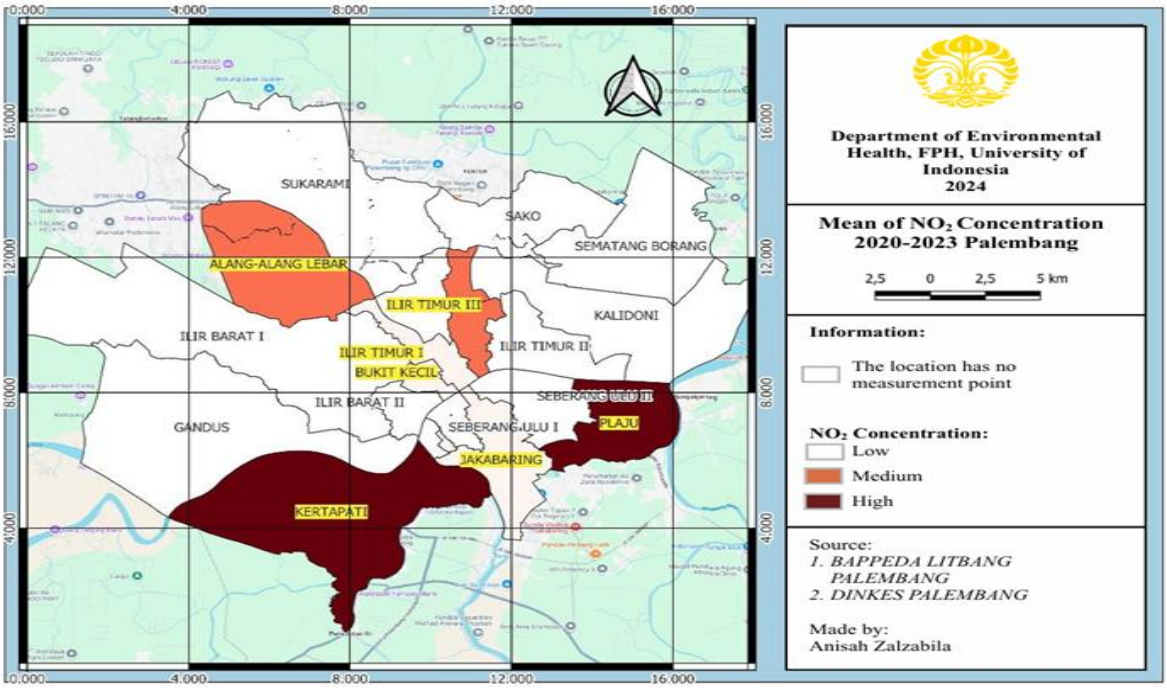


**Figure 4.** NO2 concentration in 2019-2022 in 7 districts of Palembang City

The mean $NO_2$ concentrations (Figure 4) exhibited clear spatial variation, with the highest values recorded in Plaju and Kertapati Districts (mean: 115 µg/Nm$^3$/hour). Although these levels remained below the applicable regulatory air quality standards, they tended to be higher in areas characterized by dense vehicular traffic and limited vegetation cover. Factors such as fuel type, atmospheric circulation conditions, and the presence of urban greenery play important roles in modulating $NO_2$ concentrations. Figure 5 subsequently presents the mean $SO_2$ concentrations across the seven districts of Palembang City during the 2019–2022 period.

