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RESEARCH ARTICLE

Air pollution effects on adult mortality rate in developing countries

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Abstract

Although industrialisation is a crucial aspect of economic growth across developing nations, through the release of air contaminants, industrial activities may also create adverse environmental health consequences. Noting that continuous production and other economic activities are crucial for continued survival, this study explores this issue by including the role of governance that is deemed essential but the literature is relatively sparse particularly in the context of developing countries. This research empirically analyses the relationship between air pollution and adult mortality rates from 72 developing countries from the period of 2010 until 2017. Particulate matter ($PM_{2.5}$) and carbon dioxide (CO_2) are used as indicators of air pollution. From the generalized method of moments (GMM) estimations, the results reveal that air pollution negatively affects adult mortality rate. The result reveals that a 10% increase in the $PM_{2.5}$ level induces the adult mortality rates to increase between 0.04% and 0.06%. In addition, the government significantly moderates the negative effect of air pollution on adult mortality, whereby a one-unit enhancement in governance quality index reduces mortality among the adults in the developing countries by 0.01%. On the other hand, CO_2 emission also appears to be positive, but not statistically significant. The results suggest that governance and public health interplay in the sense of a transition towards economic development for improved living and health states can be achievable with improved governance quality.

Keywords Air pollution · Particulate matters · CO2 · Adult mortality · Governance quality · GMM

Introduction

Pollution is among the many environmental challenges the world is facing today. It is a major concern in much of the developing countries as the impact of pollution is more severe with levels that often cause poor health, deaths, and disabilities for many people, which consequently leads to higher mortality rates. Air pollution was linked with 1 out of every 8 deaths or around 7 million people globally (Rees 2016). According to Pena and Rollins (2017), the effect from disclosure about environmental air pollution is much greater in developing regions, where population growth and rapid industrialisation have resulted in low air quality. The emissions from substantial industrial activities and high vehicle emissions sustained from heavy pollutants greatly contribute to air pollution and are a significant cause to global climate change. According to Marchwinska-Wyrwal et al. (2011), about half the pressure on human health from air pollution is endured by people in developing countries. This unfortunate association can be particularly relevant in developing countries, as raised by Di et al. (2017) and Deguen et al. (2015), where people with a low socioeconomic status are more vulnerable to elevated rates of pollutants, and hence,

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the adverse effect rate is greater than people with a higher socioeconomic status.

However, in many developing countries, the environmental cost of pollution is unavoidable as the industrial sector is a crucial sector that generates the primary engine of economic growth and development. Thus, the problem with linking mortality to economic growth and environmental pollution is crucial for developing nations, particularly for the countries that have lack of environmental policies (Tanaka 2015; Aliyu and Ismail 2016; Zhao 2019), inappropriate health infrastructures (Rasoulinezhad et al. 2020; Kiross et al. 2020), and fewer contributions of renewable energy resources in economic sectors (Martins et al. 2018; Van Tran 2020). Moreover, the region's economy still relies on fossil fuel consumption due to the cheapest and energy resource available, leading to higher economic growth, but eventually comes with more environmental pollution that causes social negative effects related with health problems such as increased mortality rates.

Theoretically, a sizeable number of epidemiological studies have established a positive association between air pollutant exposure and mortality incidence rate (Fang et al. 2016; Garcia et al. 2016; Yitshak-Sade et al. 2019; Fan and Wang 2020; Oluleye and Adabale 2020; Wu et al. 2020). Air pollution coming from a variety of sources has a range of chemical compositions and toxicity that can harm human health when exposed to it. Various pollutants were used in the literature, along with particulate matter (PM), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and carbon dioxide (CO_2), among others, to evaluate environmental pollution. However, this study emphasizes on particulate matter ($PM_{2.5}$) and CO_2 emissions as air pollution measurement. $PM_{2.5}$ is categorized under national pollutants, which is likely to be addressed by regulation at the national level, whereas CO_2 is classified as an international pollutant and has a global impact (Frankel and Rose 2005). This study is similar with Aliyu and Ismail (2016), albeit they use PM_{10} and CO_2 to proxy air pollution. Contrastingly, our study uses $PM_{2.5}$, which is suggested to be more toxic compared to huge particles (Zanobetti and Schwartz 2009) and presents the greatest health hazards because the particles may reach deep through the lungs and the bloodstream, which leads to cardiovascular and respiratory diseases that contribute to higher incidence of mortality (Anenberg et al. 2010; Zeger et al. 2008; Marchwinska-Wyrwal et al. 2011; Cesaroni et al. 2013; Carey et al. 2013; Garcia et al. 2016). Moreover, many of countries in developing region are among the highest exposed population to ambient pollution of PM2.5 (World Bank 2019). On the other hand, earlier research indicates that mortality rates of a country are a comprehensive measure of the health status of that country, resulting from several economic factors that may consist of income and public health expenditure, or social factors including education level of the population, and environmental factors (Halicioglu 2011). In addition, governance quality may also be a crucial factor in understanding the health outcomes (Pautrel 2009).

Despite increasing interests regarding adverse health effects from air pollution across developing nations, the majority of accessible studies on the topic focus on children (Siddique et al. 2011; Cesur et al. 2013; Greenstone and Hanna 2011; Tanaka 2015; Arceo et al. 2016). The behaviour and exposure to health risks towards adults are crucial as they are within the most economically productive age span that contribute towards economic growth. With limited studies on this, the adult mortality rate is becoming a crucial factor for a comprehensive evaluation of population mortality trends. Exposure to toxins from ambient air pollution substances in their working areas, arduous physical work, and physical activity may have long-term health implications. This presents a problem for adults, who are proportionately exposed to environmental pollutants while working. Air pollution–related health studies on adult populations showed they are a subpopulation considered vulnerable to air pollution exposure (Barreca et al. 2017; Sanyal et al. 2018; Achilleos et al. 2019). Numerous studies have supported growing evidence that the harm of $PM_{2.5}$ is expanding gradually and becomes as one of the leading risk factors for death. In various populations, it has been reported that increased concentrations of $PM_{2.5}$ cause increased susceptibility to chronic diseases such as respiratory diseases and lung cancer, thereby increasing the probability of death rates (Fang et al. 2016; Garcia et al. 2016; Li et al. 2018; Wang et al. 2020). Yu et al. (2020) found an increased risk of mortality due to the long-term exposure of $PM_{2.5}$ in areas reported with consistently low $PM_{2.5}$ concentrations in Australia. Relatedly, Tian et al. (2019) found that short-term acquaintance to $PM_{2.5}$ was positively correlated towards adult hospital admittances in China, even at rates lower than the present Chinese ambient air quality requirements. These studies show that $PM_{2.5}$ can contribute in lowering life spans even in places where the levels of concentration are considered safe, suggesting that the adverse impact could be more prevalent as air pollution increases. The results of Taghizadeh-Hesary and Taghizadeh-Hesary (2020) also confirm that $PM_{2.5}$ and CO_2 are major risk factors for lung cancer that contributes to higher incidence of mortality in Southeast Asia. In another study, Cao et al. (2018) demonstrate that in 31 provinces in China, a significant association exists between $PM_{2.5}$ and mortality based on geographically weighted regression model.

