A Hazy Future: Exploring the Effect of Air Pollution on Child Development in Indonesia

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Abstract

Air pollution is a significant issue in emerging economies like Indonesia, with detrimental effects on human health. This study aimed to analyse the impact of air pollution on child development, using various datasets and employing an instrumental variable approach. The findings revealed that an increase of 1 $\mu g/m^3$ in regional PM 2.5 concentration had a significant negative effect on child growth, reducing height-for-age and weight-for-age scores by 0.08 standard deviations. No significant impact was observed on the stunting variable. The study also found that girls were particularly susceptible to impaired child development due to air pollution. These results emphasize the need for policies targeting air pollution reduction to support healthy child development, especially in low-income households.

Keywords: Air Pollution, Child Development, PM 2.5, Instrumental Variable.

JEL Classification: I15, Q51, Q53

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I. Introduction

Air pollution is a severe externality of human economic activities and energy consumption with potentially devastating impacts on human health. Air pollution is considered more dangerous than water and land pollution because of its transportability (Feng *et al.*, 2020). According to the World Health Organization (WHO) (2016), by 2016, there were seven million deaths related to air pollution. Even worse, 94% of this number occurs in developing countries. Several studies explained possible causes of the high number of mortality due to air pollution, such as; severe respiratory ailments, blindness, and heart diseases (Branca and Ferrari, 2002; Dewey and Begum, 2011; Hoddinott *et al.*, 2013; Feng *et al.*, 2019)

Previous economics and health literature has also focused on various effects of air pollution. Several economics literature has been exploring the effect of air pollution on household's health expenditure and the number of visits to medical facilities. Previous economics and health literature has also focused on the various effects of air pollution. Several economic studies have explored the effect of air pollution on households' health expenditures and the number of visits to medical facilities (Barwick *et al.*, 2017; Yang and Zhang, 2018; Anwar *et al.*, 2022). Other studies have explained the effects of air pollution on childhood mortality, morbidity, respiratory infection, and diabetes mellitus (Ghosh and Mukherji, 2015; Naz, Page, and Agho, 2016; Sheldon and Sankaran, 2017; Jayachandran, 2019; Suryadhi *et al.*, 2020).

Regarding the harmful effects of air pollution on individual health, children are more susceptible to pollution than adults. In addition to its impact on child mortality and respiratory ailments, air pollution has a potentially negative effect on child development. Schlaudecker et al. (2011) explained the transmission of air pollution's effect on child development is possible through malnutrition due to respiratory ailments. When a child suffers from a respiratory illness, the consumed nutrition that should support its growth will be allocated to fight the disease. The fact that a child's immune system is still developing makes the problem might be more severe for child development (Rodríguez, Cervantes, and Ortiz, 2011). Therefore, even a surviving child can experience impaired growth. In some extreme cases, children who suffer from impaired growth can be categorised as stunted, which has been proven to have some serious implications, both short- and long-term, such as impaired cognitive ability, lack of physical capacity, and adult morbidity (Pollitt *et al.*, 1995; Brown and Pollitt, 1996; Rodríguez, Cervantes and Ortiz, 2011). In addition, child development is crucial for shaping quality human resources. The quality of human resources determines an economy's future productivity.

There have been limited studies on the effect of air pollution on child development, especially in the context of emerging economies (Bobak, Richards, and Wadsworth, 2004; Singh *et al.*, 2019; Balietti, Datta, and Veljanoska, 2022). Therefore, this study focuses on Indonesia, as the country with the highest prevalence of under-five stunting and one of the largest carbon emissions (UNICEF, 2013; Dunne, 2019; UCSUSA, 2022). According to Lee and Greenstone (2021), more than 93% of Indonesians live in regions with air pollution concentrations higher than the WHO standard. On average, Indonesians faced a decrease in life expectancies by two and a half years. Accordingly, this research focuses on exploring the effect of air pollution on child development in Indonesia.

