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Original Article

Air Pollution and Influenza Incidence: Evidence from Highly Polluted Countries

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Abstract

Background: Air pollution has become a serious threat to public health. Epidemiological and clinical evidence in recent years has shown air pollutants are associated with respiratory diseases. We aimed to analyze the impact of environmental factors on influenza incidence by examining the most polluted countries in the world.

Methods: To analyze the relationship between environmental factors and influenza incidence in eighteen countries, we used a system generalized method of moments (GMM) using data from 2010 to 2020.

Results: The results suggest a positive effect of air pollution ($PM_{2.5}$ and NO_2) and population density on the incidence of influenza. While government health expenditures and education have a negative effect on influenza in the studied countries.

Conclusion: Our results confirmed the importance of environmental and social factors in the incidence of influenza. Furthermore, our results are interesting and informative for policymakers to design public health policies synchronized with other policies such as education, industrial, and environmental policies, for better management of influenza.

Keywords: Air pollution; Influenza; Population density; Generalized method of moments GMM; Polluted countries

Introduction

Air pollution is a common threat to humans and the environment (1). Pollution affects the basic human requirements, such as food, air, and water, but also affects economic development (2). Some reports indicate that ninety-nine percent of the world's population is exposed to air pollution, which is considered to be the main factor contributing to the environmental burden of disease (1). Air pollution is a leading cause of death, resulting in seven million deaths worldwide. Air pollution causes stroke, cancer, ischemic heart disease, obstructive pulmonary disease, and respiratory infections each year (1).

Among all the air pollutants, particulate matter ($PM_{2.5}$) poses a higher risk to human health (3). These minute particles originate from industrial emissions, wildfires, and vehicular exhaust; moreover they are small enough to get deep inside the lungs and the bloodstream (4). Exposure to $PM_{2.5}$ leads to several cardiovascular problems including heart attacks, high blood pressure, and strokes (5). Besides, it also affects lung function, especially in children whose lungs are not fully developed (6, 7). Some studies showed higher levels of $PM_{2.5}$ to be associated with premature births, birth defects, as well as child and maternal mortality (6, 8, 9). Moreover, $PM_{2.5}$ aggravates the prevailing health conditions exposing humans to infectious diseases, especially respiratory infections (10, 11). There are various diseases associated with the prevalence of higher levels of $PM_{2.5,}$ one such disease is influenza.

Influenza is a serious public health concern, with three to five million reported cases each year and associated deaths ranging from 290,000 to 650,000 (12). The spread and severity of the disease vary across regions, individuals, and over time (13). Various factors are responsible for the spread and severity. Earlier studies highlighted various meteorological factors such as temperature, humidity, and sunlight that affect the influenza virus (13, 14), while other studies found individual factors such as age, health, and smoking habits that affect the severity of the disease (13, 15). One such study (16) showed that both high and low temperatures increase the chance of influenza virus infection (16). The risk that influenza incidence increases in cases of low temperatures and high relative humidity (17, 18). However, little is known about how air pollution affects the spread and severity of influenza (5).

Air pollution can affect influenza hospitalization through both susceptibility and exposure (17, 18). Air pollutants ($PM_{2.5}$ and PM_{10}) remain active in the air for a longer period and thus increase the transmission of the influenza virus (18). Pollution reduces the patient's respiratory function, causing damage to the Broncho epithelium and allowing the influenza virus to enter the lungs beyond the epithelium barrier (19, 20). One study (21) revealed a positive impact of PM_{10} and O_3 on pediatric influenza in Australia. However, limited studies have examined the relationship between various air pollutants and influenza incidence in highly vulnerable countries (5, 22). Additionally, studies have mixed results on the association between air pollutants and influenza (13, 18, 21). The impact of particulate matter has been studied on various diseases, including respiratory systems. However, such studies analyzed the data from a single country with a limited time duration (13, 18). Therefore, this research will try to fill this gap by using panel data involving eighteen countries for eleven years and various socio-economic indicators along with air pollutants to estimate their impact on influenza.

By dissecting the link between air pollution exposure and the incidence of influenza, this study aimed to provide valuable information for healthcare planning to decrease the burden of respiratory infections in populations exposed to elevated levels of air pollution. This study may help in developing constructive public health policies and interventions.