The study of the impacts of energy use on mortality in many studies also revealed that any increase in carbon emissions has a considerable effect on mortality (Erdoğan et al. 2019; Li et al. 2019; Matthew et al. 2019; Anser et al. 2020). Aliyu and Ismail (2016) employed an air pollution and mortality dataset in 35 African countries and found that particulate matter (PM_{10}) and carbon dioxide (CO_2) at higher levels has a major impact on increased mortality in adults. It is discovered that CO_2 emissions in the Commonwealth of Independent States region had a positive relationship with mortality from cardiovascular disease, diabetes mellitus, cancer, and chronic respiratory disease among adults (Rasoulinezhad et al. 2020). Similarly, a growing industrial sulphur dioxide (SO_2) emissions by ten thousand tonnes in some cities would lead to increased local mortality (Chen et al. 2017). On the other hand, air pollution has done harm not only to health but also economic losses. A recent study in China reported that by 2030, $PM_{2.5}$ emissions could lead to a loss of 2.0% in gross domestic production, a loss of 210 billion Chinese yuan in health spending, and a loss of about 10,000 billion lives, if no control policies undertaken (Xie et al. 2019).

However, there is a growing argument that more active governmental roles addressing this issue can help to control the adverse health effects of pollution in better-governed nations (Siddiqi et al. 2009; Lin et al. 2014; Aliyu and Ismail 2016). In some studies, the governance effect was direct and positive (Glatman-Freedman et al. 2010; Holmberg and Rothstein 2011; Burchi 2011; Olafsdottir et al. 2011). For example, according to Rosenberg (2018), if Paraguay improves the quality of governance to its fullest extent, the country can achieve almost a 16% reduction in mortality. Ahmad and Hasan (2016) found that high rate of corruption (bad governance) prevents the improvement of health status in the long run. Similarly, good governance in the country is found to play a significant role for improving the health state along with other socio-demographic factors in Ethiopia (Biadgilign et al. 2019). On the other hand, the governance effect on health was found to be indirect or modified by contextual factors (Farag et al. 2013; Hu and Mendoza 2013). Bollyky et al. (2019) suggest that democracies contribute to health benefits for mortality causes when a nation is followed by free and fair elections. Doucouliagos et al. (2019) shows that the effectiveness of health aid in reducing mortality is conditional on good governance (measured either as government effectiveness or control of corruption). A study conducted by Makuta and O'Hare (2015) found that an efficiently managed government correlates positively with better health outcomes. Its effect is modified by the governance level, by having a greater health effect in nations with a better governance level and less influence in nations with lower government performance. This can be attributed to the improved efficiency and better allocation of resources available as the quality of governance increases. This result is similar to Sirag et al. (2017). In addition, according to Kim and Wang (2019), governance quality and quantity had major impacts on public health. They measured the quantity of government performance by public expenditure on health while regulating for control, efficiency of government, regulatory quality, voice and accountability, and the rule of law for government quality.

Thus it is suggested that countries with stronger governance would certainly have better health policies that can safeguard their countries from unintended pollution adverse effects and thus benefit the population's health outcomes. Therefore, this study argues whether there is a possibility the role of governance in mitigating the effects of air pollution on mortality is feasible. With this background, the objective of this study is to investigate the air pollution effects towards adult mortality.

Recognizing the enormity of current literature about these issues in high-income settings, this study's contribution is derived from the lack of studies that focus on developing settings. The study follows the generalized method of moments (GMM) technique, which are to be discussed later, with a panel of 72 developing countries. The rest of the article is set out as follows. In the next section, the details of the estimation models, method, and data are provided. The outcomes of the estimations are then addressed in Section 3 followed by a discussion. Finally, Section 4 provides the conclusion with a few summary remarks.

Methodology

Following Coneus and Spiess (2012) and Aliyu and Ismail (2016), Eq. 1 is empirically modelled to estimate the effects of air pollution on adult mortality rate:

$$lAM_{it} = \alpha_0 + \alpha_1 lAM_{it-1} + \alpha_2 lAP_{it} + \alpha_3 lY_{it} + \alpha_4 lPHS_{it} + \alpha_5 lEDU_{it} + \mu_i + \varepsilon_{it} \quad (1)$$

where lAM is the dependent variable proxy by adult mortality rates, which refers to the probability that those who are 15 years old will die before they reach age 60. lAP is the variable of interest, namely, air pollution which is a proxy for $PM_{2.5}$ levels and CO_2 emissions. lY denotes real GDP per capita, $lPHS$ is the public health expenditure, and $lEDU$ represents the education level of the population; the subscripts i and t, respectively, represent country and time period; μt and ε denote country-specific effects and the error term, respectively. The lagged dependent variable (lAM_{it-1}) refers to the dynamic effect, where the existence of the probability of mortality relies on itself in the preceding year, and the coefficient must be less than 1 because of the persistency of the variable to be statistically significant.

The main variables of interest are air pollution proxy by using $PM_{2.5}$ and CO_2, which are expected to have a negative relationship with mortality rate. $PM_{2.5}$ can reach the lower respiratory tract due to its small size and thus have a greater potential for causing lung and heart diseases that can eventually lead to a reduced mortality expectancy (Ghorani-Azam et al. 2016). Additionally, carbon dioxide can cause severe health issues that have been shown to be significantly linked to higher mortality rates in humans (Satish et al. 2012). Thus, higher mortality rates in adults are expected throughout developing countries due to air pollution exposure.

As in the standard literature, relevant explanatory variables that may affect adult mortality are included in the regressions. Income is measured as real GDP per capita to reflect the level of economic growth for a nation. Government health spending is a measure of public investment in the health sector and human capital, which includes the provision of health facilities, family planning programs, nutrition initiatives, and emergency health assistance that include access to health care and facilities. Education level is considered to be another influential determinant of mortality where it increases labour market productivity as well as income growth. Education also raises people's health awareness and hence they tend to take precautions to create a better state of health for themselves. Therefore, a positive effect is expected from these explanatory variables on adult mortality.

Previous studies indicated that countries with stronger governance would implement health policies to favour the social variables of health (Siddiqi et al. 2009; Lin et al. 2014; Kim and Wang 2019). Thus, the need for better governance to improve health outcomes has been growing. Hence, the specified estimation below includes governance quality index *(GQI)* as an additional explanatory variable:

$$lAM_{it} = \alpha_0 + \alpha_1 lAM_{it-1} + \alpha_2 lAP_{it} + \alpha_3 lY_{it} + \alpha_4 lPHS_{it} + \alpha_5 lEDU_{it} + \alpha_6 GQI_{it} + \mu_i + \varepsilon_{it} \quad (2)$$

where *GQI* represents six components of the Worldwide Governance Indicators (WGI), namely, voice and accountability, political stability, government effectiveness, regulatory quality, rule of law, and control of corruption. All of these components are derived on the basis of a set of variables and eventually converted into standardized indices that range approximately between − 2.5 and + 2.5. The principal component analysis (PCA) method is employed to construct *GQI* from the six components of governance quality to specifically study the impact of aggregate quality of governance rather than focus on individual components, as their role is equally important.