II. Data and Methodology

This study's primary dataset was the fifth wave of the Indonesia Family Life Survey (IFLS-5). Following the WHO Child Growth Standard, this study used anthropometric data of individuals aged 0 – 5 years old from the IFLS to calculate the height-for-age (HAZ) and weight-for-age (WAZ) scores for each sample. HAZ and WAZ were basically a z-score in standard deviation unit of a child's height (or weight) relative to the median height of the population with the same age and gender. The score could be obtained by dividing the difference between one child's height (or weight) and the reference population's median height (or weight) and its standard deviation. WHO also classified children with HAZ < -2 as stunted. Therefore, this study will use three indicators of child development; HAZ, WAZ, and a dummy variable of stunted, which equals 1 if the child's HAZ < -2 and 0 otherwise.

As the main independent variable, this study uses the Particulate Matter (PM) 2.5 concentration indicator, which is an air particle less than equal to 2.5 mm in size. PM 2.5 concentration is measured in units of $\mu g/m^3$. The PM component usually consists of a complex mixture of solid and liquid particles of both organic and non-organic nature, such as sulfate, nitrate, ammonia, sodium chloride, black carbon, mineral dust, and water (WHO, 2016).

Ambient air pollution, especially when measured by satellite imageries, is often considered to have endogeneity issues. This is because the concentration of air pollution in a certain place may be caused by the behavior of individuals or groups of people in the area. Besides, high pollution concentration in certain regions might indicate more developed regions relative to others. In addition, measurement errors are also suspected to cause bias in the estimation coefficients. Therefore, this study follows in the path of previous studies in using instrumental variables (IV) or the TSLS (Two Stage Least Square) method to overcome possible simultaneity and measurement error problems (Greenstone and Jack, 2015; Sheldon and Sankaran, 2017; Balietti, Datta and Veljanoska, 2022; Li and Li, 2022).

The instrumental variable used in this study is the annual rainfall in the year and region of the child's birth (mm). The variable is assumed to be sufficiently random and able to explain variations in air pollution concentrations between regions. Several studies in the environmental field have found that rainfall is proven to contribute to variations in air pollution concentrations in various regions (Liao *et al.*, 2017; Luo *et al.*, 2018; Chen *et al.*, 2020; Zhou *et al.*, 2020; Xiao *et al.*, 2022). In general, high precipitation levels in an area tend to reduce air pollution concentrations through changes in air humidity and temperature (scavenging effect). However, high rainfall can also accumulate air pollution at certain humidity levels and wind speeds. Annual rainfall data per district was obtained from The Tropical Rainfall Measuring Mission (TRMM) data collected through satellite imagery by the National Aeronautics and Space Administration (NASA). The dataset includes daily rainfall for each site with a spatial resolution of 0.25°. The data were then summed to obtain annual rainfall and matched with the administrative boundaries of districts/cities in Indonesia using administrative area shapefiles provided by GADM (Global Administrative Areas) with QGIS software. Afterward, the annual rainfall data was merged with individual, household, and air pollution concentration data according to the individual's district/city of residence and year of birth.

After the merging process, we obtained 3148 individuals aged 0 – 5 years old samples which scattered around 240 regions (cities and municipalities). Using the TSLS method, the main empirical model consists of multi-level variables; individual, household, and regional levels. For the first-stage estimation, the empirical model could be specified as:

$$PM_{2.5_{c,t-a}} = \alpha + \beta_1 Precipitation_{c,t-a} + \beta_2 X'_{i,h,c} + \epsilon \quad (1)$$

$PM_{2.5}$ is PM 2.5 concentration in region c in the birth year of individual $(t - \alpha)$. $Precipitation$ represents the annual precipitation rate of region c in year of birth of an individual. Besides, X' represents various control variables in individual, households, and regional level. Moreover, the second-stage empirical model could be noted as:

$$H_{i,t} = \alpha + \delta_1 \widehat{PM}_{2.5_{c,t-a}} + \delta_2 X'_{i,h,c} + \mathrm{E} \quad (2)$$

On the Equation (2), H are child growth indicators (HAZ, WAZ, and binary variable of stunted). In addition, X' represent control variables such as; parent's educational level, parent's height, household food consumption, number of smokers within the household, dummy variable of various assets ownerships, household health expenditure, regional gross domestic product, and population of the region of birth.