Materials and Methods

Mensah et. al. primarily modeled climate change and socio-economic variables that influence infectious diseases such as influenza (22). We extend the above model to include the air pollution that affects the incidence of influenza. The empirical model is given as:

$M = g\ (CV, D)$

where M is the number of influenza cases reported while CV represents the climate variables i.e. air pollution proxied by $PM_{2.5}$ and nitrogen dioxide (NO_2), while D represents socio-economic variables for example government health expenditure (GHE), population density, and education level. We use the above model to estimate the incidence of influenza.

We expect the climate variables (air pollutants) to be increasing the incidence of influenza. While we expect the GHE to reduce influenza cases, because of government expenditure on health will not only help people treat the disease but will also enable them to take precautionary measures. Similarly, better education may enable people to take corrective actions but also may help them to work on precautionary measures to avoid influenza. However, population density, i.e. population per square kilometer might increase the incidence of influenza because the closer people live, the more the chances of the virus spreading.

Different studies touched on this topic using various methodologies. Most of the studies used limited time series data for regions in a country. For example, a study (23) used six years of data from 2014 to 2019 from a single province of China. The study used distributed lag non-linear estimation. This method was chosen because the study was limited to one province and limited time. Another study further explored the incidence of influenza in China for the period of five years from 2015 to 2019, using time series analysis (13). Moreover, the pollutants' relation was examined with influenza, in the city of Brisbane, Australia, using time series analysis by log-linear regression (21). The association in the Chinese province of Heifi examined, using a generalized Poisson additive regression model for time series analysis (18). Almost all studies used time series data of varying lengths and literature is almost silent on the relationship using panel data. Therefore, our study by using panel data will contribute to the literature by analyzing the relationship across time and countries. Most of the studies used lagged variables to show the lag period impact on the current cases. We followed their methodology by using system GMM method, which includes lagged values of influenza cases.

Based on the availability of data, the study used panel data estimation. Panel data estimation has several advantages: for example, such data control for inter-country differences; secondly, panel data even with unbalanced data provide reliable estimates; thirdly, panel data provides higher degrees of freedom and sample variation (24, 25). Moreover, we used the system generalized method of moments (GMM) for estimation. System GMM is more appropriate for use because it controls for the unobserved endogeneity arising out of the dependence between independent variables and the stochastic term. Besides, this method requires the number of cross sections to be greater than time i.e. number of countries is eighteen and the number of years is eleven (26). Furthermore, the number of instruments is less than the number of cross-sections.

We used the following econometric model for estimation:

$$ln \quad Inf = ln\beta_0 + ln\beta_1 PM_{2.5it} + ln\beta_2 NO_{2it} + ln\beta_3 GHE_{it} + ln\beta_4 Edu_{it} + ln\beta_5 PopD_{it} + \epsilon_{it}$$

Where Inf measures the total number of influenza cases reported in one year, $PM_{2.5}$ measures the particulate matter measured by particles of 2.5 microgram per cubic meter, similarly, NO_2, i.e. nitrogen dioxide is measured by nitrogen dioxide particles in microgram per cubic meter. Government health expenditure (GHE) is measured in US dollars. Population density (PopD) is measured by the number of people per square kilometer. Education level (Edu) is measured by the percentage of secondary school enrollment. Whereas, b's are the usual estimated coefficients, *i* and *t* are usual subscripts signifying the cross-sectional and time and *e* is the stochastic term. All the variables are measured in natural logarithmic form; therefore, these variables are interpreted as elasticities.

The current study uses a panel dataset of 18 countries, including Bangladesh, Bahrain, Bosnia, China, Egypt, Ethiopia, Ghana, India, Indonesia, Iran, Iraq, Laos, Mongolia, Nepal, Nigeria, Pakistan, Qatar, and Vietnam. These countries were selected based on the annual average $PM_{2.5}$ concentration level above 25 micrograms per cubic meter. However, some countries were omitted due to the unavailability of data. The data on all related variables were collected from the World Bank dataset.

Results

The study employed Levin-Lin-Chu and Fisher-type tests for balanced and unbalanced data to check the stationarity of the data. The results reported in Table 1 indicate that variables i.e., Influenza, $PM_{2.5}$, GHE, and PopD are stationary at level as the p-value is less than 0.05; however, NO_2 and Education are stationary at first difference (*P*-value < 0.05).

