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Effects of Air Pollution and Corruption Control on Life Expectancy in Middle-Income Countries

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ABSTRACT

Air pollution is recognised as one of the main factors affecting the health status of the population. Since environmental degradation mitigation works through public institutions, the governance quality plays a vital role in the pollution health effect. Noting that governance role may be relevant to ensure effective health care delivery, this study addresses this issue by considering corruption control, which is considered important, but especially in the setting of middle-income countries, the literature is largely vague. In consequence, it seems that there is a need to assess the air pollution-health relationship in order to develop suitable strategies toward a healthier climate. This study empirically evaluates the life expectancy and corruption effect of $PM_{2.5}$ in 72 middle-income countries from the period of 2010 until 2017 by employing the dynamic panel estimation using Generalized Method of Moment (GMM). The result suggests that the elevated level of $PM_{2.5}$ has a significant effect on reducing life span. Furthermore, the findings suggest that corruption regulation appears to mitigate the $PM_{2.5}$ harmful effects towards life expectancy. The study recommends the need to develop stricter environmental policies to protect the health of the population, as good health is important for a better living.

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INTRODUCTION

The United Nations Development Programme has introduced life expectancy as among the key metrics in calculating the Human Development Index (HDI) in determining a country's human development. Multiple factors affecting life expectancy, and the environmental quality are taken into consideration amongst the most crucial factors (Evans and Smith, 2005; Mariani et al., 2010). Environmental degradation of ambient air pollutant such as sulphur dioxide (SO_2), nitrogen dioxide (NO_2), particulate matter (PM) and carbon dioxide (CO_2) are among proven toxic indication to various diseases and lessened life expectancy (Etchie et al., 2018; Balakrishnan et al., 2019; Cheng et al., 2019). Given regular media attention and growing epidemiological studies on risks to air quality, empirical air pollution and health relation analysis is not adequate, particularly in middle-income countries. A thorough evaluation of the air pollutant effects on these nations is critically needed, as they are in the phases of economic growth and consequently facing with environmental problems gradually (Alvarado and Toledo, 2017; Pata, 2018). Apparently, with greater economic growth, but ultimately more environmental pollution, will cause social adverse effects associated with health problems that are susceptible in rising population mortality and thereby shortening life expectancy. Research on the relationship of health outcomes with air contaminants is urgently required to build sustainable regional air pollutant coping strategies.

Evidence is rising that higher levels of corruption are impoverishing populations, increasing inequality and declining health status (Witvliet et al., 2013; Naher et al., 2020). Corruption represents a violation of trust and a deliberate willful misconduct (Mostert et al., 2012; Dwiputri et al., 2019), with negative implications for population health, especially among the most vulnerable. Corruption disrupts environmental policies and the quality of the environment. The corruption at the central government level can contribute to the postponement or weakening of environmental regulations. On the other hand, local government corruption can curtail the implementation of environmental policies in businesses, contributing to a decrease in policy standards (Wang et al., 2019a). While corruption can be observed in all countries, its implications in low and middle-income countries are especially devastating (Sathyamoorthy and Cheong, 2019; Bouchard et al., 2012; Leitao, 2016). In particular, corruption can be observed as a notable contributor to environmental pollution among many developing countries with relatively rich natural resources. For instance, corruption in Ukraine has been identified as a source of obstacles to accessing health care and medical products (Mendel, 2017). While the corruption effects on a population's health are not always apparent and immediate, their existence might worsen the health system in various ways, negatively impacting the health of a group or nation. The corruption, for example, has hampered child immunisation, increased patient wait times, lowered patient contentment and reduced the functionality of clinics for care in the Philippines (Azfar and Gurgur, 2008). Kim and Wang (2019) linked quality of government upon health outcomes whereby reducing corruption can significantly improve life expectancy. Thus, anti-corruption may, on the contrary, improve health status.

