Applied Environmental Research
- RESEARCH FOR SUSTAINABLE PLANET -

Research Article

Assessing the Relationship and Effect of Air Pollution [PM 2.5] on Child Respiratory Illness and Child Mortality in the Philippines

Roel F. Ceballos[1,2,3,*], Rachell C. Gallano[3,4], Lenard D. Visaya[3,5]

[1] *Department of Mathematics and Statistics, University of Southeastern Philippines, Davao City, Philippines*
[2] *Institute of Statistics, University of the Philippines Los Baños, Laguna, Philippines*
[3] *School of Environmental Science and Management, University of the Philippines Los Baños, Laguna, Philippines*
[4] *College of Arts and Sciences, Laguna State Polytechnic University, Los Baños, Laguna, Philippines*
[5] *Agricultural Systems Institute, University of the Philippines Los Baños, Laguna, Philippines*

*Correspondence Email: roel.ceballos@usep.edu.ph

Abstract

Air pollution is the presence of harmful substances in the air, which can seriously impact human health and the environment. Among the air pollutants, fine particulate matter (PM) 2.5, being a microscopic particle, poses serious health risks since it can enter the blood circulation and go deep into the lungs. PM 2.5 has been linked to several health problems, such as early mortality, problems with children's development, and unfavorable birth outcomes. In this regard, the study aims to investigate the relationship and effect of PM 2.5 on child respiratory illness and child mortality in the Philippines. Data on child respiratory illness and mortality were sourced from the 2022 Philippine National Demographic and Health Survey by the Philippine Statistics Authority. PM 2.5 data was obtained from the official website of the Department of Environment and Natural Resources' Environmental Management Bureau (DENR-EMB). Choropleth map, correlation plot, and regression analysis were used to analyze the data. Results reveal that regions with the greatest number of highly urbanized cities and greater industrial and economic activities have higher levels of PM 2.5. The relationship is positive and significant between PM 2.5 and child respiratory illnesses. (Acute respiratory illness, r=0.87; Asthma, r=0.90) and child mortality (neonatal mortality, r=0.72; post neonatal mortality, r=0.71; under five mortality, r=0.61). As PM 2.5 levels increase, the rates of child respiratory illnesses and child mortality are also expected to increase. Mitigating elevated PM 2.5 levels in urban settings necessitates a collaborative approach involving government agencies, industries, communities, and individuals. By integrating regulatory measures, embracing technological innovations, fostering public awareness, and promoting community engagement, it is feasible to alleviate the adverse effects of air pollution on children's health and the general well-being of the public.

ARTICLE HISTORY
Received: 7 Feb. 2024
Accepted: 10 Jun. 2024
Published: 8 Aug. 2024

KEYWORDS
Child respiratory illness; Child mortality; Decision support for children's health; Environmental health; PM 2.5

Introduction

Air pollution is the presence of dangerous compounds in our air, which can have severe consequences for human health and the environment. It includes pollutants such as fine particulate matter (PM), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), carbon monoxide (CO), volatile organic compounds (VOCs), and others [1–3]. These pollutants are responsible for an estimated 7 million fatalities each year. One of these pollutants, fine particulate matter (PM 2.5), is a microscopic particle that poses serious health risks since it can enter the circulation and go deep into the lungs [4–

https://doi.org/10.35762/AER.2024033

5]. Exposure to PM 2.5, even at lower concentrations, can have adverse health effects, particularly for vulnerable groups or people with underlying medical issues. Asthma and bronchitis are two respiratory disorders that PM 2.5 can exacerbate and impair lung function. Prolonged exposure to PM 2.5 has been linked to several health problems, such as early mortality, problems with children's development, and unfavorable birth outcomes [6–8]. Prolonged exposure to contaminated air can dramatically lower life expectancy and overall quality of life. Children, the elderly, pregnant women, and people with pre-existing health disorders are especially vulnerable to the negative impacts of air pollution. Exposure to contaminated air might exacerbate health problems and have far-reaching effects for them [1, 3–5, 7–9].