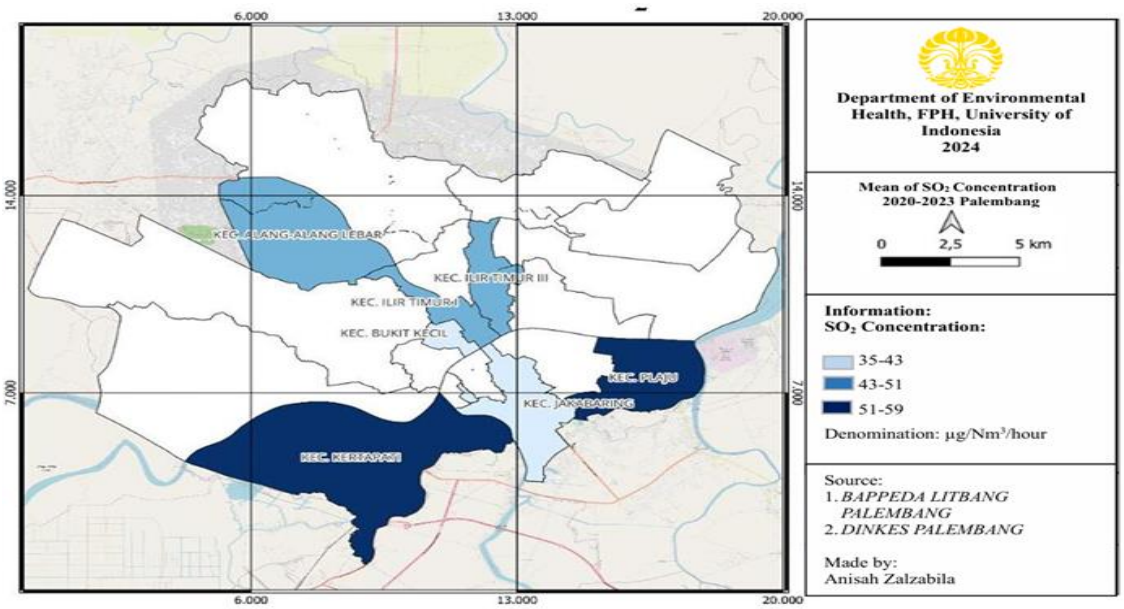


**Figure 5.** Sulfur Dioxide ($SO_2$) Concentrations in seven districts of Palembang City, 2019–2022

The highest mean $SO_2$ concentrations varied across years, with peak averages observed in Plaju District (59 µg/Nm$^3$/hour) and Kertapati District (57 µg/Nm$^3$/hour). These elevated concentrations were primarily influenced by traffic density, congestion, and the presence of heavy-duty vehicles. Overall, ambient air quality in Palembang City during the 2019–2022 period remained within national regulatory limits; however, notable spatial and temporal variations were observed, driven by transportation activities, geographic characteristics, meteorological conditions, and the availability of green spaces. These findings highlight the importance of vehicle emission control, expansion of urban green spaces, and sustainable urban planning to mitigate health risks associated with air pollution exposure.

## Estimated associations between air pollution and low birth weight

Spatial and time-series analyses indicated that the association between Carbon Monoxide (CO) concentrations and the prevalence of Low Birth Weight (LBW) was more apparent at specific spatial scales and time periods, such as in Ilir Timur I District during 2021–2022. However, this association was not evident when analyzed using overall averages for the 2019–2023 period (Figure 6).