Previous studies have shown that countries with lower levels of corruption have stronger health policies that improve the population's health. Air pollution controls, on the other hand, necessitate certain capacities of governing institutions. Leitao (2016) claims that policies and institutions can greatly minimize environmental deterioration at low-income levels. Therefore, this study argues whether corruption control could substantially mitigate the health impacts of air pollution. Observing the vast amount of current work on these concerns in high-income settings, this study contributes to empirical studies by addressing this issue in largely ambiguous literature within the context of middle-income countries. We considered life expectancy to measure the public health outcomes while $PM_{2.5}$ air pollutants are considered to be the primary environmental air pollutants that pose a threat to public health in middle-income countries. We postulated that higher $PM_{2.5}$ levels were linked to a shorter life expectancy. Further, the study looks into the interaction effect of control of corruption in moderating $PM_{2.5}$ risk on life expectancy. The findings may be used to help the decision-makers develop policy recommendations to assist the public contend with deteriorating air quality in the implementation of health strategies. In addition, the aim of this study is to add to the empirical evidence from a public health perspective on the role of government in environmental protection, as life expectancy is a well-documented and significant indicator of general public health policy.

The remainder of the study is organized as following. The second part relates with previous empirical research on the effects of air pollution and corruption on health outcomes. The third one describes the data and model specification as well as the methodology. The fourth section presents the empirical findings. The final part reviews the study's key findings and recommends several considerations for the future.

LITERATURE REVIEW

Air Pollution and Life Expectancy

Emission of air pollutants have been consistently linked to the negative consequences on human health (Nasari et al., 2016; Tsai et al., 2018; Cheng et al., 2019). Air pollution is characterised by the accumulation of harmful chemicals or substances in the air, at levels that carry a health threat (Seinfeld and Pandis, 2016). According to the United Nations Economic Commission for Europe (UNECE), it is the most prominent ecological risk to human health. Evidence also shows that air pollution is a significant trigger for morbidity (Babatola, 2018; Tong, 2019; Estol, 2020). Outdoor air pollution is a primary risk to loss of life expectancy, particularly due to cardiovascular diseases, which was proven by Lelieveld et al. (2020) study of various global risk factors. Environmental medicine is especially concerned with particulate matter that has an aerodynamic diameter smaller than 2.5 um ($PM_{2.5}$). Epidemiological findings have also showed that frequent exposure to $PM_{2.5}$ is associated with an increased risk of mortality, resulting in a loss of lifespan (Kim et al., 2017; Li et al., 2018; Wang et al., 2019b). Results of these analyses can help inform and describe the events linking air quality to human health outcomes.

According to Chen et al. (2019), people in Taiwan who lived in areas depicted as having greater concentrations of $PM_{2.5}$ had a slightly shorter life expectancy, with a rise in $PM_{2.5}$ correlated with a 0.3-year decrease in life expectancy among adults. In 2017, India recorded an excessively high mortality and disease burden associated with air pollution, according to the Global Unified Burden of Diseases, Injuries, and Risk Factors Study, it comprises 359 illnesses or injuries with 84 risk factors (Balakrishnan et al., 2019). Using the Global Burden of Disease project, $PM_{2.5}$ exposure was estimated to lower global birth life expectancy of about one year in 2016, with losses of 1.2 to 1.9 years in contaminated Asian and African countries (Apte et al., 2018). In another study, Feng et al. (2016) emphasised the health repercussion due to a widespread rise of $PM_{2.5}$. The study further found that the pollutant's concentration in target cells would influence the physiology and biochemistry of the cell, and could lead to poor birth effects and the progression of diabetes mellitus and cardiopulmonary diseases, which can shorten life expectancy. According to Bennett et al. (2019), approximately 15,612 female deaths and 14,757 male deaths was caused by $PM_{2.5}$ exposure, thus lowering national life expectancy by 0.15 years for women while 0.13 years for men. Other studies built on the association concerning fine particulate air pollution disclosure to life expectancy can be found in Schwartz et al. (2018), Hill et al. (2019) and Wu et al. (2020).

However, the available evidence is largely based on the research of people subjected to moderate exposure to air pollution, as seen in the developed countries (Aliyu and Ismail, 2016; Ebenstein et al., 2017). Despite this, air pollution causes death and shortens life expectancy, with lower-income community suffering the most. The global health burden of air pollution resulted in nearly 9 million deaths annually, with roughly 90% of deaths due to ambient air pollution occurring in low and middle-income countries (Carlsten et al., 2020). The problem is more severe due to overpopulation and unregulated urbanisation and the growth of industrialisation in the developing countries (Manisalidis et al., 2020). This leads to poor air quality, especially in countries where there are social disparities and a lack of awareness about long-term environmental management.