The regression specification is extended by allowing the interaction of the air pollution measure with the governance quality index. According to Lin et al. (2014), sound policymaking and effective policy execution by the government are viewed to be an important determinant of the population's health. Good governance, therefore, can impose better environmental policies to improve the environmental conditions (Tamazian and Rao 2010; Greenstone and Hanna 2011; Tanaka 2015; Ibrahim and Law 2016). Accordingly, the equation for regression with an interaction term is as follows:

$$lAM_{it} = \alpha_0 + \alpha_1 lAM_{it-1} + \alpha_2 lAP_{it} + \alpha_3 lY_{it} + \alpha_4 lPHS_{it} + \alpha_5 lEDU_{it} + \alpha_6 GQI_{it} + \alpha_7 (lAP_{it} * GQI_{it}) + \mu_i + \varepsilon_{it} \quad (3)$$

where $(lAP_{it} * GQI_{it})$ measures the interaction between $PM_{2.5}$ and governance quality index. The coefficients of these interaction terms are employed to test whether the negative effect of air pollution on adult mortality is modified by the quality of governance. A negative and significant β_7 in Eq. 3 confirms that governance quality plays a role as moderator on reducing air pollution risk to reduce adult mortality. Understandably, this interaction suggests that in order to achieve an environmental goal consistent with the public's interest, there is a need for specific task allocation to the appropriate governance to ensure its role is effective. The environmental benefits from this could enhance population health and would contribute to greater productivity in the economy.

Given the panel nature of the data, Eqs. 1, 2, and 3 were assessed by employing the panel generalized method of moments (GMM) estimator, designed for dynamic panel data models that were proposed by Holtz-Eakin et al. (1988), Arellano and Bond (1991), and Arellano and Bover (1995). GMM is employed because it controls the country-specific effects, which cannot be used with country-specific dummies because of the dynamic structure of the equation (Abdul Bahri et al. 2019). In addition, GMM controls over the simultaneity bias, since few from the explanatory variables are possibly endogenous.

Table 1 Descriptive statistics for adult mortality rates and its determinants

Variables	Mean	Within standard deviation	Between standard deviation	Overall standard deviation	Minimum	Maximum
AM	180.356	10.741	88.639	89.261	57.869	548.497
PM2.5	29.381	2.879	15.268	15.446	10.538	97.599
CO2	2.75	0.363	2.779	2.788	0.185	16.072
Y	4547.09	361.546	3200.17	3135.624	785.693	14,936.4
PHS	2.921	0.338	1.654	1.678	0.178	11.546
EDU	104.489	3.455	7.941	8.637	69.752	134.52
GQI	- 1.87e-08	0.395	1.967	1.995	− 5.553	4.846

Table 2 Correlation matrix

	lAMR	*lPM25*	*lY*	*lPHS*	*lEDU*	*GQI*	*lPM2.5*GQI*
Panel A							
lAMR	1.000						
lPM25	0.071	1.000					
lY	− 0.421	− 0.336	1.000				
lPHS	− 0.191	− 0.363	0.286	1.000			
lEDU	− 0.064	− 0.185	0.081	0.095	1.000		
GQI	− 0.16	− 0.319	0.416	0.294	0.226	1.000	
*lPM2.5*GQI*	− 0.158	− 0.332	0.422	0.31	0.252	0.991	1.000
	lAMR	*lCO2*	*lY*	*lPHS*	*lEDU*	*GQI*	*lCO2*GQI*
Panel B							
lAMR	1.000						
lCO2	0.155	1.000					
lY	− 0.421	0.611	1.000				
lPHS	− 0.191	0.084	0.286	1.000			
lEDU	− 0.064	− 0.029	0.081	0.095	1.000		
GQI	− 0.16	0.003	0.416	0.294	0.226	1.000	
*lCO2*GQI*	− 0.037	− 0.157	0.135	0.083	0.03	0.736	1.000

Consequently, the traditional panel models (such as pooled OLS, fixed-effect panel model, and random-effect panel model) are not suitable due to the presence of country-specific effects and the lagged dependent variable or potential endogeneity of explanatory variables. Thus, to tackle these problems, the GMM estimator is employed. There are two types of GMM estimators, which are the difference and system GMM. Precisely, by compelling first the differences, the GMM method removes the country-specific effects or whichever time-invariant country-specific variable. Later, to overcome the resultant correlation of lagged dependent variable and disturbance terms following first differencing, Arellano and Bond (1991) propose the applying of instrumental variables to deal with the regressors' endogeneity problem.

In the first difference GMM estimation, the difference lagged dependent variables and the endogenous variables may be instrumented accordingly by their lags in levels, whereas the exogenous variables may become their own instruments. While the above difference estimator is capable of controlling the country-specific effects and simultaneity bias, it still has a considerable shortcoming. Alonso-Borrego and Arellano (1999) and Blundell and Bond (1998) indicate that while the explanatory variables are persistent, the variables' lagged levels turn out to be weak instruments and thus can result in biased parameter estimates within small samples and

Table 3 GMM estimation results: $PM_{2.5}$ and governance quality index effects on adult mortality rates

Dependent variables	AM (1)	AM (2)	AM (3)
Lagged dependent variable	0.971*** (276.19)	0.973*** (276.4)	0.975*** (630.53)
lAP (*lPM2.5*)	0.004** (3.04)	0.006*** (3.3)	0.0004 (0.49)
lY	− 0.004* (− 2.29)	− 0.007** (− 3.02)	− 0.007*** (− 7.08)
lPHS	− 0.002*** (− 5.27)	− 0.002*** (− 4.42)	− 0.002*** (14.3)
lEDU	− 0.036*** (− 6.34)	− 0.039*** (− 4.66)	− 0.031*** (− 8.31)
GQI		0.002 (1.59)	0.003*** (3.46)
lPM2.5 GQI*			− 0.001** (− 3.16)
Constant	0.325** (8.36)	− 0.347*** (6.97)	0.317*** (14.02)
Groups	72	72	72
Instruments	57	45	66
Hansen J test: *p* value	0.379	0.421	0.496
AR (2): *p* value	0.79	0.747	0.770

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

Table 4 GMM estimation results: CO_2 and governance quality index effects on adult mortality rates