Table 1: Test results of Levin-Lin-Chu and Fisher-type

Variable	At Level	1st Difference
Influenza	-6.8117 (0.0000)	
$PM_{2.5}$	-4.0281 (0.0000)	
NO_2		-32.2524 (0.0000)
GHE	-2.2908 (0.0110)	
Edu		-15.2644 (0.0000)
PopD	-2.8774 (0.0020)	

Note: *P*-values are in parenthesis

The variables' descriptive statistics are reported in Table 2. The mean number of Influenza cases reported is about 75.5347 with a standard deviation of 251.0568. The mean value of air pollution ($PM_{2.5}$) is about 52.7214 μg/m^3 with a standard deviation of 21.2418 μg/m^3. However, NO_2 has a mean value of 62960.39 microgram per cubic meter and standard deviation of 126936.8. GHE, Edu and PopD have a mean value of 305.2905, 68.3457 and 300.6122 and standard deviation of 489.7412, 19.0209 and 441.6959 respectively.

Table 2: Variables Descriptive Statistics

Variables	Obs	Mean	Std. Dev.	Min	Max
Influenza	187	75.5347	251.0568	0.0576	2011.061
$PM_{2.5}$	180	52.7214	21.2418	18.5557	95.2426
NO_2	198	62960.39	126936.8	118.7113	551682.8
GHE	198	305.2905	489.7412	14.83501	2470.489
Edu	197	68.3457	19.0209	33.17973	105.4658
PopD	198	300.6122	441.6959	1.7353	1915.626

Table 3 reports the results of the one-step system GMM. We employed regression on the dependent variable i.e., Influenza cases, and independent variables i.e., air pollution ($PM_{2.5}$ & NO_2). The results indicate a positive and significant impact of air pollutants ($PM_{2.5}$ & NO_2) on influenza cases in the selected countries. About 1% increase in $PM_{2.5}$ and NO_2 would lead to an increase in influenza cases by 0.42% and 0.15% (95% CI: 0.0628~0.7904 and 0.0592~0.2499, P<0.05) respectively. While the results also show a significant impact of lagged value of influenza cases on current case i.e., by 16% (95% CI: -0.0002~0.3267).

Apart from air pollution, other socio-economic variables like education, government health expenditures, and population density also affect the number of influenza cases. The results indicate that government health expenditures and education reduce the number of influenza cases. About 1% increase in health spending and education level can reduce the number of influenza cases by 0.49 and 2.92% (95% CI: -0.7187~-0.2728 and -2.0432~3.8028, P<0.05) respectively in the studied countries. However, population density 0.1852 (95% CI: 0.3417~0.0287, P<0.05) shows a positive association with the incidence of influenza.

Table 3: Results of the one-step system GMM

Influenza	Coefficient Beta	Std. Dev.	t-Statistics	Prob.	[95% Conf. Interval]	
Air Pollution Variables						
Influenza L1.	0.1633	0.0834	1.96	0.050	-0.0002	0.3267
$PM_{2.5}$	0.4266	0.1856	2.30	0.022	0.0628	0.7904
NO_2	0.1546	0.0486	3.18	0.001	0.0592	0.2499
Socioeconomic Variables						
GHE	-0.4957	0.1138	-4.36	0.000	-0.7187	-0.2728
Edu	-2.9230	0.4489	-6.51	0.000	-2.0432	3.8028
PopD	0.1852	0.0798	2.32	0.020	0.3417	0.0287
_cons	-10.1937	1.7464	-5.84	0.000	-13.6165	-6.7709

Discussion

The study examined the relationship between air pollution and the incidence of influenza in the most vulnerable countries. The result shows a positive and statistically significant relationship between air pollution ($PM_{2.5}$ and NO_2) and the number of influenza cases in the selected countries. The results are consistent with the previous studies confirming that long-term exposure to air pollution is closely connected with the incidence of influenza (13, 18, 23, 27). The high concentration of $PM_{2.5}$ was related to a higher risk of influenza cases in China's city of Shijiazhuang (31). A similar outcome was also observed in a study conducted in the USA by (25), which confirmed a 6% increase in influenza cases with increased air pollution. Using various air pollutants ($PM_{2.5}$, SO_2, PM_{10}, NO_2, CO, and O_3), (13) indicated a higher risk of influenza (3.08%, 3.0%, 6.46%, 7.21%, 4.37%, and -9.26%) cases in China. Moreover, we found a significant yearly lagged effect of influenza cases. This study confirmed the results which showed significant lagged effect of influenza on current cases (28).

The US Environmental Protection Agency termed ambient particulate matter as a leading cause of unhealthy air harming human health (27). Influenza is a severe infectious disease caused by the influenza virus. The positive impact of $PM_{2.5}$ on the incidence of influenza relates to its ability to increase the viability and transmissibility of the influenza virus. $PM_{2.5}$ acts as a carrier for the influenza virus by extending its survival in the atmosphere and increasing its ability to infect people (29). $PM_{2.5}$ affects the respiratory system and makes an individual more vulnerable to the respiratory diseases like influenza (30, 31).