To protect public health, the World Health Organization (WHO) establishes air quality recommendations that prescribe safe amounts of contaminants in the air. A recommended yearly mean guideline of 5 µg m^{-3} of air is set for PM 2.5. In order to reduce the health risks related to these tiny particles, the average concentration of PM 2.5 throughout a year should not exceed 5 µg m^{-3}. It is crucial to remember that this recommenddation is an idealistic goal meant to safeguard public health as much as feasible. Based on substantial scientific research, these guidelines aim to identify levels below which the risk of undesirable health impacts is significantly decreased. [1, 5–6].

In 2019, 99% of the world's population lived in areas where the WHO's severe air quality guidelines for 2021 were not reached. This widespread inability to achieve air quality regulations seriously threatens human health. Low -and middle-income countries have significantly suffered from severe air quality; in particular, around 89% of premature deaths worldwide occur in these areas. People living in Southeast Asia and the Western Pacific Regions were exposed to more pollutants, which can cause a variety of health problems, including respiratory disorders, cardiovascular illness, and premature death [1, 6–8].

Like many other nations, the Philippines has needed help achieving the PM 2.5 limits that the WHO recommends. Many parts of the Philippines have experienced air pollution, particularly PM 2.5, due to industrial operations, burning of agricultural land, urbanization, and vehicle emissions. PM 2.5 levels are higher in several Philippine cities, especially those with dense populations and a lot of industrial or vehicle activity. For example, Metro Manila has frequently experienced problems with air quality, including high concentrations of PM 2.5 and other particulate matter. Within the Philippines, different areas and localities may have different levels of compliance with WHO guidelines. While certain regions may struggle to meet the recommended PM 2.5 levels due to increased pollution levels from many sources, other locations may have improved air quality that approaches or meets the recommended levels. The Philippines has implemented many efforts to tackle air quality concerns, including increased car emission requirements, the promotion of cleaner energy sources, and campaigns to curtail open burning habits. The government has also consistently prioritized keeping an eye on the air quality and putting policies in place to reduce pollution. Maintaining public health in the Philippines will require sustained efforts to lower PM 2.5 levels and raise air quality standards. These efforts often require a comprehensive approach involving government policies, public awareness campaigns, technological advancements, and community participation to mitigate the impacts of air pollution, including PM 2.5 effectively.

Children are among the most susceptible and at-risk demographics for PM 2.5 because they have smaller air passages, developing respiratory and immune systems, and a relatively high capacity to absorb pollutants [8–9]. Determining how PM 2.5 affects respiratory illnesses and child mortality in children is essential. Because their respiratory systems are still developing, children—especially newborns and young children—are particularly vulnerable to the negative health impacts of air pollution. Compared to adults, they breathe in more air per kilogram of body weight, which could expose them to higher pollution levels, given their size. PM 2.5 can cause bronchitis, pneumonia, asthma, and other respiratory conditions in children by penetrating deeply into the lungs. Children who are exposed to high levels of PM 2.5 for an extended period may experience long-term health effects due to impaired lung function and development. Elevations of PM 2.5 have been linked to higher death rates, with children being especially susceptible. The degree to which air pollution contributes to childhood deaths can be determined by examining the link between PM 2.5 exposure and child mortality. This information can be used to inform preventative strategies. Although other factors associated with child respiratory illness, such as adequate nutrition and access to healthcare services, must also be taken into account, several studies have shown that the impacts of PM 2.5 on child mortality and child respiratory illnesses have become a mainstream issue over the past few years. Policies can benefit significantly from research results about the effects of PM 2.5 on child health and death. These statistics can influence stricter regulations governing air quality, emission-reduction plans, and child-protection initiatives. Public understanding of the significance of clean air and its direct influence on children's health is increased by studies demonstrating the connection between PM 2.5 and child health outcomes. This knowledge can enable communities to proactively protect children's health and fight for more substantial environmental restrictions. In order to identify at-risk populations, understand the extent of the issue, inform policy decisions, and ultimately safeguard the health and well-being of children who are especially susceptible to the adverse effects of air pollution, research on the impact of PM 2.5 on child respiratory illness and mortality is crucial. Addressing PM 2.5 pollution involves various measures, including reducing emissions from vehicles, industries, and power plants and implementing stricter regulations on sources of pollution. Improving air quality through these measures is crucial to mitigating the health risks associated with PM 2.5 and achieving WHO guidelines, ensuring better public health outcomes.