Dependent variables	AM (1)	AM (2)	AM (3)
Lagged dependent variable	0.996*** (601.11)	0.986*** (630.29)	0.994*** (398.93)
lAP (*lCO2*)	0.001 (1.78)	0.0001 (0.48)	0.001 (0.81)
lY	− 0.004*** (− 4.54)	− 0.002* (− 2.48)	− 0.005*** (− 4.14)
lPHS	− 0.001*** (− 5.42)	− 0.002*** (− 6.56)	− 0.0001 (− 0.75)
lEDU	− 0.008** (− 2.69)	0.023*** (− 6.6)	− 0.017*** (− 4.21)
GQI		− 0.001 (− 0.48)	0.001 (1.94)
*lCO2*GQI*			− 0.0004 (− 0.98)
Constant	0.054* (2.36)	0.184*** (8.72)	0.136*** (4.13)
Groups	72	72	72
Instruments	44	67	52
Hansen J test: *p* value	0.370	0.410	0.348
AR (2): *p* value	0.756	0.772	0.219

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

a larger variance asymptotically. Blundell and Bond (1998) display that the system GMM estimator is capable of lessening the biases and imprecision related to the difference estimator. This estimator is used as it increases efficiency by utilizing both lagged levels and lagged differences. Further, alternatively, GMM estimators deemed in their one-step and two-step forms. Theoretically, the two-step estimator is farther efficient in regard to the one-step estimator due to the use of optimal weighting matrices. Hence, a two-step system GMM estimator is adopted as it provides a better result, and for this cause, this study also employs this estimation technique.

GMM estimator consistency leans on two validity tests. First, the Hansen overidentification restrictions shall be used to check the instruments' validity. From the test, the instruments are shown to be valid and endogeneity bias can be overcome when the null of overidentification hypothesis is failed to be rejected. Secondly, in regard to the serial correlation checking, the null hypothesis of no serial correlation is not rejected in AR (2). The failure to reject the Hansen J-test and AR (2) test's null hypothesis suggests that the GMM estimator is reliable and efficient and has a lack of bias, and the instruments are valid (Arellano and Bond 1991; Arellano and Bover 1995; Blundell and Bond 1998).

This study employed data from a panel of 72 developing countries covering the 2010–2017 period. The countries and time period were chosen dependent on the data's availability. Mortality rates for adults were collected from the World Development Indicators of the World Bank. Particulate matter ($PM_{2.5}$) was estimated via micrograms per cubic meter, while carbon dioxide (CO_2) was estimated via metric tons per capita, real GDP per capita shows the level of income or economic progress, public health spending is the amount of public and private health spending as a percentage of total GDP, and education level is measured by the school enrolment rate. These data likewise were extracted from the World Bank. Nevertheless, the government quality indicator comprises of voice and accountability, political stability, government effectiveness, regulatory quality, rule of law, and control of corruption measures which were taken from the World Governance Indicator of the World Bank.

Results and discussion

In this section, the results are reported following the two-step system GMM estimator. The results of Hansen J test are stated to report the validity of the dynamic panel model. Since the *p* value of the Hansen test in any of the models is statistically not significant, the null hypothesis cannot be rejected. The AR (2) revealed that the moment conditions of the models are satisfied since the *p* values are not statistically significant. Therefore, the Arellano-Bond test confirms the second-order serial correlation and the Hansen test indicates that the over-instrumentation problem is minimized in all regressions, justifying that the estimated model met the diagnostic tests.

The datasets of descriptive statistics are presented in Table 1. The table shows the means, standard deviations (within countries, between countries, and overall countries), as well as minimum and maximum values. According to the table, the difference of minimum and maximum values for adult mortality rates is large, which is 490 (per 1000 adults). It is shown that Lebanon and Lesotho have the lowest and highest rate of mortality at 57 and 548, respectively. In the $PM_{2.5}$ tabulation, the same discrepancy is shown. The maximum concentration of $PM_{2.5}$ from the samples is 97.6, whereas the lowest concentration is 10.5 in micrograms per cubic meter as reported in India and Kiribati. This may indicate plausibly that air pollution could be a significant factor in the rising adult mortality in developing countries. In addition, the governance quality index is low (indicated by negative values) for most countries, as shown by the mean in the table.

The correlation results show that there is a positive correlation between adult mortality and pollutants, i.e. the correlation coefficient is 0.071 for PM2.5 and 0.155 for CO2. On another hand, there is a negative correlation between adult mortality and the rest of the variables, including the interactive terms, i.e. the correlation coefficient is 0.158 for PM2.5 and 0.037 for CO2. The overall results come to the conclusion that a negative association of interactive terms emphasized the need for government role to moderate the adverse effect of air pollution on health (Table 2).

Regression results are given in Tables 3 and 4. Table 3 displays the results of the basic regression (column 1) and the regressions results, where governance quality index is added (column 2). In addition, the expanded regression models with the added interaction between air pollution ($PM_{2.5}$) and governance quality index are shown in column 3. The robustness of the estimated results was then tested by re-estimating the models with CO_2 as the air pollution predictor as presented in Table 3.

The basic regression indicates consistent findings with the past empirical studies. $PM_{2.5}$ carries a significantly positive coefficient, indicating that the increasing level of particulate air pollution contributes to an increase in adult mortality rates in the developing countries. The analysis shows that a 10% rise in the $PM_{2.5}$ level causes adult mortality rates to rise between 0.04% and 0.06%. Therefore, the indication that higher adult mortality is associated with $PM_{2.5}$ seems to confirm the epidemiologic finding that air-polluting particles can lead to higher mortality rates (Yitshak-Sade et al. 2019; Oluleye and Adabale 2020; Wu et al. 2020). These findings are compatible with He et al. (2016) and Aliyu and Ismail (2016) and de Keijzer et al. (2017) and Cao et al. (2018). Moreover, the proxies of real GDP per capita, government health spending, and education level have negative and significant coefficients, denoting their beneficial impact on reducing the adult mortality rates as expected. This result confirms the findings of Zhang et al. (2014) and Grigoli and Kapsoli (2017) that these explanatory variables are associated with lower mortality.

With the addition of governance quality index in the model, the coefficient tends to be not statistically significant in affecting adult mortality. However, when $PM_{2.5}$ and governance quality index in the equivalent model are examined, the result shows that adult mortality has negative signs and is statistically significant at 5% significant level. With a one-unit improvement in governance quality index, it decreases mortality among adults in the developing countries by 0.001%. This suggests that with government action initiatives, the negative impact of pollution can be lessened. The fact that government indicator is only significant in evaluating adult mortality rates with this interaction effect suggests that countries with better governance quality can act as a plausible channel to reduce air pollution risk on health outcomes (lower adult mortality rates). Along that narrative, Biadgilign et al. (2019) and Kim and Wang (2019) conducted studies that provide evidence that good governance could correspond to better health outcomes. Nevertheless, the reported results here are slightly lower, perhaps because this study focuses on developing sample where the scores of governance level are particularly lesser.

The interactive terms' result implies that the quality of governance influences health outcomes more effectively when it is directly targeted towards air pollution. The other study found to examine the effect of governance quality on air pollution is a study by Aliyu and Ismail (2016), while other studies interact public health spending with the quality of government to measure the effects on health outcomes (Makuta and O'hare 2015; Sirag et al. 2017; Doucouliagos et al. 2019; Kim and Wang 2019). The findings of Aliyu and Ismail (2016) were, however, unclear where there is no general conclusion that can be drawn by interacting the only component of government effectiveness of governance quality with PM_{10} and CO_2.

