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Original Research

Correlation between fine particulate matter air pollution and under-five children mortality in Indonesia: A secondary data analysis of WHO Global Health Observatory

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Abstract

Background: Fine particulate matter ($PM_{2.5}$) is an environmental factor contributing to the death rate. However, few studies have demonstrated the association between $PM_{2.5}$ and the under-five mortality rate.

Objective: To determine the correlation between $PM_{2.5}$ and under-five children mortality in Indonesia.

Methods: A secondary data analysis of the WHO Global Health Observatory on Environmental Pollution and Children Mortality during 2012-2016 was conducted. The environmental pollution was measured by $PM_{2.5}$ levels (μg/m3) in rural, urban, and both areas. Mortality data were categorized by specific causes—meningitis/encephalitis, acute lower respiratory infection, diarrhoeal diseases, tetanus, prematurity, birth asphyxia, and congenital anomalies. Data were analyzed using Mann-Whitney and Spearman correlations.

Results: The $PM_{2.5}$ total concentration in urban areas was greater than in rural areas for four years (18.4±1.19 vs. 15.4±1.1, p = 0.016). Prematurity, acute lower respiratory infection, and birth asphyxia were the leading causes of under-five mortality. The $PM_{2.5}$ concentration in urban and rural areas was significantly associated with an acute lower respiratory infection, tetanus, prematurity, birth asphyxia, and congenital anomalies (p <0.05). Additionally, the $PM_{2.5}$ concentration was negatively correlated with tetanus, prematurity, birth asphyxia, and congenital anomalies (p <0.001; r = -0.8, -0.8, -0.82, -0.83, respectively).

Conclusion: $PM_{2.5}$ air pollution was correlated with tetanus, prematurity, birth asphyxia, and congenital anomalies from 2012-2016 in Indonesia. Further action is needed to handle the sources of air pollution contamination to preventing under-five mortality in the community.

Keywords: $PM_{2.5}$; particulate matter; under-five mortality rate; specific causes; child; Indonesia

Background

Air pollution has been a significant environmental hazard to the global disease burden for years. The World Health Organization (WHO) in 2021 declared that people are exposed to contaminated air, and more notably, it is attributable to a 7 million mortality rate worldwide (World Health Organization, 2021a).

One of the most pollutants, $PM_{2.5}$, leads to the ecological risk factor of burden diseases in the population by an estimated three million worldwide mortality (Global Burden of Disease Study results, 2019). World Health Organization (WHO) predicts that greater 90% of worldwide inhabitants are contaminated by $PM_{2.5}$ higher than 10 ug/m3, surpassing the air quality index for $PM_{2.5}$ (World Health Organization, 2021b). It is noted that $PM_{2.5}$ can penetrate the human body through inhalation, skin, and ingestion routes. Studies have examined that the health effects of $PM_{2.5}$ continued; concentration in urban, rural, and remote areas does not vary from country to country.

A recent study shows the global estimation of annual $PM_{2.5}$ concentration and trend for 20 years (1998 – 2018) (Hammer et al., 2020). It was illustrated that the trend for worldwide and India was positive (0.04 ± 0.02 vs. 1.13 ± 0.15 μg/m3/yr). Conversely, the negative trend occurred in Europe and North America (-0.15 ± 0.03 vs. -0.28±0.03 μg/m3/yr) (Hammer et al., 2020). Those data show that the global concentration of $PM_{2.5}$ is still challenging for public health. Residents in rural and urban are the most affected and pose a health risk, as mentioned by Clements et al. (2016) in northeastern Colorado. The study compared the mass concentration and composition of $PM_{10-2.5}$ in the Greenly and Denver regions (Clements et al., 2016). The $PM_{10-2.5}$ was continuous over three years, from 2009 to 2012. The study's result claimed that Greenly had donated to the highest PM concentration, yet the concentration commonly in Greenly was lower than in Denver. Transportation pollution significantly influences the concentration of $PM_{10-2.5}$ in Denver. Notably, the concentration of coarse particulate matter was greater than in settlement areas in both Denver and Greely (Clements et al., 2016).