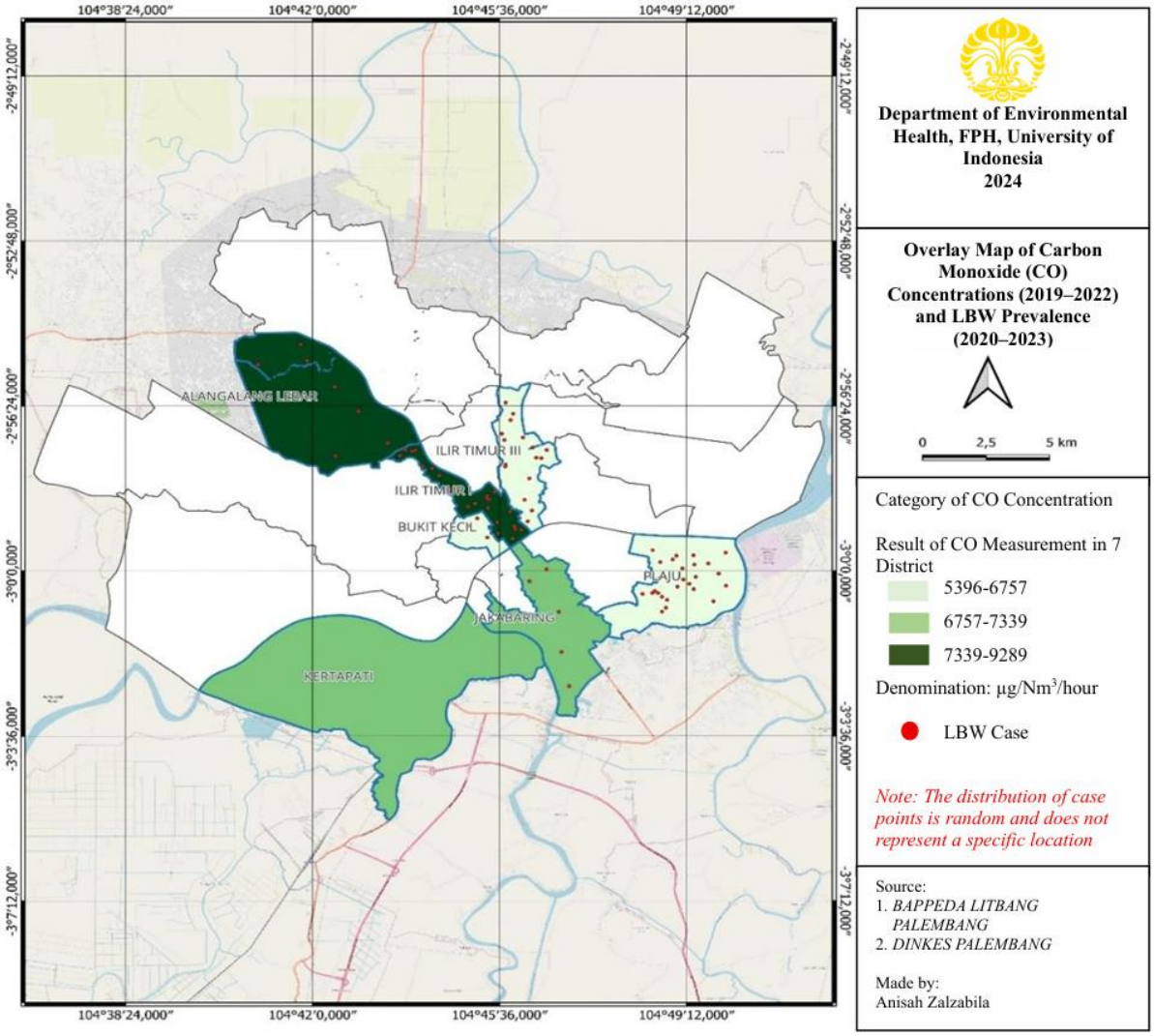


**Figure 6.** Overlay Map of Carbon Monoxide (CO) Concentrations (2019–2022) and Low Birth Weight (LBW) Prevalence (2020–2023)

Carbon Monoxide (CO) concentrations in Palembang City exhibited substantial fluctuations and reflected periods of declining air quality, consistent with the definition of air pollution stipulated in Government Regulation of the Republic of Indonesia No. 22 of 2021. Maternal exposure to CO has been shown to increase the risk of adverse pregnancy outcomes, including preterm birth, low birth weight (LBW), and fetal mortality, through mechanisms such as carboxyhemoglobin formation, transplacental hypoxia, and placental oxidative stress. Previous studies have reported that CO exposure exceeding 1.25 ppm during the first trimester may increase the risk of preterm birth by up to 25%. Fetal

Carboxyhemoglobin (COHb) levels are higher than maternal levels and are eliminated more slowly, rendering the fetus more vulnerable to hypoxic conditions. Even at relatively low COHb concentrations, CO exposure may contribute to cardiovascular disturbances, arrhythmias, and myocardial damage. Experimental animal studies further support these findings, demonstrating that exposure levels above 400 ppm are associated with reduced birth weight and increased fetal mortality.

Spatial mapping revealed that the distribution of LBW cases did not consistently correspond with the spatial distribution of air pollutants. In the 2019–2023 overlay analysis, the highest numbers of LBW cases were observed in areas with comparatively lower CO concentrations, particularly Ilir Timur I District, while Plaju and Kertapati Districts exhibited the highest $SO_2$ concentrations. Overall, the highest LBW case counts were recorded in Plaju District (103 cases) and Ilir Timur I District (93 cases). The subsequent map presents the combined spatial distribution of LBW cases and $NO_2$ concentrations across districts included in the air quality monitoring network (Figure 7).