Table 4 presents robustness findings by re-estimating the estimation models in Table 3 by replacing the air pollution indicator with CO_2. An association between air pollution and adult mortality remains robust across all specifications. In basic estimations (column 1), carbon dioxide emission positively affects adult mortality but is not statistically significant. This result indicates that despite the wide usage of CO_2 as the indicator of air pollutants present, $PM_{2.5}$ could be a better measurement of an air pollutant as it is more harmful to health (significantly affects mortality). The estimation analyses in Table 3 also consistently show that the real GDP per capita, government health spending, and education level reduce levels of mortality for adults (except for education level in column 3).

However, in all regressions (columns 2 and 3), the inclusion of governance quality index as well as with CO_2 shows that there is a negative association on adult mortality rates, but the variables are statistically not significant. This result is compatible with empirical findings in other developing country studies made by Delavari et al. (2008), Monsef and Mehrjardi (2015), and Amuka et al. (2018). Compared to CO_2, which is considered to be a global pollutant, there is obvious public policy imperative to mitigate local pollutants ($PM_{2.5}$) made by the government as global pollution requires participation from other countries altogether.

Conclusion

This study investigates the effects of air pollution on adult mortality levels in developing countries. From the air pollution and adult mortality analyses, the increasing particulate air pollution levels ($PM_{2.5}$) are likely to have a significant effect on the rising rates of adult mortality rates. Additionally, the effects of air pollution appear to be more noticeable in particulate air pollution ($PM_{2.5}$) than carbon dioxide emissions. The indication on the interaction effects of air pollution ($PM_{2.5}$) and government quality on adult mortality rates is clear, implying that the government does not independently affect adult health, but only significant when measured together in the same model in the respective developing nations. The findings suggest that the adverse effect of air pollution could be mitigated when the government plays an effective role.

Consequently, our analysis suggests that a country should concentrate its efforts to improve air quality and creating healthy physical and social living environments with finer governance. Effective governance can lead to better policies as effective environmental regulations can be implemented, thus affecting all other functions of the health system, leading to enhanced health system performance and, therefore, better health outcomes. Increased health status may not only an outcome in its own right but also a requirement for the development process, as good health is an essential source of human capital. With better health costs for healthcare, services can be reduced and consequently improve labour productivity of a country (Dormont et al. 2010). Therefore, the interplay of governance levels and population health can be accomplished with higher governance quality in light of the movement towards economic growth for preferable living and health status in addition, government should focus on fostering local institution to monitor and promoting the use of technological developments in economic sectors and extrapolating these to develop effective policies for international sustainability.

Authors' contributions Nor Asma Ahmad and Normaz Wana Ismail contributed to the study conception and model specifications. Material preparation, data collection, and analysis were performed by Nor Asma Ahmad and Normaz Wana Ismail. The first draft of the manuscript was written by Nor Asma Ahmad and commented by Normaz Wana Ismail, Shaufique Fahmi Ahmad Sidique, and Nur Syazwani Mazlan. Nor Asma Ahmad, Normaz Wana Ismail, Shaufique Fahmi Ahmad Sidique, and Nur Syazwani Mazlan read and approved the final manuscript.

Data availability The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Compliance with ethical standards

Competing interests The authors declare that they have no competing interests.

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent to publish Not applicable.

Appendix

Table 5 List of countries used in the analysis

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

Table 6 GMM estimation results: $PM_{2.5}$ and governance quality effects on adult mortality rates

AM (1)	Coef.	Std. err.	z	*P* > *z*	95% CI	
Lagged dependent variable	0.971	0.003	276.19	0.000	0.964	0.978
lAP (*lPM2.5*)	0.004	0.001	3.04	0.002	0.001	0.006
lY	− 0.004	0.002	− 2.29	0.022	− 0.008	− 0.001
lPHS	− 0.002	0.0004	− 5.27	0.000	− 0.003	− 0.001
lEDU	− 0.036	0.006	− 6.34	0.000	− 0.047	− 0.025
Constant	0.325	0.039	8.36	0.000	0.248	0.401
Groups	72					
Instruments	57					
Hansen J test	0.379					
AR (2)	0.79					
AM (2)	Coef.	Std. err.	z	*P* > *z*	95% CI	
Lagged dependent variable	0.973	0.004	276.4	0.000	0.966	0.98
lAP (*lPM2.5*)	0.006	0.002	3.3	0.001	0.002	0.009
lY	− 0.007	0.002	− 3.02	0.003	− 0.0112	− 0.002
lPHS	− 0.002	0.0005	− 4.42	0.000	− 0.003	− 0.001
lEDU	− 0.039	0.008	− 4.66	0.000	− 0.056	− 0.023
GQI	0.002	0.001	− 1.59	0.111	− 0.0004	0.003
Constant	− 0.347	0.049	6.97	0.000	0.249	0.444
Groups	72					
Instruments	45					
Hansen J test	0.421					
AR (2)	0.747					
AM (3)	Coef.	Std. err.	z	*P* > *z*	95% CI	
Lagged dependent variable	0.975	0.002	630.53	0.000	0.972	0.978
lAP (*lPM2.5*)	0.0004	0.001	0.49	0.627	− 0.001	0.002
lY	− 0.007	0.001	− 7.08	0.000	− 0.009	− 0.005
lPHS	− 0.022	0.0001	14.3	0.000	− 0.002	− 0.002
lEDU	− 0.031	0.004	− 8.31	0.000	− 0.038	− 0.023
GQI	0.003	0.001	3.46	0.001	0.001	0.005
lPM2.5 GQI*	− 0.001	0.0003	− 3.16	0.002	− 0.001	− 0.0003
Constant	0.317	0.023	14.02	0.000	0.272	0.361
Groups	72					
Instruments	66					
Hansen J test	0.496					
AR (2)	0.77					

Table 7 GMM estimation results: CO_2 and governance quality effects on adult mortality rates