In using the TSLS method, the instrumental variables used must fulfill two assumptions; 1) relevant and 2) exogenous. Relevant means that the IV is able to explain the main independent variable. A relevance test will be conducted in the first stage of estimation to test this assumption. Meanwhile, exogenous means that the IV only affects the outcome of interest through the main independent variable (Gertler *et al.*, 2016). In the case of this study, the annual rainfall variable should be able to explain variations in air pollution concentrations between regions and assumed not to affect children's height directly.

III.RESULT

3.1. Main Estimation

Table 1 presents the estimation results. The first to third columns show the estimation results obtained using the OLS method. Columns (4) to (6) show the estimation results using the TSLS method with the instrument variable log annual rainfall in the year of individual birth. The results of the OLS method show that air pollution concentration has a positive effect on child growth. However, the results are highly susceptible to bias owing to measurement errors and inverse relationships, so the estimation result is close to zero (attenuation bias). Meanwhile, the estimation results using the TSLS with clustered standard errors at the district/city level show the opposite result.

A 1 $\mu g/m^3$ increase in air pollution concentration implies a 0.08 standard deviation decrease in HAZ, ceteris paribus. For WAZ, a 1 $\mu g/m^3$ increase in air pollution concentration also decreased children's WAZ by 0.079 standard deviations, ceteris paribus. Meanwhile, an increase in air pollution did not significantly affect the stunting dummy variable. This finding provides evidence that exposure to air pollution negatively affects child growth in Indonesia. These results are relatively larger when compared to the findings by Balietti et al. (2022), which showed that an increase of 1 $\mu g/m^3$ PM 2.5 implied a decrease in HAZ score by 0.11 and showed no significant effect on WAZ score. On the other hand, various other control variables that were statistically significant at the 5% level for almost all dependent variables included household health expenditure, the mother's education level, and the father's and mother's height. These variables positively affected HAZ and WAZ while negatively affecting the probability of child stunting.

	OLS			TSLS		
Dependent Variable	**HAZ**	**WAZ**	**Stunted**	**HAZ**	**WAZ**	**Stunted**
	(1)	(2)	(3)	(4)	(5)	(6)
PM 2,5 concentration ($\mu g/m^3$)	0.0195**	0.0333**	-0.00139	-0.0808*	-0.0797*	-0.00459
	(0.00636)	(0.00552)	(0.000950)	(0.0385)	(0.0365)	(0.00375)
(Log) Regional Gross Domestic Product (GDP) in 2015	0.0118	-0.0541	-0.00843	0.358*	0.336*	0.00259
	(0.0556)	(0.0493)	(0.00946)	(0.152)	(0.144)	(0.0156)
(Log) Population in 2015	-0.0416	-0.0243	0.0132	-0.0953	-0.0850	0.0115
	(0.0668)	(0.0600)	(0.0120)	(0.0906)	(0.100)	(0.0105)
(Log) Household food consumption	-0.0685	0.0523	-0.00300	-0.110+	0.00593	-0.00432
	(0.0607)	(0.0578)	(0.0101)	(0.0605)	(0.0608)	(0.0102)
(Log) Household health expenditure	0.118**	0.141**	-0.0124**	0.158**	0.186**	-0.0111**
	(0.0255)	(0.0238)	(0.00402)	(0.0315)	(0.0298)	(0.00419)
Number of smokers within Household	-0.0189	-0.0351	-0.00325	0.0197	0.00840	-0.00202
	(0.0514)	(0.0465)	(0.00877)	(0.0624)	(0.0589)	(0.00786)
Dummy variable of house ownership (= 1 if own)	0.00642	-0.0420	-0.0000933	-0.154	-0.223*	-0.00521
	(0.0763)	(0.0672)	(0.0131)	(0.114)	(0.0948)	(0.0157)
Dummy variable of other house/building ownership (=1 if own)	0.204+	0.153	-0.0323+	0.186	0.133	-0.0329+
	(0.115)	(0.111)	(0.0173)	(0.133)	(0.124)	(0.0184)
Dummy variable of other land/farm ownership (=1 if own)	0.108	0.0949	-0.0131	0.0268	0.00346	-0.0156
	(0.112)	(0.105)	(0.0185)	(0.117)	(0.104)	(0.0203)
Father's educational level	0.0269+	0.0281*	-0.00388	0.0296+	0.0312*	-0.00379
	(0.0153)	(0.0132)	(0.00276)	(0.0166)	(0.0151)	(0.00294)
Mother's educational level	0.0494**	0.0544**	-0.00675*	0.0530**	0.0585**	-0.00663*
	(0.0168)	(0.0146)	(0.00321)	(0.0180)	(0.0144)	(0.00314)
Father's height (cm)	0.0394**	0.0208**	-0.00662**	0.0401**	0.0215**	-0.00660**
	(0.00620)	(0.00595)	(0.00104)	(0.00658)	(0.00657)	(0.00116)
Mother's height (cm)	0.0484**	0.0334**	-0.00615**	0.0454**	0.0301**	-0.00625**
	(0.00661)	(0.00582)	(0.00118)	(0.00677)	(0.00653)	(0.00111)