$PM_{2.5}$ consists of prominent chemicals and physical features, along with a tendency toward spatial variability (30). $PM_{2.5}$ can enter the body through the respiratory system and trigger an inflammatory response (31, 32). Air pollutants like $PM_{2.5}$ affect the cells' functions by stimulating the manifestation of transcription factors and inflammation-related factors in the body, causing inflammatory reactions and lung oxidative stress in the affected body (31, 33, 34). Simultaneously, the $PM_{2.5}$ phenomenon occurs due to the transition of metal components containing fine particles that tend to react within the body by producing reactive oxygen species and promoting lipid peroxidation (34). Studies endorse that extremely high concentrations of $PM_{2.5}$ can even promote remodeling of lung tissue and reduce lung function (32) leading to a higher vulnerability to the influenza virus. In addition, $PM_{2.5}$ and NO_2 can damage the anti-infection immunity process. Studies have found that environmental pollutants ($PM_{2.5}$, NO_2) can affect the intake and phagocytosis of macrophages and NK cells on virus-infected cells, causing reduced immune ability in the body and expediting the chance of influenza infection (34, 35).

The results also validate the positive and significant impact of NO_2 on the number of influenza cases. NO_2 causes a quick spread of flu by inducing oxidative stress and initiating the production of free radicals. These free radicals potentially cause detrimental effects on the lungs' epithelial cells, exacerbating pulmonary inflammation, impairing the capacity of macrophages to control and eradicate foreign particles through phagocytosis, and increasing their vulnerability to viral infections (36). The association between higher concentrations of NO_2 and the diagnosis of respiratory diseases has been extensively studied. Studies have reported a stronger correlation between increased NO_2 levels and an increased number of patients with respiratory diseases (33, 37). These findings contribute to the growing body of research by showing the detrimental effects of NO_2 on respiratory health.

The study also confirms the important role of government health expenditures in reducing influenza cases. The results showed a negative impact of government health expenditures on the incidence of influenza in the studied countries. Theoretically, higher health expenditures are associated with fewer cases of influenza. Because governments with higher and more effective health spending have more resources to cope with diseases, such resources might include better access to influenza vaccines, effective medical treatment, as well as better living conditions that might mitigate the spread of the influenza virus. Therefore, people with lower health facilities and guidance are more likely to be severely affected by contagious diseases, including influenza. Previous literature also supports our results, for example, severe influenza outcomes was found in the case of poorer communities in the USA (38). Another report also found the poor to be badly hit by influenza (39).

Moreover, education showed a negative impact on influenza. This result indicated the effectiveness of education in mitigating and ameliorating the influenza spread. This is because education helps in spreading the health information (40). Health education improves people's knowledge about prevention measures, such as personal hygiene as well as proper vaccination against diseases (41, 42). Various studies have shown that educational intervention successfully mitigated influenza and other respiratory tract infections (43, 44).

Our results found a positive impact of population density on the incidence of influenza. It is plausible because of the infectious nature of the virus, which requires a higher host density (45). People living close by are more likely to transmit the influenza virus. Our findings are in line with the other studies, for example, a positive association was found between mortality rates and population in the case of the USA (46). Similarly, in the case of Nigeria, densely populated areas are more likely to have suffered because of influenza (47). This was also confirmed in the case of Taiwan (48).

Conclusion

The study revealed a positive and significant impact of air pollutants ($PM_{2.5}$ and NO_2) on the incidence of influenza in the studied countries using the panel system GMM model. Other socioeconomic factors, such as government health expenditures, population density, and education, also influence the incidence of influenza. The influence of such variables may help in the design as well as improvement of existing public health policies. The study has important policy implications. While designing health policy, it is important to link it with environmental and industrial policy as they are highly related. Public health policy must include input from specialists in industry and the environment. Reducing emissions is an important issue; our study contributes to the growing literature on the rationalization of environmental and industrial policies to cope up with health issues, as sometimes an increase in industrial output may be offset by the losses in terms of health thereby increasing the health expenditures. Moreover, one important contribution is the importance of education in the reduction of influenza and for that matter any contagious disease, where educational intervention might reduce the disease's impact. Therefore, educational policy may be prepared with input from public health policy.

Journalism Ethics considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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Conflict of interest

The authors declare no conflict of interest.

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