AM (3)	Coef.	Std. err.	z	P > z	95% CI	
Lagged dependent variable	0.996	0.002	601.11	0.000	0.991	1.003
lAP (lCO2)	0.001	0.0003	1.78	0.074	− 0.0001	0.001
lY	− 0.004	0.0008	− 4.54	0.000	− 0.005	− 0.002
lPHS	− 0.001	0.0001	− 5.42	0.000	− 0.001	− 0.0004
lEDU	− 0.008	0.003	2.69	0.007	− 0.013	− 0.002
Constant	0.054	0.023	2.36	0.018	0.009	0.098
Groups	72					
Instruments	48					
Hansen J test	0.059					
AR (2)	0.739					
Panel AM (2)	Coef.	Std. err.	z	P > z	95% CI	
Lagged dependent variable	0.986	0.002	630.29	0.000	0.983	0.989
lAP (lCO2)	0.0001	0.0002	0.48	0.629	− 0.0003	0.0006
lY	− 0.002	0.001	− 2.48	0.013	− 0.004	− 0.0005
lPHS	− 0.002	0.0002	− 6.56	0.000	− 0.002	− 0.001
lEDU	− 0.023	0.003	− 6.6	0.000	− 0.029	− 0.016
GQI	− 0.001	0.009	− 0.48	0.693	− 0.021	0.014
Constant	0.184	0.021	8.72	0.000	0.143	0.225
Groups	72					
Instruments	48					
Hansen J test	0.235					
AR (2)	0.788					
AM (3)	Coef.	Std. err.	z	P > z	95% CI	
Lagged dependent variable	0.994	0.002	398.93	0.000	0.989	0.999
lAP (lCO2)	0.001	0.001	0.81	0.418	− 0.001	0.002
lY	− 0.005	0.001	− 4.14	0.000	− 0.008	− 0.003
lPHS	− 0.0001	0.0002	− 0.75	0.455	− 0.0005	0.0002
lEDU	− 0.017	0.004	− 4.21	0.000	− 0.025	− 0.009
GQI	0.001	0.0003	1.94	0.052	− 0.00004	0.001
*lCO2*GQI*	− 0.0004	0.0004	− 0.98	0.329	− 0.001	0.0004
Constant	0.136	0.033	4.13	0.000	0.071	0.2
Groups	72					
Instruments	52					
Hansen J test	0.348					
AR (2)	0.746					

References

Abdul Bahri EN, Shaari Md Nor AH, Sarmidi T, Haji Mohd Nor NH (2019) The role of financial development in the relationship between foreign direct investment and economic growth: a nonlinear approach. Rev Pac Basin Financ Mark Policies 22(02):1950009. https://doi.org/10.1142/S0219091519500097

Achilleos S, Al-Ozairi E, Alahmad B, Garshick E, Neophytou AM, Bouhamra W, Koutrakis P (2019) Acute effects of air pollution on mortality: a 17-year analysis in Kuwait. Environ Int 126:476–483. https://doi.org/10.1016/j.envint.2019.01.072

Ahmad R, Hasan J (2016) Public health expenditure, governance and health outcomes in Malaysia. J Ekonomi Malaysia 50(1):29–40. https://doi.org/10.17576/JEM-2016-5001-03

Aliyu AJ, Ismail NW (2016) The effects of air pollution on human mortality: does gender difference matter in African countries? Environ Sci Pollut Res 23(21):21288–21298. https://doi.org/10.1007/s11356-016-7253-5

Alonso-Borrego C, Arellano M (1999) Symmetrically normalized instrumental-variable estimation using panel data. J Bus Econ Stat 17(1):36–49

Amuka JI, Asogwa FO, Ugwuanyi RO, Omeje AN, Onyechi T (2018) Climate change and life expectancy in a developing country: evidence from greenhouse gas (CO2) emission in Nigeria. Int J Econ Financ Issues 8(4):113. https://doi.org/10.3402/gha.v5io.19065

Anenberg SC, Horowitz LW, Tong DQ, West JJ (2010) An estimate of the global burden of anthropogenic ozone and fine particulate matter on premature human mortality using atmospheric modeling. Environ Health Perspect 118(9):1189–1195. https://doi.org/10.1289/ehp.0901220

Anser MK, Hanif I, Vo XV, Alharthi M (2020) The long-run and short-run influence of environmental pollution, energy consumption, and economic activities on health quality in emerging countries. Environ Sci Pollut Res 27:1–15. https://doi.org/10.1007/s11356-020-09348-1

Arceo E, Hanna R, Oliva P (2016) Does the effect of pollution on infant mortality differ between developing and developed countries? Evidence from Mexico City. Econ J 126(591):257–280. https://doi.org/10.1111/ecoj.12273

Arellano M, Bond S (1991) Some tests of specification for panel data: Monte Carlo evidence with an application to employment equations. Rev Econ Stud 58:277–297. https://doi.org/10.2307/2297968

Arellano M, Bover O (1995) Another look at the instrumental variable estimation of error-components models. J Econ 68(1):29–51. https://doi.org/10.1016/0304-4076(94)01642-D

Barreca AI, Neidell M, Sanders NJ (2017) Long-run pollution exposure and adult mortality: evidence from the acid rain program (no. w23524). National Bureau of economic research. https://doi.org/10.3386/w23524

Biadgilign S, Ayenew HY, Shumetie A, Chitekwe S, Tolla A, Haile D, Gebreyesus SH, Deribew A, Gebre B (2019) Good governance, public health expenditures, urbanization and child undernutrition Nexus in Ethiopia: an ecological analysis. BMC Health Serv Res 19(1):1–10. https://doi.org/10.1186/s12913-018-3822-2

Blundell R, Bond S (1998) Initial conditions and moments restrictions in dynamic panel data models. J Econ 87(1):115–143. https://doi.org/10.1016/S0304-4076(98)00009-8

Bollyky TJ, Templin T, Cohen M, Schoder D, Dieleman JL, Wigley S (2019) The relationships between democratic experience, adult health, and cause-specific mortality in 170 countries between 1980 and 2016: an observational analysis. Lancet 393(10181):1628–1640. https://doi.org/10.1016/S0140-6736(19)30235-1

Burchi F (2011) Democracy, institutions and famines in developing and emerging countries. Can J Dev Stud 32(1):17e31. https://doi.org/10.1080/02255189.2011.576136

Cao Q, Rui G, Liang Y (2018) Study on PM2. 5 pollution and the mortality due to lung cancer in China based on geographic weighted regression model. BMC Public Health 18(1):925. https://doi.org/10.1186/s12889-018-5844-4

Carey IM, Atkinson RW, Kent AJ, Van Staa T, Cook DG, Anderson HR (2013) Mortality associations with long-term exposure to outdoor air pollution in a national English cohort. Am J Respir Crit Care Med 187(11):1226–1233. https://doi.org/10.1164/rccm.201210-1758OC

Cesaroni G, Badaloni C, Gariazzo C, Stafoggia M, Sozzi R, Davoli M, Forastiere F (2013) Long-term exposure to urban air pollution and mortality in a cohort of more than a million adults in Rome. Environ Health Perspect 121(3):324–331. https://doi.org/10.1289/ehp.1205862

Cesur R, Tekin E, Ulker A (2013) Air pollution and infant mortality: evidence from the expansion of natural gas infrastructure. Econ J 127(600):330–362. https://doi.org/10.3386/w18736

Chen X, Shao S, Tian Z, Xie Z, Yin P (2017) Impacts of air pollution and its spatial spillover effect on public health based on China's big data sample. J Clean Prod 142:915–925. https://doi.org/10.1016/j.jclepro.2016.02.119