Corruption and Health Outcomes

Reducing the air pollution risk could depend on rapid implementation of effective environmental policies throughout a country, which correspond with the enormity of air pollution as suggested by previous studies including that of Zhang et al. (2016), Lisciandra and Migliardo (2017), and Wang et al. (2018). However, higher corruption aggravates the pollutant release when the level of trust is little and has a huge effect on access to and health services quality and weakens environmental regulation. In turn, these further impact health outcomes. A previous study that looked into the relationship between corruption and health in various countries revealed that the more corruption there is, the worse the health results are (Pinzón-Flórez et al., 2015; Gaitonde et al., 2016; Ferrari and Salustri, 2020). For example, Gaitonde et al. (2016) discovered that corruption reduces the quality of health services, efficiency and parity, which has a huge impact on health. Likewise, in 20 African countries, greater corruption levels have been linked to poor general health in all socioeconomic groups over the lifecycle (Witvliet et al., 2013). Achim et al. (2019) also found that the degree of corruption has a substantial effect on both physical and mental health in a study consisting of high-income as well as low-income countries. In addition, according to Nadpara and Samanta (2015), corruption has a bigger impact on health outcomes in impoverished, developing nations than it does in richer, developed nations (along with a shorter life span and a higher child mortality).

The essentiality of enhancing governance efficiency by decrease in corruption and maladministration is likely to contribute to the effective use of health sector resources (Yaqub et al., 2012). The corroborated positive relationships in Holmberg and Rothstein (2011) revealed that improvement in the government variables such as Rule of Law and Government Effectiveness together with Corruption Perception Index are significantly related to relatively high life expectancy and lower child mortality rates. Similarly, analysis of studies in 148 to 194 countries shows that an enhancement in governance points to a greater level of health outcomes (Kim and Wang, 2019). The results showed that a government's quality (corruption control and other governance indicators) and quantity (share of government budget in GDP) have an optimistic influence on life expectancy with government quality having a stronger bearing over people's health. In accordance with Lio and Lee (2016), a lower level of corruption or better corruption regulation in such a nation can contribute to a long life span and lesser mortality rate among children. On another study, Makuta and O'Hare (2015) employed the World Bank's World Governance Indicators (WGI), which included corruption control, to measure the association of governance quality and general health throughout Sub-Saharan Africa. The results showed that better governance improves population health, as measured using under-five mortality and life expectancy.

Despite the fact that corruption is more common across low and middle-income countries, empirical research on the effect of corruption on physical health (such as life expectancy) are still lacking, which further detriments the poor. This study therefore, can provide valuable insights for that important field of study.

METHODOLOGY

Data Sources

This study employed a panel data framework in 72 middle-income countries from 2010 to 2017. The total number of countries covered represents 68% of total lower and upper middle-income countries based on World Bank country classifications by income. The selection of samples for this analysis is primarily subjected to data availability. Table 1 illustrates the variables used in the study, as well as their sources. The dependent variable is determined by life expectancy at birth, while the other variables are altogether explanatory variables. The corruption control variable was taken from the World Bank's World Governance Indicators (WGI) database, while the rest of the remaining variables were derived from the World Bank's World Development Indicators (WDI) database. The level of air pollution that prevails in the economy is measured by the levels of particulate matter ($PM_{2.5}$) in micrograms per cubic meter. The remaining of the variables are the real GDP per capita, public health spending as a percentage of total GDP, and education level of population. In addition, the indicator of corruption control lies between –2.5 to 2.5, with a higher score signifying a better quality of governance and lower score indicating otherwise. This corruption regulation represents the reversal of the degree of corruption as viewed by the government officials and private sectors within national institutions.