This global situation makes people in the city and countryside areas prone to disease, as estimated by WHO in 2021 (World Health Organization, 2021b). This report claimed that 93% of children breathe polluted air, posing their health at serious illnesses such as acute lower respiratory infections. This report also claimed that 600,000 children were ill from respiratory infections. In addition, 4.2 million untimely death across the globe was considered caused by ambient air pollution in rural and urban ones (World Health Organization, 2021a). Air pollution, such as $PM_{2.5}$ and PM_{10}, has become the majority cause of non-communicable diseases in adults and children for years. It is important to note that the PM compositions are nitrates, ammonia, carbon, sodium chloride, water, and dust (World Health Organization, 2021b). The small molecule of those substances enters the human body through oral, respiratory, and dermal contact, causing intercellular interaction with the immune system. Thus, this mechanism becomes a primary hazard in mortality and morbidity in the vulnerable population, including the elderly and under-five children.

Under-five mortality (UFM) rate captured the quality of health services. However, recent causes are not related to the quality of health services, but several aspects have been identified, such as $PM_{2.5}$ and $PM_{10-2.5}$, as environmental hazards (Karimi & Shokrinezhad, 2020). The trend of UFM in Indonesia from 2000-2017 declined gradually, while the highest causes of mortality were premature birth and acute respiratory diseases (Soleman, 2020). Related studies about the concentration of $PM_{2.5}$ on UFM in Indonesia are limited. However, exposure to $PM_{2.5}$ in Indonesia is massive because sources of contamination have been detected. Thus, this study must disclose the association of $PM_{2.5}$ with the incidence of UFM based on WHO's data. This study gives several implications to the policy maker to handle a source of contamination of $PM_{2.5}$ in the community to minimize UFM.

Methods

Study Design

Secondary data analysis was performed to analyze $PM_{2.5}$ on the incidence of caused specific death in under-five children. In addition, this study also compared $PM_{2.5}$ concentration in urban and rural to observe temporal trends from 2012 to 2016.

Data Collection

Global Health Observatory (GHO), managed by World Health Organization (WHO), is a repository of health-related statistical data for 194 member states (https://www.who.int/data/gho). It offers over 1000 data indicators on the most prioritized health topic, including environmental pollution and children's mortality rate. Environmental pollution data such as fine $PM_{2.5}$ was divided into total concentration, urban and rural. In addition, the UFM rate was divided into meningitis/encephalitis, acute lower respiratory infection, diarrhoeal diseases, tetanus, prematurity, birth asphyxia, and congenital anomalies. Pertussis, malaria, and measles were excluded because the annual rate was zero. The availability date was adjusted based on years of collecting data from 2012-2016. Since the data was accessible to the public, ethical permission was not needed.

Data Analysis

Mean, standard deviation (SD), and minimum maximum were used to describe the data. The $PM_{2.5}$ concentration from 2012-2016 was shown by the graphical 3D bar. Comparison between cause-specific UFM and concentration $PM_{2.5}$ was analyzed using Mann-Whitney test, and correlation analysis was conducted using Spearman Correlation with SPSS version 23.

Results

Table 1 shows that the most concentrated $PM_{2.5}$ was in the urban area. The most common specific cause of UFM was prematurity, acute lower respiratory infection, birth asphyxia, and congenital anomalies. Comparing the total concentration of $PM_{2.5}$ with cause-specific mortality found that acute lower respiratory infection, tetanus, prematurity, birth asphyxia, and congenital disorder were statistically associated. A study reported the concentration of $PM_{2.5}$ in urban and suburban Colorado (Clements et al., 2016), showing that peak concentrations of $PM_{10-2.5}$ in suburban were generally lower than in urban ones. The concentration in rural and suburban areas is lower than in urban ones. In the city area, where traffic activity was greater than in rural, the average concentration was 14.6 to 19.7 μg/m^3. During summer and timely autumn, the $PM_{10-2.5}$ values were uppermost, while $PM_{2.5}$ reached maximum concentration during winter. In both particulates, the corresponding concentration peaked of traffic activity in the morning and afternoon (Clements et al., 2016). A study by He et al. (2022) recorded that the leading cause of the UFM rate from 2009-2019 was low birth weight/ preterm birth, followed by pneumonia, birth asphyxia, and congenital anomalies (He et al., 2022). Similar to this study, in which $PM_{2.5}$ predominantly accumulated in the suburban area, the highest incidence of UFM was non-communicable diseases. However, in this study, which locates in an urban or suburban area, the most affected death and specific age of children were not assigned. Further study is warranted to assess this overlooking aspect in Indonesia.