Coneus K, Spiess CK (2012) Pollution exposure and child health: evidence for infants and toddlers in Germany. J Health Econ 31(1):180–196. https://doi.org/10.1016/j.jhealeco.2011.09.006

de Keijzer C, Agis D, Ambrós A, Arévalo G, Baldasano JM, Bande S, Ghigo S (2017) The association of air pollution and greenness with mortality and life expectancy in Spain: a small-area study. Environ Int 99:170–176. https://doi.org/10.1016/j.envint.2016.11.009

Deguen S, Petit C, Delbarre A, Kihal W, Padilla C, Benmarhnia T, Zmirou-Navier D (2015) Neighbourhood characteristics and long-term air pollution levels modify the association between the short-term nitrogen dioxide concentrations and all-cause mortality in Paris. PLoS One 10(7):e0131463. https://doi.org/10.1371/journal.pone.0131463

Delavari S, Zandian H, Rezaei S, Morandinazar M, Delavari S, Saber A, Fallah R (2008) Life expectancy and its socioeconomic determinants in Iran. Electron Phys 8(10):3062–3068. https://doi.org/10.19082/3062

Di Q, Wang Y, Zanobetti A, Wang Y, Koutrakis P, Choirat C, Schwartz JD (2017) Air pollution and mortality in the Medicare population. N Engl J Med 376(26):2513–2522. https://doi.org/10.1056/NEJMoa1702747

Dormont B, Oliveira Martins J, Pelgrin F, Suhrcke M (2010) Health expenditures, longevity and growth. Longevity and growth. In: Book: ageing, health, and productivity, pp 73–94. https://doi.org/10.1093/acprof:oso/9780199587131.003.0007

Doucouliagos H, Hennessy J, Mallick D (2019) Health aid, governance and infant mortality. IZA discussion papers 12166, Institute of Labor Economics (IZA)

Erdoğan S, Yıldırım DÇ, Gedikli A (2019) The relationship between CO2 emissions and health indicators: the case of Turkey. Econ Lett 6(1):28–39

Fan M, Wang Y (2020) The impact of PM 2.5 on mortality in older adults: evidence from retirement of coal-fired power plants in the United States. Environ Health 19(1):1–13. https://doi.org/10.1186/s12940-020-00573-2

Fang D, Wang QG, Li H, Yu Y, Lu Y, Qian X (2016) Mortality effects assessment of ambient PM2. 5 pollution in the 74 leading cities of China. Sci Total Environ 569:1545–1552. https://doi.org/10.1016/j.scitotenv.2016.06.248

Farag M, Nandakumar AK, Wallack S, Hodgkin D, Gaumer G, Erbil C (2013) Health expenditures, health outcomes and the role of good governance. Int J Health Care Finance Econ 13(1):33–52. https://doi.org/10.1007/s10754-012-9120-3

Frankel JA, Rose AK (2005) Is trade good or bad for the environment? Sorting out the causality. Rev Econ Stat 87(1):85–91. https://doi.org/10.3386/w9201

Garcia CA, Yap PS, Park HY, Weller BL (2016) Association of long-term PM2. 5 exposure with mortality using different air pollution exposure models: impacts in rural and urban California. Int J Environ Health Res 26(2):145–157. https://doi.org/10.1080/09603123.2015.1061113

Ghorani-Azam A, Riahi-Zanjani B, Balali-Mood M (2016) Effects of air pollution on human health and practical measures for prevention in Iran. J Res Med Sci 21. https://doi.org/10.4103/1735-1995.189646

Glatman-Freedman A, Cohen ML, Nichols KA, Porges RF, Saludes IR, Steffens K, Britt DW (2010) Factors affecting the introduction of new vaccines in poor nations: a comparative study of the Haemophilus influenzae type B and hepatitis B vaccines. PLoS One 5(11):e13802. https://doi.org/10.1371/journal.pone.0013802

Greenstone M, Hanna R (2011) Environmental regulations, air and water pollution, and infant mortality in India (no. w17210). National Bureau of Economic Research. https://doi.org/10.3386/w17210

Grigoli F, Kapsoli J (2017) Waste not, want not: the efficiency of health expenditure in emerging and developing economies. Rev Dev Econ 22(1):384–403. https://doi.org/10.1111/rode.12346

Halicioglu F (2011) Modeling life expectancy in Turkey. Econ Model 28(5):2075–2082. https://doi.org/10.1016/j.econmod.2011.05.002

He G, Fan M, Zhou M (2016) The effect of air pollution on mortality in China: evidence from the 2008 Beijing Olympic Games. J Environ Econ Manag 79:18–39. https://doi.org/10.1016/j.jeem.2016.04.004

Holmberg S, Rothstein B (2011) Dying of corruption. Health Econ Policy Law 6(4):529e547. https://doi.org/10.1017/S174413311000023X

Holtz-Eakin D, Newey W, Rosen HS (1988) Estimating vector autoregressions with panel data. Econometrica J Econ Soc:1371–1395. https://doi.org/10.2307/1913103

Hu B, Mendoza RU (2013) Public health spending, governance and child health outcomes: revisiting the links. J Hum Dev Capabilities 14(2): 285–311. https://doi.org/10.1080/19452829.2013.765392

Ibrahim MH, Law SH (2016) Institutional quality and CO2 emission–trade relations: evidence from sub-Saharan Africa. South Afr J Economics 84(2):323–340. https://doi.org/10.1111/saje.12095

Kim S, Wang J (2019) Does quality of government matter in public health?: comparing the role of quality and quantity of government at the national level. Sustainability 11(11):3229. https://doi.org/10.3390/su11113229

Kiross GT, Chojenta C, Barker D, Loxton D (2020) The effects of health expenditure on infant mortality in sub-Saharan Africa: evidence from panel data analysis. Health Econ Rev 10(1):1–9. https://doi.org/10.1186/s13561-020-00262-3

Li T, Hu R, Chen Z, Li Q, Huang S, Zhu Z, Zhou LF (2018) Fine particulate matter (PM2. 5): the culprit for chronic lung diseases in China. Chronic Dis Transl Med 4(3):176–186. https://doi.org/10.1016/j.cdtm.2018.07.002

Li Y, Chiu YH, Lin TY (2019) The impact of economic growth and air pollution on public health in 31 Chinese cities. Int J Environ Res Public Health 16(3):393. https://doi.org/10.3390/ijerph16030393

Lin RT, Chien LC, Chen YM, Chan CC (2014) Governance matters: an ecological association between governance and child mortality. Int Health 6(3):249–257. https://doi.org/10.1093/inthealth/ihu018

Makuta I, O'Hare B (2015) Quality of governance, public spending on health and health status in sub-Saharan Africa: a panel data regression analysis. BMC Public Health 15(1):932. https://doi.org/10.1186/s12889-015-2287-z

Marchwinska-Wyrwal E, Dziubanek G, Hajok I, Rusin M, Oleksiuk K, Kubasiak M (2011) Impact of air pollution on public health. The impact of air pollution on health, economy, environment and agricultural sources. 1. https://doi.org/10.5772/17906

Martins F, Felgueiras C, Smitková M (2018) Fossil fuel energy consumption in European countries. Energy Procedia 153:107–111. https://doi.org/10.1016/j.egypro.2018.10.050