This study aims to assess the impact of air pollution (PM 2.5) on child health across various regions in the Philippines and establish the relationship between air pollution and health outcomes in children. The study will provide insights to the environmental and health sectors regarding the magnitude of the effect of air pollution on the prevalence of child respiratory illnesses and child mortality rates in the Philippines. Its findings will provide evidence to support the need for more rigorous implementation of policies and regulations related to air quality standards and pollution control measures in the Philippines. Reducing air pollution may also reduce child mortality and improve children's and women's health. It may highlight the necessity to allocate resources, create community-based interventions, and strengthen specialized healthcare services for children - the vulnerable population, in regions with elevated air pollution levels. Moreover, the study's results will also be added to the literature on similar topics.

Methods

1) Data sources, study design, and population

The study involves a cross-sectional research design involving children aged 5 years and below who are reported to have child respiratory illnesses and mortality in the 2022 National Demographic and Health Survey (NDHS) of the Philippine Statistics Authority (PSA) [10]. The NDHS is a nationally representative survey conducted every five years since 1993 by the PSA in collaboration with the Department of Health (DOH) and other partner agencies in the Philippines. The 2022 NDHS collects data on various demographic and health indicators to inform policymakers, program managers, researchers, and other stakeholders. The 2022 NDHS data were accessible on a regional level for each child's respiratory illness and child mortality indicator: acute respiratory infection, asthma, neonatal mortality, post-neonatal mortality, and mortality under 5 years old. On the other hand, data sets for the fine particulate matter PM 2.5 are collected and monitored by the Environmental Management Bureau of the Department of Environment and Natural Resources from their 70 stations throughout the country. The locations of these stations are highly concentrated in the National Capital Region and other highly urbanized cities and municipalities where human and industrial activities contributing to air pollution are immensely high [11]. Many municipalities still need air quality monitoring stations; hence, the data aggregation level is only possible on a regional level. The reason for using annualized data for PM 2.5 is to match it with the annual data for child respiratory illnesses and child mortality indicators, as the analysis requires that these variables should have similar data aggregated levels.

Regarding limitations, the researchers acknowledge that it is always preferable to perform analysis on the lowest level of aggregation, say daily or weekly, and on a community level, like barangay, city, or municipality. However, due to constraints on the availability of the datasets on these levels, we opt for regional level and annualized aggregation. Another limitation is the exclusion of possible confounding factors, such as those other factors that may influence child respiratory illnesses and child mortality that are not captured in the study.

2) Statistical analysis

The study used a Choropleth map to present the 5-year cumulative PM 2.5 levels from 2018 to 2022 of the different regions in the Philippines. It is generated using an online application called Datawrapper, which creates interactive data visualizations [12]. Further, descriptive statistics such as percentages were used for the prevalence of child respiratory illnesses, while rates per 1000 population were used for child mortality in the Philippines. Spearman correlation analysis and correlation plots measured the relationship between PM 2.5 and child respiratory illness and mortality rates. Gamma regression analysis was used to evaluate the effect of PM 2.5 on child respiratory illnesses in the Philippines since it is suitable when the response variable is continuous and strictly positive. Negative binomial regression analysis (NB) was used to determine the effect of PM 2.5 on child mortality in the Philippines.

NB is suitable when the response variable is strictly positive and integer-valued. NB and Gamma regression are extensions of the linear regression model and are part of the broader class of generalized linear models. The dispersion parameter was used to assess the suitability of the model further. A dispersion parameter greater than 0 means the negative binomial is suitable.

On the other hand, a dispersion parameter less than 0 implies that the gamma family is appropriate. The models were further assessed using diagnostic plots of residuals to determine if the model captures all the components, leaving the residuals pattern less or random. All statistical analysis was performed using the R programming language [13]. R library called 'MASS' was used in performing gamma and NB regression analysis [14].