Table 1 Summary of data

Variables	Definition	Unit measurement	Source
LE	Life expectancy	Life expectancy at birth, total (years)	World Bank (WDI, 2018)
PM2.5	Emissions of $PM_{2.5}$	Country level, $PM_{2.5}$ (micrograms per cubic meter)	World Bank (WDI, 2018)
Y	Real GDP per capita	Constant 2010 US dollars	World Bank (WDI, 2018)
ED	Years schooling	Percentage of school enrollment of the total population age 15 and over	World Bank (WDI, 2018)
HS	Public health expenditure	Public health expenditure (percentage of GDP)	World Bank (WDI, 2018)
CC	Control of corruption	Scaled from –2.5 to 2.5 (in standard deviations)	World Governance Indicators (WGI, 2018)

Models Specification

To investigate the potential impact of air pollution on health outcomes in middle-income countries, the empirical models proposed by Makuta and O'Hare (2015), Aliyu and Ismail (2016), and Ahmad et al. (2021) are employed:

$$LE_{i,t} = \alpha_1 lPM2.5_{i,t} + \alpha_2 lY_{i,t} + \alpha_3 lHS_{i,t} + \alpha_4 lED_{i,t} + \mu_i + \varepsilon_{i,t} \quad (1)$$

From the model specification, life expectancy *(LE)* is defined as the number of years a person may possibly live at birth. This indicator is commonly seen to assess the health of a population due to its reliability in reflecting health outcomes and availability in finding the measurements for many countries over the years (Halicioglu, 2011; Makuta and O'Hare, 2015). *PM2.5* is the indicator for air pollution measured by the $PM_{2.5}$ levels. Because of its small size, particulate air pollution ($PM_{2.5}$) can enter the narrower respiratory tract and pulmonary system, causing serious health problems (Miah et al., 2011; Ghorani-Azam et al., 2016). It is predicted, air pollutants would have a negative effect on *LE*.

Y, on the other hand, is a measure of a country's income in real gross domestic product (GDP) per capita. GDP shows the average per-person income and represents the country's economic development and it is anticipated that it would have a positive effect on *LE*. *HS* stands for health spending as a percentage of GDP, where it is the measure of government interference within that health sector and also in residents' human capital. *ED* is the educational level of the population. When education reduces the cost of knowledge, health quality will then improve, and the people with better traits of education will develop a better comprehension of the value of public health facilities and will be wiser to locate and use them. Thus, it is predicted that *HS* and *ED* will have a positive effect on LE. μ denotes country-specific effects, and ε represents an error term. The subscripts *i* and *t* represent cross-sectional countries and time (year), respectively.

Further, there are strong grounds to directly link the country's level of corruption with the health status of the population (Yaqub et al., 2012; Lio and Lee, 2016). Therefore, the regression equation is estimated as follows:

$$LE_{i,t} = \alpha_1 lPM2.5_{i,t} + \alpha_2 lY_{i,t} + \alpha_3 lHS_{i,t} + \alpha_4 lED_{i,t} + \alpha_5 CC_{i,t} + \mu_i + \varepsilon_{i,t} \quad (2)$$

Paucity in transparency of governance can foster corruption and lower health-care quality. Regulating corruption and creating environments least susceptible to misconduct, such as adequate funding the public health care system, enhancing social transparency, and improving structures from outside healthcare system, are deemed critical in making the health sector less prone to corruption (Naher et al., 2020; Kankeu et al., 2016). Accordingly, it is predicted that corruption control *(CC)* would possess a positive relationship with health outcomes.

Corruption could have an effect on the regulatory process for environmental legislation as well as the implementation of current environmental regulations, affecting pollutant discharge (Wang et al., 2019a). To take account on the moderation effect of the corruption regulation on the air pollution impact toward life expectancy, an interaction term is implemented:

$$LE_{i,t} = \alpha_1 lPM2.5_{i,t} + \alpha_2 lY_{i,t} + \alpha_3 lHS_{i,t} + \alpha_4 l\mathrm{ED}_{i,t} + \alpha_5 CC_{i,t} + \alpha_6\left(lPM2.5_{i,t} * CC_{i,t}\right) + \mu_i + \varepsilon_{i,t} \quad (3)$$

Where $\left(lPM2.5_{i,t} * CC_{i,t}\right)$ measures the interaction of $PM_{2.5}$ and corruption control. The interaction term was employed to examine whether corruption regulation played a moderator role, influencing how effective a governance is in mitigating air pollution risk on health. If the quality of governance lessens the negative effect of air pollution, the expected coefficient from this interaction would be positive.