Matthew O, Osabohien R, Olawande TI, Urhie ES (2019) Manufacturing industries and construction emissions in Nigeria: examining the effects on health conditions. Int J Civ Eng Technol 10(1):2401–2414

Monsef A, Mehrjardi AS (2015) Determinants of life expectancy: a panel data approach. Asian Econ Financ Rev 5(11):1251–1257. https://doi.org/10.18488/journal.aefr/2015.5.11/102.11.1251.1257

Olafsdottir AE, Reidpath DD, Pokhrel S, Allotey P (2011) Health systems performance in sub-Saharan Africa: governance, outcome and equity. BMC Public Health 11:237 1471-2458/11/237

Oluleye A, Adabale A (2020) Potential impact of pollutant emitted by generator-powered telecommunication masts on air quality of Oja Oba in Akure metropolis. Environ Sci Pollut Res Int 27:32554–32568. https://doi.org/10.1007/s11356-020-09430-8

Pautrel X (2009) Pollution and life expectancy: how environmental policy can promote growth. Ecol Econ 68(4):1040–1051. https://doi.org/10.1016/j.ecolecon.2008.07.011

Pena MSB, Rollins A (2017) Environmental exposures and cardiovascular disease: a challenge for health and development in low-and middle-income countries. Cardiol Clin 35(1):71–86. https://doi.org/10.1016/j.ccl.2016.09.001

Rasoulinezhad E, Taghizadeh-Hesary F, Taghizadeh-Hesary F (2020) How is mortality affected by fossil fuel consumption, CO2 emissions and economic factors in CIS region? Energies 13(9):2255. https://doi.org/10.3390/en13092255

Rees N (2016) Clear the air for children: the impact of air pollution on children. https://www.unicef.org/media/60106/file. Accessed 15 Jan 2020

Rosenberg DY (2018) Political economy of infant mortality rate: role of democracy versus good governance. Int J Health Serv 48(3):435–460. https://doi.org/10.1177/0020731418774226

Sanyal S, Rochereau T, Maesano CN, Com-Ruelle L, Annesi-Maesano I (2018) Long-term effect of outdoor air pollution on mortality and morbidity: a 12-year follow-up study for metropolitan France. Int J Environ Res Public Health 15(11):2487. https://doi.org/10.3390/ijerph15112487

Satish U, Mendell MJ, Shekhar K, Hotchi T, Sullivan D, Streufert S, Fisk WJ (2012) Is CO2 an indoor pollutant? Direct effects of low-to-moderate CO2 concentrations on human decision-making performance. Environ Health Perspect 120(12):1671–1677. https://doi.org/10.1289/ehp.1104789

Siddiqi S, Masud TI, Nishtar S, Peters DH, Sabri B, Bile KM, Jama MA (2009) Framework for assessing governance of the health system in developing countries: gateway to good governance. Health policy 90(1):13–25. https://doi.org/10.1016/j.healthpol.2008.08.005

Siddique S, Ray MR, Lahiri T (2011) Effects of air pollution on the respiratory health of children: a study in the capital city of India. Air Qual Atmos Health 4(2):95–102. https://doi.org/10.1007/s11869-010-0079-2

Sirag A, Nor NM, Abdullah NMR, Abd Ghani J (2017) Public health financing and infant mortality: does governance quality matter? Public Finance Manag 17(4):341–370

Taghizadeh-Hesary F, Taghizadeh-Hesary F (2020) The impacts of air pollution on health and economy in Southeast Asia. Energies 13(7): 1812. https://doi.org/10.3390/en13071812

Tamazian A, Rao BB (2010) Do economic, financial and institutional developments matter for environmental degradation? Evidence from transitional economies. Energy Econ 32(1):137–145. https://doi.org/10.1016/j.eneco.2009.04.004

Tanaka S (2015) Environmental regulations on air pollution in China and their impact on infant mortality. J Health Econ 42:90–103. https://doi.org/10.1016/j.jhealeco.2015.02.004

Tian Y, Liu H, Liang T, Xiang X, Li M, Juan J et al (2019) Fine particulate air pollution and adult hospital admissions in 200 Chinese cities: a time-series analysis. Int J Epidemiol 48(4):1142–1151. https://doi.org/10.1093/ije/dyz106

Van Tran N (2020) The environmental effects of trade openness in developing countries: conflict or cooperation? Environ Sci Pollut Res 27:1–15. https://doi.org/10.1007/s11356-020-08352-9

Wang J, Lu M, An Z, Jiang J, Li J, Wang Y et al (2020) Associations between air pollution and outpatient visits for allergic rhinitis in Xinxiang, China. Environ Sci Pollut Res 27:1–10. https://doi.org/10.1007/s11356-020-08709-0

World Bank (2019) The global distribution of air pollution. World Development Indicators

Wu Y, Wang W, Liu C, Chen R, Kan H (2020) The association between long-term fine particulate air pollution and life expectancy in China, 2013 to 2017. Sci Total Environ 712:136507. https://doi.org/10.1016/j.scitotenv.2020.136507

Xie Y, Dai H, Zhang Y, Wu Y, Hanaoka T, Masui T (2019) Comparison of health and economic impacts of PM2. 5 and ozone pollution in China. Environ Int 130:104881. https://doi.org/10.1016/j.envint.2019.05.075

Yitshak-Sade M, Kloog I, Zanobetti A, Schwartz JD (2019) Estimating the causal effect of annual PM2. 5 exposure on mortality rates in the northeastern and mid-Atlantic states. Environ Epidemiol 3(4):e052. https://doi.org/10.1097/EE9.0000000000000052

Yu W, Guo Y, Shi L, Li S (2020) The association between long-term exposure to low-level PM2.5 and mortality in the state of Queensland, Australia: a modelling study with the difference-in-differences approach. PLoS Med 17(6):e1003141. https://doi.org/10.1371/journal.pmed.1003141

Zanobetti A, Schwartz J (2009) The effect of fine and coarse particulatr air pollution on mortality: a national analysis. Environ Health Perspect 117(6):898–903. https://doi.org/10.1289/ehp.0800108

Zeger SL, Dominici F, McDermott A, Samet JM (2008) Mortality in the Medicare population and chronic exposure to fine particulate air pollution in urban centers (2000–2005). Environ Health Perspect 116(12):1614–1619. https://doi.org/10.1289/ehp.11449

Zhang LW, Chen X, Xue XD, Sun M, Han B, Li CP, Zhao BX (2014) Long-term exposure to high particulate matter pollution and cardiovascular mortality: a 12-year cohort study in four cities in northern China. Environ Int 62:41–47. https://doi.org/10.1016/j.envint.2013.09.012

Zhao J (2019) Environmental regulation: lessons for developing economies in Asia. ADBI working paper 980. Asian Development Bank Institute, Tokyo www.adb.org/publications/environmental-regulation-lessons-developing-economies-asia. Accessed 15 Jan 2020