Constant	-14.89**	-10.86**	2.409**	-17.63**	-13.95**	2.322**
	(1.512)	(1.421)	(0.266)	(2.033)	(2.164)	(0.355)
Observation	3148	3147	3148	3148	3147	3148
R-sq	0.0627	0.0662	0.0413	.	.	0.0380
Adj. R-sq	0.0588	0.0624	0.0373	.	.	0.0340

Notes: +,*,** indicate significance at the 10%, 5%, and 1% levels. Negative R-sq and Adj. R-sq values that are negative will automatically be reported by STATA as "." (dot).

Table 1. Main Estimation Results

Model	**(4)**	**(5)**	**(6)**
(Log) Annual Precipitation Rate at Region and Year of Birth (mm)	5.17**	5.17**	5.17**
	(1.13)	(1.13)	(1.13)
Control Variables	Yes	Yes	Yes
Relevance test (*F-statistic*)	20.8567	20.906	20.8567
	(0.00)	(0.00)	(0.00)

Notes: +,*,** indicate significance at the 10%, 5%, and 1% levels. The control variables used in the first stage regression are other exogenous variables that are also used in the second stage regression.

Table 2. First Stage Estimation Result and Relevance Test for IV

The coefficient estimates of the instrument variable log annual rainfall on the endogenous variable (PM 2.5 concentration) in the birth year are statistically significant at the 5% level. The direction of the coefficient indicates a positive relationship between the annual rainfall and air pollution concentration. This has been explained by several studies that analysed the possible positive relationship between the two. Wang et al. (2018) suggested that high precipitation levels eliminate more PM10 than PM2.5. Meanwhile, in areas with high humidity levels, moderate to low rainfall levels tended to increase PM 2.5 concentrations. Another study explains that rainfall particles falling to the ground in areas with relatively high air pollution concentrations can actually collect pollutant particles in a process known as coagulation, which tends to increase air pollution concentrations in these areas (Ardon-Dryer, Huang, and Cziczo, 2015). Furthermore, low precipitation levels increase atmospheric moisture (successive hygroscopic) that captures and increases PM 2.5 concentrations (Chen *et al.*, 2020).

In addition, the positive coefficient estimates in the first-stage estimation may be due to the use of annual data periods for the rainfall and air pollution concentration variables. Various studies in the field of meteorology suggest using hourly, daily, or monthly data to analyse the influence of weather variables on air pollution concentrations. In addition, a more specific seasonal context is required to consider other variables, such as wind speed, humidity level, and regional topography, to explain the influence of weather variables on air pollution concentrations. This is also a limitation of this study owing to limited data access and availability. Meanwhile, the relevant test results show a significant F statistic value greater than the critical value in the Wald test, which is 16.38. This implies that the instrumental variables are relevant and can explain the variation in the endogenous variables. Thus, the assumption of relevance for the instrumental variable was tested.