In pursuance to further explore the corruption regulation marginal effects, the total $PM_{2.5}$ impact on life expectancy is examined both directly and indirectly through control of corruption following Ibrahim and Law (2016). To do so, the relative corruption control elasticity as regards to life expectancy from regression Eq. (3) would be comprehended as follows:

$$\delta lLE / \delta lPM2.5 = \alpha_1 + (\alpha_6 * CC) \quad (4)$$

Thus, the comprehensive influence between air pollution and life expectancy refers to the amount of the direct (α_1) and indirect effects ($\alpha_6 * CC$) across corruption levels. As shown in Eq. (4), the effect of air pollution on life expectancy is based on the degree of corruption. This effect is measured at two different levels of the minimum score and maximum score. From the equation, α_6 is expected to be positive. As a baseline, the health effect of emission may be α_1, which is negative. With negative α_1, a positive α_6 indicates the capability of corruption control to improve health effect from air pollution. Therefore, governance role might be perceived as important in order to achieve improved health.

Dynamic Panel Data Models

Because of the panel type of data, the estimating models were evaluated following the panel generalized method of moments (GMM) estimator established by Arellano and Bond (1991), Arellano and Bover (1995), and Blundell and Bond (1998). GMM estimator is used within this study as it is a dynamic model capable of controlling endogeneity problems arising from the dynamic model specification, measurement error, Nickell bias, heteroskedasticity, unobserved heterogeneity as well as reverse causation (Ibrahim and Law, 2016; Goh et al., 2018). Furthermore, this technique is suited for conditions in which the number of cross-sectional units (N) beyond the time period (T). Thus, the dynamic panel GMM estimator is perfectly suited for this study because the cross-section (72) is greater than the period span (8).

As seen below, a framework of dynamic panel regression is employed to incorporate a lagged dependent variable:

Model 1:

$$LE_{i,t} = \alpha_0 LE_{i,t-1} + \alpha_1 lPM2.5_{i,t} + \alpha_2 lY_{i,t} + \alpha_3 lHS_{i,t} + \alpha_4 lED_{i,t} + \mu_i + \varepsilon_{i,t} \quad (5)$$

Model 2:

$$LE_{i,t} = \alpha_0 LE_{i,t-1} + \alpha_1 lPM2.5_{i,t} + \alpha_2 lY_{i,t} + \alpha_3 lHS_{i,t} + \alpha_4 l\mathrm{ED}_{i,t} + \alpha_5 CC_{i,t} + \mu_i + \varepsilon_{i,t} + \varepsilon_{i,t} \quad (6)$$

Model 3:

$$LE_{i,t} = \alpha_0 LE_{i,t-1} + \alpha_1 lPM2.5_{i,t} + \alpha_2 lY_{i,t} + \alpha_3 lHS_{i,t} + \alpha_4 l\mathrm{ED}_{i,t} + \alpha_5 CC_{i,t} + \alpha_6 (lPM2.5_{i,t} * CC_{i,t}) + \mu_i + \varepsilon_{i,t} \quad (7)$$

$LE_{i,t-1}$ is a one-year lagged dependent variable that incorporates dynamism in the model (i.e. past health status determines the current one). Based on the underlying models (equations 5, 6, and 7), the existence of lagged dependent variables will cause the endogeneity issue. According to Arellano and Bond (1991), endogeneity can be addressed by transforming the data using the differentiation method as proposed in the difference GMM. However, a later study by Blundell and Bond (1998) argued that the difference GMM might affect huge sample bias, thus, proposed the system GMM estimators to improve efficiency by using both lagged levels and different information. It is a common practice in the commonly used GMM method to use a two-step approach to increase the performance of the GMM estimation technique and the strength of the related tests (Hwang and Sun, 2018). The two-step system GMM is more efficient than the one-step system GMM because it generates much asymptotic efficient results, which is especially important in circumstances where heteroskedasticity issues are well contained within the one-system GMM (Roodman, 2009; Oseni, 2016). Therefore, for this reason, a two-step system GMM is employed throughout the analysis. Nonetheless, the instrument validity required both Hansen test and Autocorrelation test to overrule the null hypothesis in inhibiting the two-step GMM from producing a biased standard error leading to a weakened over-identification test.