Table 1 Distribution PM2.5 and specific cause UFM rate in Indonesia from 2012-2016

Variables	Mean ± SD	Min-Max	*p*-value*
$PM_{2.5}$ (μg/m^3)			
Total	16.95±1.13	15.6-19	0.016
Urban	18.40±119	17.1-20.6	
Rural	15.48±1.1	14-17.4	
Cause-specific mortality			
Meningitis/Encephalitis	2447±448.4	1909-3012	0.25
Acute lower respiratory infection	23779±2474.1	20740-26879	0.047
Diarrhoeal diseases	9146±687.9	8275-10053	0.602
Tetanus	248±26.84	215-283	0.009
Prematurity	26190±1730	24080-28438	0.009
Birth Asphyxia	17091±1143	15669-18574	0.009
Congenital	14960±441.3	14365-15490	0.009

*Mann-Whitney test for comparison $PM_{2.5}$ with specific mortality cause. PM = particulate matter. SD = standard deviation

Figure 1 elucidates that the total $PM_{2.5}$ concentration was gradually greater from 2012 to 2016. The highest concentration was found in the urban area at 21 μg/m^3, compared to the total concentration of $PM_{2.5}$. Furthermore, it is reported that $PM_{2.5}$ concentration in India increased by 20% from 1998 to 2018, and in China improved by 16% from 2008 to 2018 (Hammer et al., 2020). Since China surveyed for 10 years, the PM concentration was greater than India, which performed the survey for 20 years. Both countries gave PM concentration during the survey at 50-100 μg/m^3 (Hammer et al., 2020). However, compared to Indonesia, the $PM_{2.5}$ in Indonesia was lower than in both countries. This finding suggested that in developed countries is higher than in developing ones, and evidence proved that the concentration of $PM_{2.5}$ exceeds the WHO air quality guideline at 10 μg/m^3.

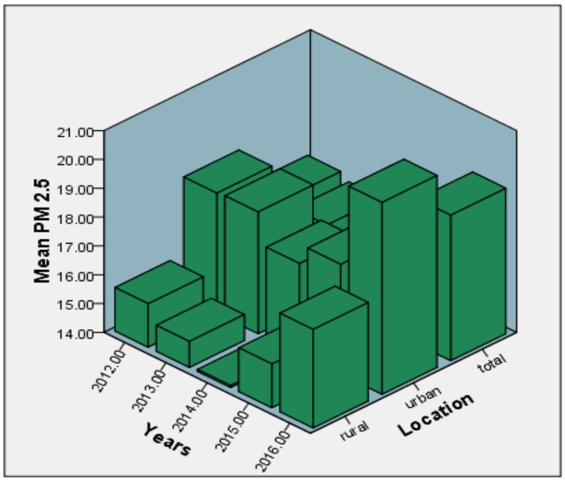

Figure 1 Temporal trend $PM_{2.5}$ in Indonesia from 2012-2016

Figure 2 described that R^2 or coefficient determinant found that congenital anomalies were the highest value, followed by tetanus, prematurity, and birth asphyxia at 0.517, 0.462, 0.460, and 0.478, respectively. He et al. (2022) reported that 10 μg/m^3 $PM_{2.5}$ concentration increased on 0-1 day, and the corresponding under-five mortality was 1.15% for all-cause, 1.30% for pneumonia, 1.66% for birth asphyxia, 1.66% for congenital anomalies, 2.90% for diarrhoeal diseases, and 7.56% for digestive diseases (He et al., 2022). There is a different result in this study that congenital disorder is the most associated with $PM_{2.5}$. However, this study has varied trends that non-communicable diseases are more related to the value of $PM_{2.5}$, despite being negatively correlated.