3.2. Subgroup Analysis by Gender

	Male		Female	
	HAZ	**WAZ**	**HAZ**	**WAZ**
PM 2.5 concentration ($\mu g/m^3$)	-0,047	-0,026	-0,116*	-0,137**
	(0,04)	(0,04)	(0,05)	(0.05)
Control variables	Yes	Yes	Yes	Yes
Observation	1645	1645	1503	1502
R-sq	0.03	0.04	.	.

Notes: +,*,** indicate significance at the 10%, 5%, and 1% levels. Negative R-sq values are automatically reported by STATA as "." (dot).

Table 3. Subgroup Analysis by Gender

This study also analysed the differences in the effect of air pollution on child growth between male and female toddlers. The results of the analysis of the sex subgroups are presented in Table 3. Using the TSLS method on two dependent variables (HAZ and WAZ), significant results were obtained only for the female subgroup. The result of the relative estimation coefficient in the subgroup analysis is larger than that of the main estimation. This indicates that the under-five female sample was relatively more vulnerable to the adverse effects of air pollution on growth. A 1 $\mu g/m^3$ increase in air pollution in the region and year of birth of female children under five years of age resulted in a 0.12 and 0.14 decrease in HAZ and WAZ scores, respectively.

Previous studies have described possible gender biases when exploring various aspects of child health in developing countries. In their studies measuring the effect of air pollution on child mortality and child growth, Jayachandran (2019) and Balietti, Datta, and Veljanoska (2022) found that households in Indonesia and India tend to prioritise the health of boys over girls. Therefore, exposure to air pollution is more likely to affect the health of girls than that of boys. In addition, Behrman (1988) and Behrman and Deolalikar (1990) also explained that households in India tend to prioritise boys in terms of nutrition allocation in crisis situations. Alderman and Gertler (1997) also explain that girls' demand for health services tends to be more price and income elastic than boys' in Pakistani households. This means that households prioritise sons in terms of nutrition allocation and access to health services during infancy. Thus, the results from the gender subgroup analysis in this study show similar results to previous studies in that there is a gender bias in terms of vulnerability to the adverse effects of air pollution on children's growth.

IV. CONCLUSION

The study found that exposure to air pollution negatively affects child growth and is statistically significant. Specifically, a 1 $\mu g/m^3$ increase in air pollution concentration in districts implies a decrease in HAZ (height-for-age) and WAZ (weight-for-age) scores by 0.08 and 0.079 standard deviations, respectively. The decrease in HAZ and WAZ scores is an indication that exposure to air pollution inhibits child growth. The study also showed that the sample of under-five girls was relatively more vulnerable to the adverse effects of air pollution on child growth compared to boys. Previous studies have suggested that this may be due to gender bias in nutrition allocation and access to health services.

However, there are at least three points of limitation in this study. First, this study did not specify the sources of pollution that had the greatest influence on child growth indicators. Although PM 2.5 is a fairly comprehensive indicator of air pollution and is widely used in environmental and health studies, the PM 2.5 concentration figure also includes particles that may not have an influence on child growth. This is because PM 2.5 concentration measurements only limit the size of the particles, not the elements or compounds that make them up. Second, the use of PM 2.5 concentrations according to administrative boundaries does not capture variations in air pollution concentrations within administrative regions (districts/cities) or in border areas between regions. In fact, PM 2.5 concentrations within an administrative area also vary. Air pollution concentrations in neighboring regions may also affect border areas with other regions. Finally, this study only measured air pollution concentrations in the year of birth and did not specifically distinguish in-utero exposure from post-birth exposure.

Besides its limitations, this study provides new evidence of the adverse effects of air pollution exposure on child development in the context of Indonesia. Since air pollution is still a policy challenge for Indonesia, this study urges the government to limit exposure to air pollution, especially for underprivileged groups. Every preventive and curative approach should be considered to minimize the adverse effects of all types of pollution.