RESULTS AND DISCUSSION

Table 2 shows the descriptive statistics datasets in their original forms, including the mean, standard deviations, and minimum and maximum values. On average, the findings demonstrate that the overall mean PM2.5 (29.4), income (4547), public health expenditures (2.9), education attainment (104.5) and control of corruption (–0.41). The discrepancy shows that for most countries, government quality indicators represented by corruption control are low (as shown by the average), suggesting plausible economic and environmental complications.

Table 2 Summary statistics for health outcomes indicators and its determinants

Variables	Standard Deviation	Mean	Minimum	Maximum
LE	6.296	70.236	50.423	80.03
PM2.5	15.446	29.381	10.538	97.599
Y	3135.624	4547.09	785.693	14936.4
HS	1.678	2.921	0.178	11.546
ED	8.637	104.489	69.752	134.52
CC	0.553	-0.41	-1.673	1.568

The regression results were measured using the two-step system GMM estimation technique. Table 3 shows the results of the basic regression (column 1), followed by the addition of corruption control variables (column 2) and the models with moderation terms (column 3). In addition, Table 4 shows the marginal effects of the interaction terms based on column 3.

The diagnostic tests show that in all of the models, the p-value of the Hansen test is greater than 0.05 indicates that there is not enough evidence at the 5% level to say that the assumptions of valid instruments are false. In addition, the p-value fails to reject the null of no second-order autocorrelation (AR2), which shows that the residuals of the level regressions are free of autocorrelation issues.

The findings of system GMM revealed that in all three models, the lagged dependent variable of life expectancy was positive and significant, justifying the dynamic description. The previous level of life expectancy is highly persistent and has an effect, which carries over into the next period. The results in Table 3 are consistent with those found in the literature about the harmful effects of air pollution particles (PM2.5) on life expectancy. In the baseline specification (column 1), life expectancy has coefficients of –0.125 and consistently carries negative coefficient (–0.132) when control of corruption is added in the regression (column 2). This proves that a rise in $PM_{2.5}$, of say 10%, decreases 0.013 years (approximately 0.2 months) in life expectancy. The negative association of $PM_{2.5}$ levels and life expectancy are similar as those with Apte et al. (2018), Hill et al. (2019), and Wu et al. (2020). While income is statistically significant, the sign of the coefficient differs from that of air pollution. Likewise, government spending on health and education has a significant and positive relationship with public health outcomes. This result lends credence to the commonly held belief that these explanatory variables may have a significant direct effect on health outcomes.

Table 3 Findings of the GMM estimation

Dependent variables	LE (1)	LE (2)	LE (3)
Lagged dependent variable	0.94***	0.928***	0.958***
	(790.37)	(302.8)	(460.74)
LPM2.5	-0.125***	-0.132***	0.05
	(-8.45)	(-4.90)	(1.21)
LY	0.093***	0.171***	0.117***
	(5.44)	(3.39)	(7.07)
LHS	0.128***	0.031***	0.166***
	(15.87)	(3.77)	(9.07)
LED	0.267**	0.913***	0.578***
	(3.21)	(6.46)	(6.18)
CC		0.009	-0.469**
		(0.03)	(-3.25)
LPM2.5*CC			0.148**
			(2.89)
Observations	458	462	463
Groups	69	70	70
Instruments	57	51	66
Hansen J-test (p-value)	0.219	0.534	0.287
AR(2) (p-value)	0.684	0.954	0.59

Note: Figures in parentheses are the standard errors for coefficients. ***, ** and * indicate statistical significance at the 1%, 5% and 10% levels, respectively.

However, when looking at the estimation model including the control of corruption (column 2), the results indicate the existence of the enhancing impact of governance on life expectancy is insignificant. Then, when control of corruption is interacted with $PM_{2.5}$, a health-improving effect can be observed in the regression (column 3). The positive coefficient of the interactive term indicates that wellbeing is better in countries with better governance. Consequently, this suggests that improving the corruption level in a country reduces the harmful effects of air pollution on life span.

Table 4 shows the marginal effects of corruption control and $PM_{2.5}$ on life expectancy, as determined by Eq. (4). A look at Table 4 shows some indications that the impact of $PM_{2.5}$ on life expectancy varies depending on the degree of corruption. To look more deeply, the impact of a one-unit raise with corruption control conditional on $PM_{2.5}$ levels and a raise in $PM_{2.5}$ conditional to corruption levels are estimated for a variety of cases.