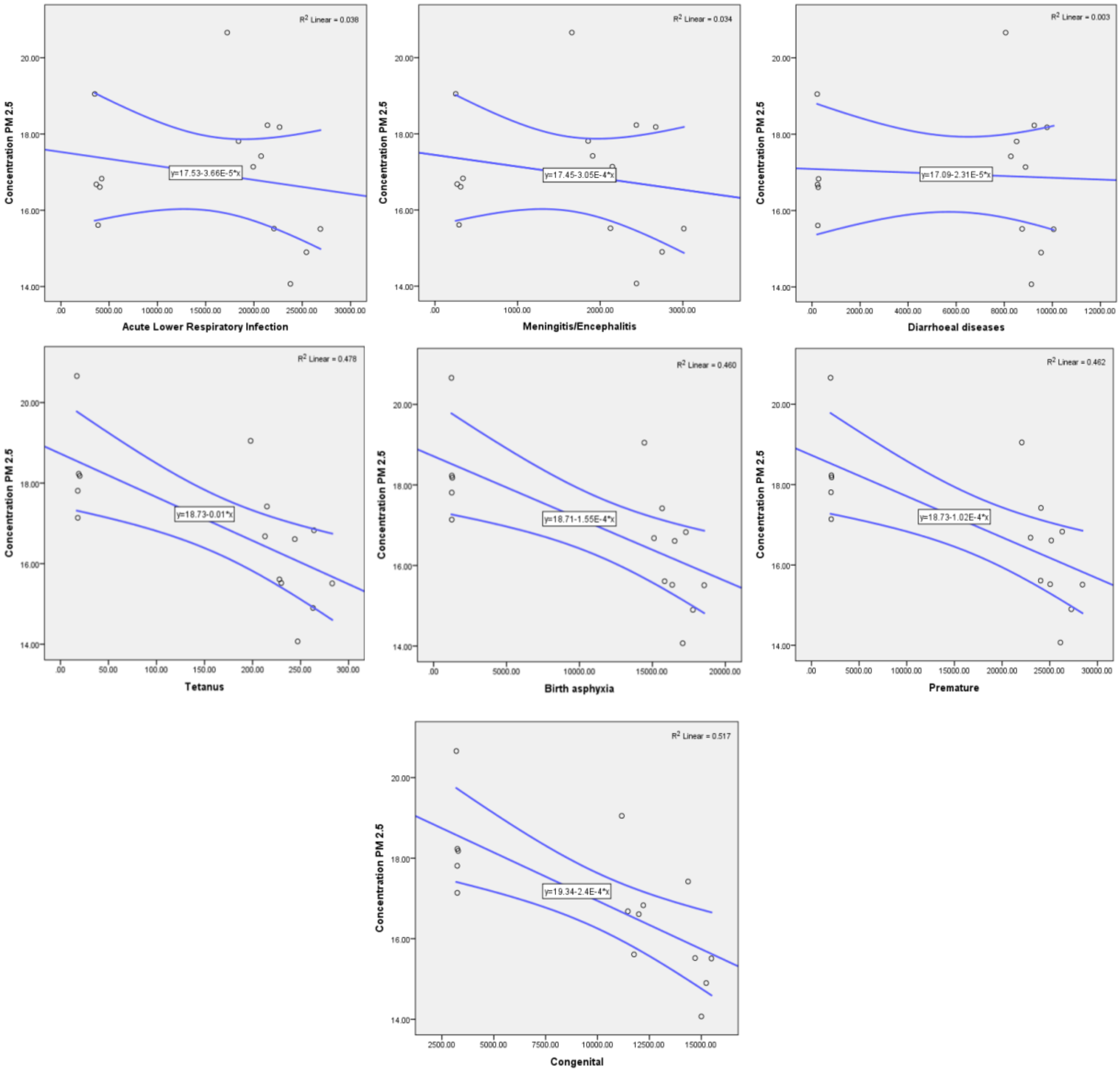

Figure 2 Association between $PM_{2.5}$ concentration and under-five children mortality

Table 2 Correlation between total concentrations PM2.5 and specific causes of under-five mortality rate