Results and discussion

The annual trend of PM 2.5 in the Philippines from 2013 to 2022 is presented in Figure 1.

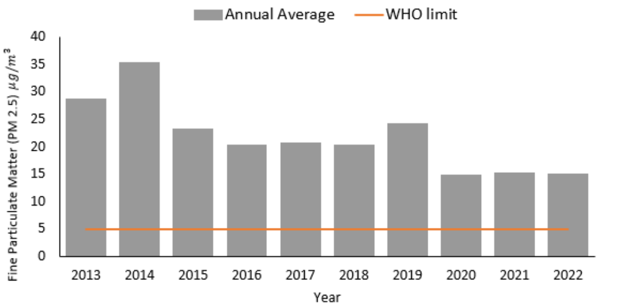

Figure 1 PM 2.5 Trend in the Philippines from 2013 to 2022.

It can be observed that the PM 2.5 levels have been decreasing over the past few years. However, the levels are still above the threshold limit set by WHO, which is 5 μg m^{-3} annually. Throughout these years, highly urbanized cities and municipalities in the Philippines and those localities with high industrial economic activities, urbanization, and vehicle emissions have higher levels of PM 2.5 consistently as supported by 5-year cumulative PM 2.5 levels of the different regions in the Philippines, shown in Figures 2 and 3.

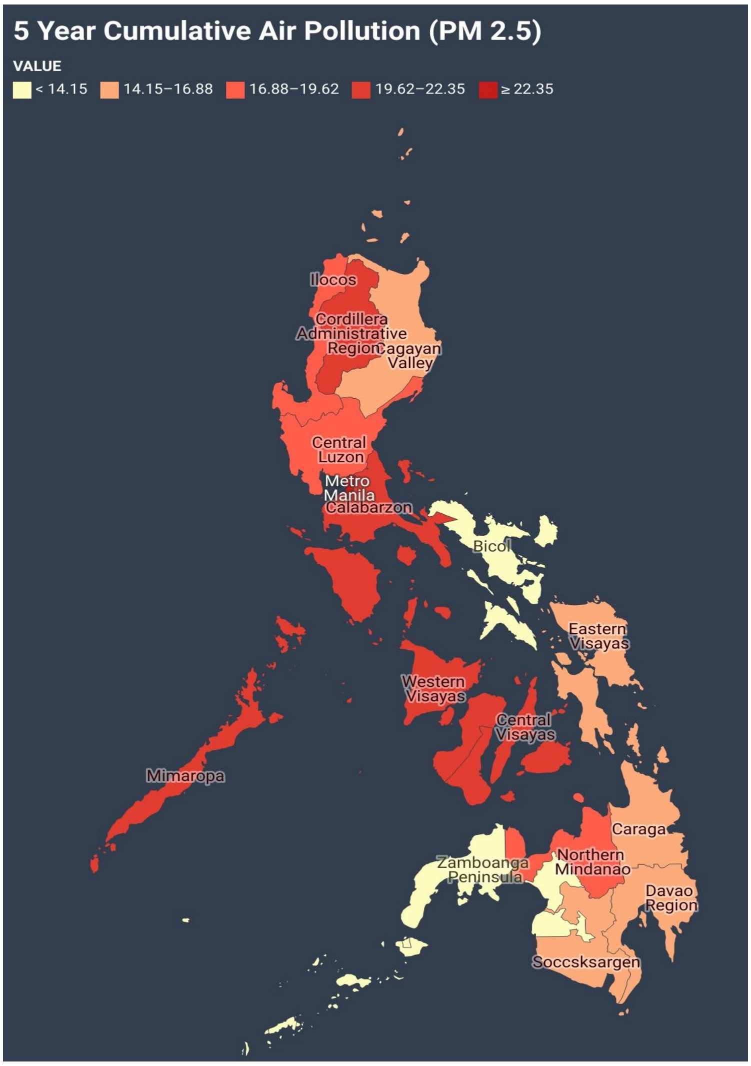

Figure 2 Choropleth map of PM 2.5 levels.