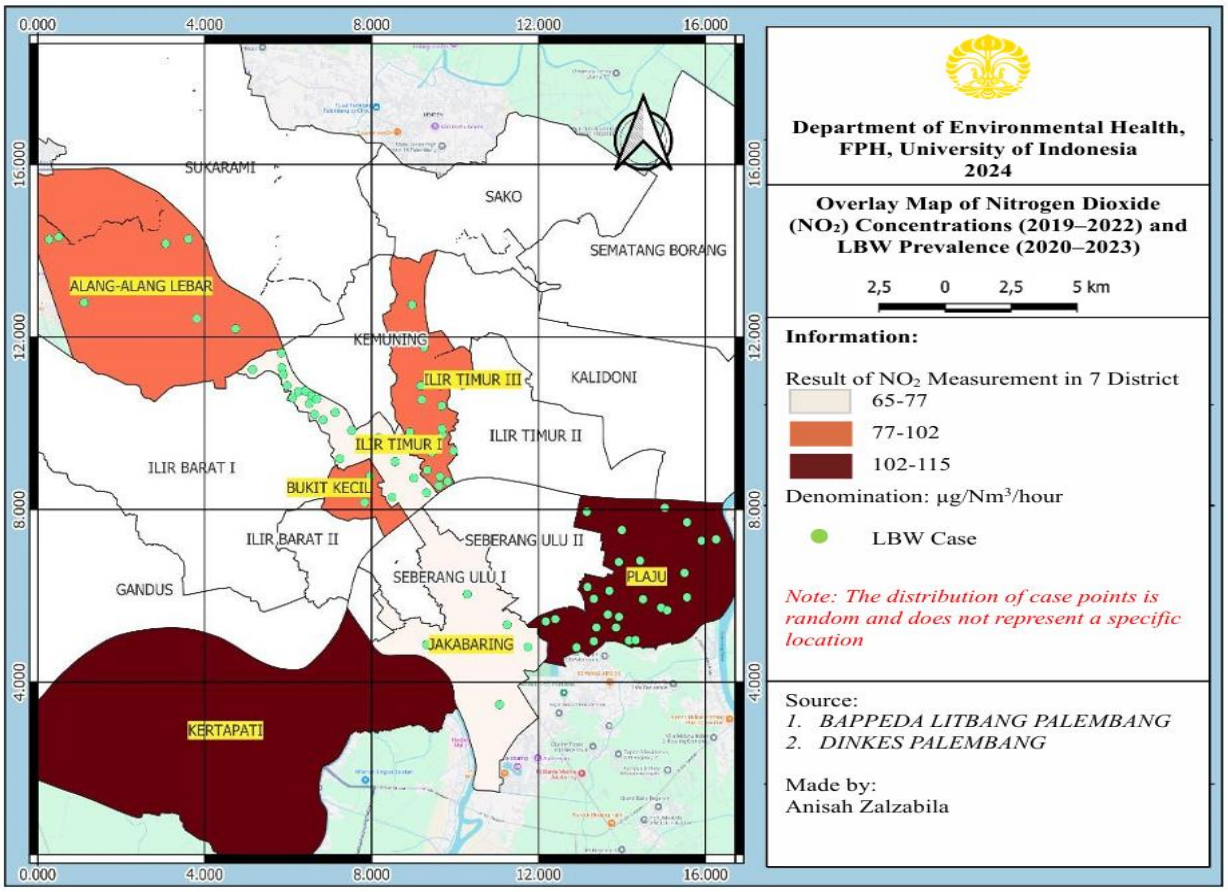


**Figure 7.** Overlay Map of Nitrogen Dioxide ($NO_2$) Concentrations (2019–2022) and Low Birth Weight (LBW) Prevalence (2020–2023)

Figure 7 combines the average number of low birth weight (LBW) cases recorded during 2020–2023 with Nitrogen Dioxide ($NO_2$) concentrations measured between 2019 and 2022. The map shows that during the 2019–2022 period, Plaju District fell into the high $NO_2$ concentration category and also exhibited the presence of LBW cases. In contrast, Ilir Timur I and Jakabaring Districts were classified as low $NO_2$ concentration areas while still displaying a distribution of LBW cases.

Exposure to sulfur dioxide ($SO_2$) may impair placental blood supply through mechanisms involving increased coagulation, inflammation, and metabolic disturbances, thereby restricting fetal growth. The spatial distribution of $SO_2$ concentrations during the 2019–2022 period indicates that Plaju and Kertapati Districts consistently recorded the highest $SO_2$ levels, with mean concentrations of 59 µg/Nm$^3$/hour and 57 µg/Nm$^3$/hour, respectively. Spatial analysis examining the relationship between mean $SO_2$ concentrations and average LBW incidence is presented in Figure 8.