	PM 2.5	ME	ALRI	DD	Tetanus	Premature	BA	CD
PM 2.5								
r	1	-0.34	-0.42	-0.26	-0.81	-0.80	-0.82	-0.83
p		0.21	0.11	0.34	0.00	0.00	0.00	0.00
ME								
r	-0.34	1	0.97	0.98	0.227	0.28	0.25	0.36
p	0.21		0.00	0.00	0.416	0.30	0.31	0.18
ALRI								
r	-0.42	0.97	1	0.95	0.32	0.37	0.35	0.48
p	0.11	0.00		0.00	0.24	0.16	0.19	0.69
DD								
r	-0.26	0.98	0.95	1	0.15	0.19	0.17	0.26
p	0.34	0.00	0.00		0.59	0.48	0.52	0.33
Tetanus								
r	-0.81	0.227	0.32	0.15	1	0.99	0.99	0.93
p	0.00	0.416	0.24	0.59		0.00	0.00	0.00
Premature								
r	-0.80	0.28	0.37	0.19	0.99	1	0.99	0.96
p	0.00	0.30	0.16	0.48	0.00		0.00	0.00
BA								
r	-0.82	0.25	0.35	0.17	0.99	0.99	1	0.94
p	0.00	0.31	0.19	0.52	0.00	0.00		0.00
CD								
r	-0.83	0.36	0.48	0.26	0.93	0.96	0.94	1
p	0.00	0.18	0.69	0.33	0.00	0.00	0.00	

N for all variables = 15; *r* = a coefficient correlation; *p* = the value for the spearman correlation test. ME = meningitis/encephalitis; ALRI = acute lower respiratory infection; DD = a diarrhoeal disease; BA = birth asphyxia; CD = congenital disease

Discussion

$PM_{2.5}$ have been documented in urban and rural area. Several studies declared that the $PM_{2.5}$ concentration in rural or urban areas depends on the source of activities (Clements et al., 2016; Kundu & Stone, 2014). In the agricultural area, unpaved road activities and rural sites significantly increased crustal material such as silicon and aluminum. Meanwhile, urban locations boosted secondary aerosol and combustion levels such as nitrate, sulfate, ammonium, and organic and elemental carbon. On the other hand, industrialized regions knowingly had the greatest $PM_{2.5}$, with trace elements as the most dominant source of hazards as iron, plumbum, and zinc (Kundu & Stone, 2014). Sources of $PM_{2.5}$ documented that gasoline and diesel engines have negative health consequences for vehicular emissions. Our study did not evaluate the source of exposure to $PM_{2.5}$; however, in our research, the urban site is the highest concentration compared to rural ones. This finding stated that the concentration of $PM_{2.5}$ in Indonesia is likely from traffic activity and industrialized sources from gasoline and diesel engines. Hence the component of $PM_{2.5}$ is Fe, Pb, and Zn.

A temporal trend of PM $_{2.5}$ has been reported by Southerland et al. (2022). Their study estimated that the annual average population-weighted $PM_{2.5}$ from 2000 to 2019 increased more in South East Asia countries than in other WHO regions. In addition, the attributable mortality rate induced by PM $_{2.5}$ was meaningfully South East Asia and Western Pacific regions. Both data suggested that the global trend of $PM_{2.5}$ in the South East is the most affected by $PM_{2.5}$. In 2019, the $PM_{2.5}$ concentration in urban was 35 µg/m^3, over three times fold than the permissible concentration in WHO guidelines (Southerland et al., 2022). The concentration level in urban sites was 16 µg/m^3, exceeding the WHO 2005 guideline. This finding is consistent with our study that the trend of $PM_{2.5}$ in Indonesia is increased regularly.

Environmental $PM_{2.5}$ caused children mortality and disability. Short-range exposure to $PM_{2.5}$ was obtained to affect the severity of neonatal and post-neonatal death severity, particularly respiratory infection-related mortality (Wang et al., 2019; Yorifuji et al., 2016). A robust correlation between $PM_{2.5}$ and child mortality has also been verified in high-tech countries (Anwar et al., 2021; Goyal et al., 2019). This situation placed developing countries at a high risk of child mortality due to agriculture or farming source of air pollution. Conversely, in high-income countries, industrial pollution is the primary source of air pollution that induces child mortality. Some studies have also recognized that $PM_{2.5}$ contamination among pregnant or post-partum women had a severe influence on newborn conditions and consequences in later results, such as preterm delivery, low birth weight, perinatal mortality, and congenital respiratory diseases (Macchi et al., 2021; Proietti et al., 2013; Smith et al., 2017; Yuan et al., 2022; Zhang et al., 2019). Our study has also documented under-five children's death, such as meningitis encephalitis, acute lower respiratory infection, diarrhoeal disease, tetanus, prematurity, birth asphyxia, and congenital anomaly. This study found that non-communicable diseases such as prematurity, birth asphyxia, and congenital disorders are the most associated with air pollution in Indonesia. This result is consistent with previous projects on the contact to $PM_{2.5}$ with children mortality.