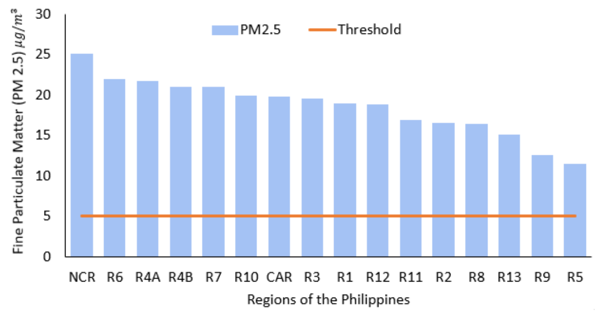

Figure 3 Cumulative PM 2.5 levels (2018–2022).

The National Capital Region (NCR) has the highest PM 2.5 air pollution levels. It is somewhat expected as NCR has 16 highly urbanized cities, namely, the City of Manila, Caloocan, Las Piñas, Makati, Malabon, Mandaluyong, Marikina, Muntinlupa, Navotas, Parañaque, Pasay, Pasig, Quezon City, San Juan, Taguig, and Valenzuela. Manila, the capital city of the Philippines and one of the most urbanized cities within the NCR has often experienced elevated levels of air pollution, including PM 2.5, an annual average of 25 μg m^{-3}. Other highly urbanized cities in the NCR, such as Quezon City and Pasig, have also encountered air quality issues, with PM 2.5 levels exceeding recommended thresholds on certain occasions. Highly urbanized cities in the Philippines are characterized by many economic and industrial activities, which generate higher air pollution.

Although all regions have exceeded the 5 μg m^{-3} annual threshold set by the WHO, four other regions are notable for having PM 2.5 levels higher than 20 μg m^{-3}. These are Region 6 (Western Visayas), Region 4A (Cavite, Laguna, Batangas, Rizal and Quezon), Region 4B (Mindoro, Marinduque, Romblon and Palawan) and Region 7 (Central Visayas). Like NCR, these regions have higher economic and industrial activities than others.

The prevalence of acute respiratory infection in NCR, CALABARZON, MIMAROPA, CAR, Central Luzon, and Western Visayas is above 10%. Furthermore, the prevalence of asthma is also more than 10% in these regions (Table 1). Central Visayas, Cagayan Valley, and Ilocos have a prevalence of asthma greater than 10%. The neonatal mortality rates per 1000 for NCR, CAR, SOCCSKSARGEN, and Western Visayas are 20, 18, 18, and 18, respectively. Furthermore, for post-neonatal mortality, a similar list of regions has higher deaths per 1000 population, with the addition of the Zamboanga Peninsula. Lastly, for mortality under five years old, BARMM and MIMAROPA have the highest rates.

Figure 4 shows the correlation plot of the child's respiratory illness, mortality indicators, and PM 2.5. Acute Respiratory Infection and Asthma correlate with PM 2.5, with Spearman rank correlation r of 0.87 and 0.90, respectively. On the other hand, neonatal mortality, post-neonatal mortality, and mortality under five years old are moderately correlated with PM 2.5, with Pearson correlation r values of 0.72, 0.71, and 0.61, respectively. A similar result was found in another study wherein significant relationships/correlation was found between PM 2.5 and child respiratory illnesses and child mortality [6, 15–17]. A one-unit annual increase in PM 2.5 leads to a nearly 14.5% increase in the number of children dying before the age of five, suggesting the severity of the impact of PM 2.5 in child mortality in sixteen countries being studied [6]. In urban slums, respiratory illness is significantly higher for children in high-pollution areas (OR=1.25, 95%CI=1.11–1.41). High pollution levels exposure was associated with a high child mortality rate under five (IRR=1.22, 95%CI=1.08–1.39) [7].