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Appendices

Appendice 1 Descriptive Statistics

Variable	Mean	Std. Dev	Min.	Max.
Age (months)	33.507	18.857	0	60
Gender (= 1 if male)	.517	.5	0	1
Height-for-age (HAZ)	-.092	1.921	-5.93	5.98
Weight-for-age (WAZ)	-.136	1.754	-7.77	10.83
Dummy variable stunted (= 1 if HAZ < -2)	.134	.341	0	1
Father's education (years)	5.832	2.299	0	7
Mother's education (years)	6.101	2.048	0	7
Father's height (cm)	163.375	5.97	128.5	198
Mother's height (cm)	151.751	5.402	104.6	173.4
Household food consumption (thousand Rupiah)	187.51	185.7	0	2804.99
Household health expenditure (thousand Rupiah)	1244.15	10395.61	0	400000
Number of smokers within Household	.842	.697	0	5
Dummy variable of house ownership (= 1 if own)	.668	.471	0	1
Dummy variable of other house/building ownership (=1 if own)	.101	.301	0	1
Dummy variable of other land/farm ownership (=1 if own)	.115	.319	0	1
PM 2,5 concentration ($\mu g/m^3$)	19.915	7.324	4.42	61.87
Annual precipitation rate at region and Year of Birth (mm)	2591.899	672.22	929.786	4978.31
Regional Gross Domestic Product (GDP) in 2015 (million Rupiah)	48369.71	73219.51	2066.25	354947.4
Population in 2015	1128.23	950.43	50.99	5483.8
Observation	3148			

Appendice 2 Subgroup Analysis by Gender (Detail)

	Male		Female	
	HAZ	**WAZ**	**HAZ**	**WAZ**
PM 2,5 concentration ($\mu g/m^3$)	-0.0477 (0.0387)	-0.0263 (0.0395)	-0.116* (0.0525)	-0.137** (0.0496)
(Log) Regional Gross Domestic Product (GDP) in 2015	0.232 (0.152)	0.155 (0.153)	0.480* (0.209)	0.522** (0.194)
(Log) Population in 2015	-0.0457 (0.101)	-0.0369 (0.112)	-0.139 (0.135)	-0.131 (0.141)
(Log) Household food consumption	-0.135 (0.0897)	-0.0561 (0.0847)	-0.0835 (0.0888)	0.0665 (0.0948)
(Log) Household health expenditure	0.121** (0.0377)	0.165** (0.0357)	0.198** (0.0480)	0.208** (0.0474)
Number of smokers within Household	-0.0217 (0.0770)	-0.0916 (0.0784)	0.0647 (0.0935)	0.131 (0.0870)
Dummy variable of house ownership (= 1 if own)	-0.0892 (0.114)	-0.155 (0.105)	-0.237 (0.174)	-0.322* (0.153)
Dummy variable of other house/building ownership (=1 if own)	0.122 (0.171)	0.0982 (0.164)	0.239 (0.196)	0.119 (0.180)
Dummy variable of other land/farm ownership (=1 if own)	0.0890 (0.156)	0.162 (0.149)	-0.00785 (0.187)	-0.117 (0.164)
Father's educational level	0.0402+ (0.0225)	0.0363* (0.0168)	0.0154 (0.0238)	0.0168 (0.0227)
Mother's educational level	0.0556** (0.0209)	0.0459* (0.0189)	0.0438 (0.0290)	0.0652** (0.0232)
Father's height (cm)	0.0455** (0.00957)	0.0217* (0.00930)	0.0359** (0.00981)	0.0260** (0.0100)
Mother's height (cm)	0.0516** (0.00866)	0.0467** (0.00790)	0.0391** (0.0122)	0.0105 (0.0120)
Constant	-18.04** (2.566)	-14.04** (2.674)	-17.35** (2.982)	-14.08** (2.972)
Observation	1645	1645	1503	1502
R-sq	0.0346	0.0410	.	.
Adj. R-sq	0.0269	0.0333	.	.

Notes: +,*,** indicate significance at the 10%, 5%, and 1% levels. Negative R-sq values are automatically reported by STATA as "." (dot).