The first case involves a country with low corruption regulation (CC) and $PM_{2.5}$ levels (PM2.5). As shown in the table, a one-unit rise in the CC is associated with a 0.12 year (over 1 month) reduction in life expectancy when the PM2.5 is held at the minimum level and all other factors remain constant. Similarly, when the CC is at its minimum, an increase in PM2.5 is linked to a decrease in life expectancy (-0.2). Table 4 also shows the marginal effects for a country with the maximum CC and PM2.5 levels. In the next case, a one-unit rise in the CC is associated with a 0.21-year (nearly 3-month) increase in life expectancy when the PM2.5 is at its maximum level and everything else remains constant. In the same way, when the CC is at its maximum, an increase in PM2.5 is linked to a shorter life expectancy (-0.18).

Table 4 Marginal effects of corruption control and PM2.5 on life expectancy

	Minimum	Maximum
Corruption control (CC)	-1.673	1.568
PM2.5	2.355	4.581
$\Delta LE/\Delta CC$	-0.12	0.209
$\Delta LE/\Delta PM2.5$	-0.198	-0.182

Note: PM2.5 is expressed in natural logarithm. The calculation is based on regressions Table 1 (column 3): $\Delta\delta LE/\delta CC = -0.469 + 0.148AP$; $\Delta\delta LE/\delta PM2.5 = 0.05 + 0.148CC$.

The marginal effects of corruption control on health status imply that health status tends to be worse for country with lesser control of corruption (poor governance). However, it can be noticed that the impact of PM2.5 on health is consistently harmful across the countries. From these, it can be concluded that higher rates of corruption regulation in middle-income countries are able to reduce the air pollution hazard on health status more effectively. Good governance, nevertheless, is vigorous in improving the air quality of a country optimally. In fact, low corruption may prevent public resources from suffering from leakages and therefore be able to translate into social investments such as higher quality of health. These findings largely support those of Kim and Wang (2019), Biadgilign et al. (2019) and Sirag et al. (2017), who found that corruption has a major impact on health outcomes.

CONCLUSION

The aim of this study is to look into the impact of $PM_{2.5}$ and corruption control on life expectancy. The empirical findings showed that air pollution was negatively linked to life expectancy in middle-income countries. Besides that, socioeconomic factors including such income, public health spending, and educational attainment tended to be influential in extending life expectancy. Most importantly, the governance quality through corruption control was found to be significant in moderating the negative impact of $PM_{2.5}$ on life expectancy. This endorses the study's claim that the governance role in reducing air pollution risk is more effective in promoting population health when there is a higher level of corruption control than when there is a low level of corruption control.

We recommend middle-income nations to improve their corruption control mechanisms for improved health outcomes, as enhancing corruption control reduces the negative health effects of $PM_{2.5}$. Lower corruption can be connected to higher environmental policy stringency, which will result in better environmental outcomes. In middle-income countries, where corruption enforcement is stronger, environmental pressures may lessen, resulting in decreased health risk and improved health outcomes. It is consequently critical to adopt stronger environmental standards in order to protect the population's health, as good health is essential for a better quality of life.

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APPENDIX

Apendix 1 Country lists

Bhutan	Bolivia	Cabo Verde
Cambodia	Cameroon	Cote d'Ivoire
Egypt	El Salvador	Swaziland
Ghana	Honduras	India
Indonesia	Kenya	Kiribati
Kyrgyz Republic	Laos	Lesotho
Mauritania	Moldova	Mongolia
Morocco	Myanmar	Nigeria
Pakistan	Philippines	Sao Tome and Principe
Solomon Islands	Sudan	Tunisia
Ukraine	Uzbekistan	Vietnam
Zambia	Albania	Algeria
Turkey	Venezuela	Armenia
Azerbaijan	Brazil	Belarus
Belize	China	Colombia
Costa Rica	Cuba	Dominican Republic
Ecuador	Fiji	Georgia
Grenada	Guatemala	Iran
Kazakhstan	Lebanon	North Macedonia
Malaysia	Mauritius	Mexico
Namibia	Peru	Romania
Russian Federation	Samoa	Serbia
South Africa	Sri Lanka	St. Vincent and the Grenadines
Suriname	Thailand	Tonga