Table 1 Child Respiratory Illness (%) and Child Mortality Indicators (rate per 1000)

Region	Acute Respiratory Infection	Prevalence of Asthma	Neonatal Mortality	Post-neonatal mortality	Under 5 Mortality
NCR	15.7	19.1	20	15	18
CAR	10.2	13.6	18	15	19
Ilocos	9.9	13.3	15	10	20
Cagayan Valley	6.8	10.2	8	9	11
Central Luzon	11.2	14.6	11	10	15
CALABARZON	15.2	18.6	14	5	16
MIMAROPA	11.9	15.3	15	14	27
Bicol	2.3	4.3	10	2	15
Western Visayas	12.3	15.8	18	15	25
Central Visayas	9.4	12.9	12	9	16
Eastern Visayas	3.9	7.3	14	5	17
Zamboanga Peninsula	4.6	4.5	7	14	14

Table 1 Child Respiratory Illness (%) and Child Mortality Indicators (rate per 1000) (*continued*)

Region	Acute Respiratory Infection	Prevalence of Asthma	Neonatal Mortality	Post-neonatal mortality	Under 5 Mortality
Northern Mindanao	4.3	7.7	8	7	19
Davao	5.9	9.4	7	6	13
SOCCSKSARGEN	5.3	8.7	17	7	19
Caraga	2.8	6.2	7	6	14
BARMM	3.2	4.6	8	12	27

Source: *2022 National Demographic and Health Survey*

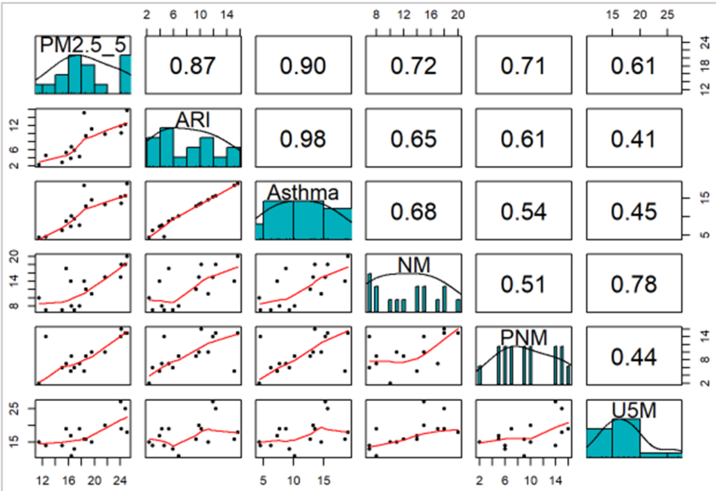

Figure 4 Correlation plots of PM 2.5 and child respiratory illness and child mortality.
Notes: ARI-Acute Respiratory Illness, NM – neonatal mortality, PNM – post-neonatal mortality, U5M-under-five mortality

Children are highly susceptible to the adverse effects of air pollution due to their physical characteristics and developing physiology. These include smaller air passages, developing respiratory and immune systems, elevated respiratory rate, and a relatively high capacity to absorb pollutants [15]. Research conducted in urban settings through epidemiological studies has established a direct link between exposure to PM 2.5 and health problems in children. These encompass respiratory infections [18], asthma symptoms [19–20], impaired growth [21–22], and occurrences of metabolic disorders [21]. All these contribute to an increased likelihood of mortality among children exposed to air pollution.

Table 2 shows the results of the gamma regression analysis to measure the effect of PM 2.5 on child respiratory illnesses. The reasons for choosing gamma regression are discussed in the methodology section. The estimate of the coefficient of PM 2.5 for Acute Respiratory Infection (ARI) is highly significant (p-value<0.001), which means that PM 2.5 greatly influences the incidence of ARI among children in the Philippines. The coefficient estimate (0.1123) is positive, implying that an increase in PM 2.5 is expected to contribute to an increase in ARI. In particular, a one microgram increase of PM 2.5 is associated with an 11.23% increase in the ARI among children. A similar study conducted in Korea [14] found that short-term exposure to PM 2.5 increases the risk of acute respiratory infection and bronchitis.