Our study's primary causes of under-five children's death are prematurity, birth asphyxia, congenital anomaly, and tetanus. It is undoubtedly that non-communicable diseases are the most affected by $PM_{2.5.}$ By handling air pollution, those prevented-based diseases could be diminished. World Health Organization 2017 estimated that newborn deaths were caused by prematurity complications (35%), delivery process (24%), including birth asphyxia, and central nervous system infection, including meningitis encephalitis (14%) (Hug et al., 2019). Despite a significant improvement in neonatal life, and reduction of mortality, exposure to air pollution is still a common problem that sometimes could be worst and stimulate the burden of diseases in children.

Prematurity, birth asphyxia, and congenital disorders are global health conditions induced by preterm birth. Our study claimed that prematurity is the primary etiology of death in Indonesia, followed by acute lower respiratory infection and birth asphyxia (Soleman, 2020). Of 15 million preterm newborns delivered yearly, over 1 million babies vanish immediately after delivery, according to a WHO report (Soon, 2012). These conditions are also the principal sector of passing away in under-five children. Many studies claimed that air smog, including $PM_{2.5}$, had been shown to affect prematurity (Guan et al., 2019; Li et al., 2017; Sun et al., 2015; Wang et al., 2019). The particles in the air across the human body via breathing and ingesting contaminated foods. When pregnant women live and are exposed to the polluted area, it accumulates in the bloodstream and enters the fetus's circulation, resulting from preterm and prematurity. An exciting study in China documented that the greatest death and affliction of very-early birth corresponding to $PM_{2.5}$ contamination, with 197100 people every year for daily adjusted life years (DALY), 300.16 persons every year for years lived with disability (YLD) and 196,800 people every year for years life lost (YLL) (Yuan et al., 2022). This finding in China suggested that prematurity complications with suitable treatment decrease mortality caused by early birth.

Tetanus is a life-threatening contagious disease and highly death in children. Our study declared that tetanus is one case under five children mortality attributable to $PM_{2.5}$ in Indonesia. A study in China in 2019 showed a rate of neonatal infection, including tetanus years lost with a disability, correlated to $PM_{2.5}$ ranked second, while death is the fourth highest (Yuan et al., 2022). This finding is consistent with our data that an increasing infection rate in children correlated with $PM_{2.5.}$ However, most papers cited that $PM_{2.5}$ is attributed to respiratory infections. Conversely, tetanus infection is scarce. Therefore, further investigation is warranted to investigate the correlation between exposures to $PM_{2.5}$ with tetanus in children.

There were restrictions in this secondary data study. First, the $PM_{2.5}$ data in Indonesia is limited from 2012 to 2016. To what extent spatial-temporal trend $PM_{2.5}$ should be provided with long-period data to disclose the phenomena entirely? The under-five mortality data is not sufficiently detailed and could not adjust the distribution in the countryside and non-countryside areas. Additionally, accurate data about the source of air pollution in urban and rural Indonesia is inadequate. A further prospective study is required to evaluate the correlation between $PM_{2.5}$ levels in urban and rural areas and the incidence of the under-five mortality rate in Indonesia, including specific causes of death.

Conclusion

Using the WHO data on air pollution and under-five disease, this study investigated the under-five mortality rate attributable to $PM_{2.5}$ exposure in Indonesia from 2012-2016. The result claimed a high level of $PM_{2.5}$ concentration in the city regions compared to rural ones (18.40 vs. 15.48 µg/m^3). The $PM_{2.5}$ level in an environmental sample is negatively and robustly linked with tetanus, prematurity, birth asphyxia, and congenital anomaly. Furthermore, exposure to $PM_{2.5}$ regularly increased in rural and urban sites. This situation concluded that $PM_{2.5}$ is still necessarily attributable to childhood mortality. This study recommends measures to improve air quality and focus on prevention actions to increase the under-five children's survival.

Declaration Conflicting Interest

All authors declared that there was no conflict of interest in this manuscript.

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None.

Author Contribution

SRS collected the data, analysis, writing, and editing; MR writing and editing; MFI editing and review. All authors approved the final version of the article to be published.

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Ethical Consideration

Not applicable.

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