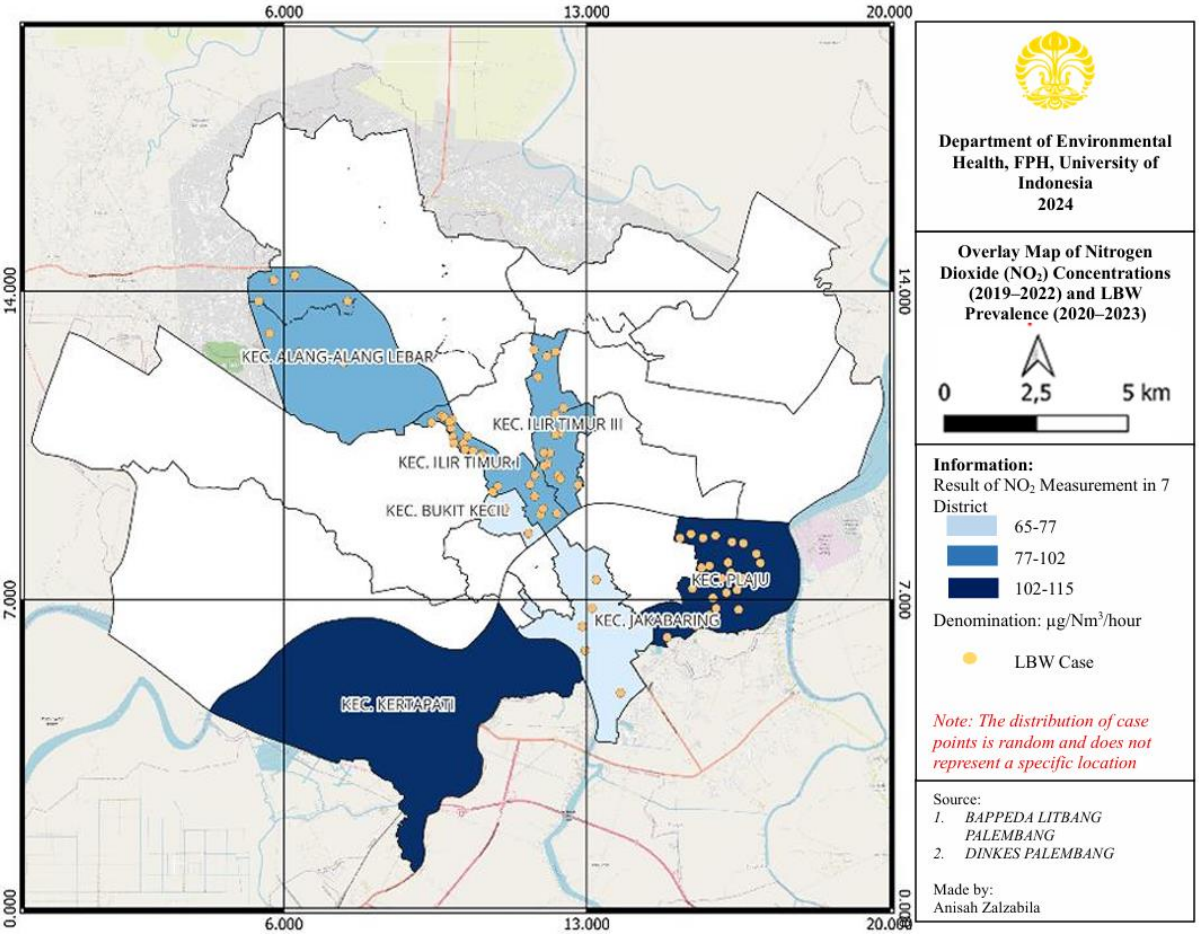


**Figure 8.** Overlay Map of Sulfur Dioxide ($SO_2$) Concentrations (2019–2022) and Low Birth Weight (LBW) Prevalence (2020–2023)

Measurements obtained during the 2019–2022 period indicated that the highest $SO_2$ concentration was recorded in Kertapati District (59 µg/Nm$^3$/hour), where no LBW cases were reported, followed by Plaju District (57 µg/Nm$^3$/hour), which recorded 26 LBW cases. Based on the findings from Plaju District, a potential association between $SO_2$ concentrations and LBW incidence was observed. Previous studies have suggested that the relationship between $SO_2$ exposure and low birth weight may be mediated by alterations in blood viscosity due to increased coagulation factors, leading to reduced

placental blood supply and impaired fetal growth.

In addition to air pollution, other factors such as maternal nutrition, access to health care services, educational attainment, and exposure to tobacco smoke also contribute to an increased risk of LBW. Overall, this study supports the conclusion that air pollution represents a significant risk factor for LBW, although it is not a sole determinant. Recommended mitigation measures include regular antenatal care, balanced nutritional intake (including vitamin C, omega-3 fatty acids, and antioxidants), limiting outdoor activities during periods of high air pollution, and the use of protective masks by pregnant women.

## Conclusion

This study demonstrates that the average concentrations of ambient air pollutants (CO, $NO_2$, and $SO_2$) in Palembang City during the 2019–2022 period remained below national ambient air quality standards, although their distribution varied across districts. The prevalence of low birth weight (LBW) during the 2020–2023 period also fluctuated, with considerable variation in case numbers among districts. Spatial analysis identified heterogeneity in both pollutant concentrations and LBW distribution, with case hotspots becoming more apparent when data were examined at the district level and across specific time periods. However, the association between air pollution and LBW was not consistent when assessed over the entire study period.

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