Table 2 Effect of PM 2.5 on child respiratory illness

	Acute respiratory infection	Asthma
Intercept	-0.0834	0.5962
p-value	0.8533	0.0818
PM 2.5	0.1123	0.0946
p-value	<0.001	<0.001
Dispersion	0.1475	0.8866

Similarly, for asthma, the estimate of the coefficient of PM 2.5 is highly significant (p-value<0.001). It is also positive (0.0946), which implies that an increase in PM 2.5 will also mean an increase in asthma incidence among children. In particular, a one microgram increase of PM 2.5 is associated with a 9.46% increase in asthma among children. A previous study [16] emphasized that young children with asthma are particularly susceptible to PM 2.5, and authors in the study have found that Emergency Department visits in hospitals have increased among children with asthma as the level of PM 2.5 increases. Previous studies have found that PM

2.5 causes asthma exacerbation and increases hospital visits [20, 23].

Table 3 shows the results of the negative binomial regression analysis to measure the effect of PM 2.5 on child mortality indicators. The reasons for choosing negative binomial regression are discussed in the methodology section. The estimate of the coefficient of PM 2.5 is highly significant for neonatal mortality, post-neonatal mortality, and mortality under five years old (all p-values<0.001), which means that PM 2.5 greatly influences the rates of neonatal mortality, post-neonatal mortality and mortality under five years old in the Philippines. The IRRs are 1.063, 1.080, and 1.039 for neonatal mortality, post-neonatal mortality, and mortality under five years old, respectively. The IRRs indicate that a one microgram increase in PM 2.5 is associated with a 6.3% increase in neonatal mortality, 8.0% in post-neonatal mortality, and a 3.9% increase in mortality of children under five years old in the Philippines. In another study, the IRR is also greater than 1 for all-cause mortality (children below the age of 5), which indicates that a one microgram increase in PM 2.5 will significantly increase the rate of child mortality [22].

Table 3 Effect of PM 2.5 on child mortality rates

	Neonatal mortality	**Post-neonatal mortality**	**Under 5 mortality**
Intercept	1.365	0.7492	2.1267
p-value	<0.001	0.0646	<0.001
PM 2.5	0.0608	0.0771	0.0384
p-value	<0.001	<0.001	0.0078
Dispersion	26,407.4	87,158.4	67,688.3
Incidence rate ratios (IRR)	1.063	1.080	1.039

After investigating 29 European countries, [14] found that respiratory mortality increased by 0.58% for every 10 μg m^{-3} increase of PM 2.5. It was recently reported that the prevalence rate of respiratory diseases increased by 2.07%. Other previous studies [16–17] reported that elevated air particle pollutants were directly associated with more severe symptoms of respiratory tract diseases, undermined lung function, and raised morbidity and mortality of cardiopulmonary diseases. Furthermore, this correlation was more evident in the elderly, pregnant women, adolescents, infants, patients with a history of cardiopulmonary problems, and other susceptible populations [18–25].

These findings are probably because the period from birth to age five is a critical phase of developing the lungs and immune system [26–28]. The intensity of development during this early childhood period could contribute to the increased susceptibility of younger children to the effects of PM 2.5 exposure on respiratory health.

Conclusions

Regions with numerous highly urbanized cities (HUCs) will likely have higher cumulative PM 2.5 levels. Furthermore, regions with high PM 2.5 levels also exhibit high rates of respiratory illnesses and child mortality. The relationship is positive and significant between PM 2.5, child respiratory illnesses, and child mortality. As PM 2.5 levels increase, the rates of child respiratory illnesses and child mortality are also expected to increase.

Mitigating elevated PM 2.5 levels in urban settings necessitates a collaborative approach involving government agencies, industries, communities, and individuals. By integrating regulatory measures, embracing technological innovations, fostering public awareness, and promoting community engagement, it becomes feasible to alleviate the adverse effects of air pollution on children's health and the general well-being of the public.

There should also be a high allocation of medical care resources in the identified localities and regions with high PM 2.5 and respiratory illness and child mortality rates. Strengthening healthcare infrastructure, especially in areas with high pollution levels, is recommended to address the increased demand for medical services. Moreover, the provision of training for healthcare professionals to effectively diagnose and treat respiratory illnesses can also be performed.

For further research, it is recommended to conduct a study using granular level data or data on lower geographic levels such as cities, municipalities, or barangay levels to have a spatial-specific look at the PM 2.5 problems. Also, other factors leading to children's respiratory illness and mortality should be investigated to have a comprehensive outlook on air pollution's effect on children's health.

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