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RESEARCH ARTICLE

Industrial pollution and human health: evidence from middle-income countries

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Abstract

The hasty economic development in developing countries comes along with poorer air quality, which has severe toxicological effects on the environment and human health. This study is carried out to explore and empirically investigate the relationship between industrial pollution and health using the panel of middle-income countries (MIC) over 1990–2016. This study uses two indicators of health status, namely life expectancy and infant mortality, and two indicators of industrial pollution, namely carbon dioxide emissions and nitrous oxide emissions. This analysis is carried out using fixed effects (FE) technique on the grounds of the Hausman test. The empirical results suggest that industrial pollution tends to decrease life expectancy and increases infant mortality. In addition, this study suggests that the adverse impact of industrial pollution is greater in lower-middle-income countries (LMIC) in comparison with upper-middle-income countries (UMIC). This study recommends the programs to improve human health status and needs to focus on policies that mitigate industrial pollution burden.

Keywords Industrial pollution · Life expectancy · Infant mortality · Fixed effects model

Introduction

Industry is playing a vital role to fuel the output by enhancing the production of goods and services. A strong industrial sector leads to huge economic growth. It reduces unemployment and increases productive efficiency of inputs. Additionally, high levels of productivity raise individual income, which in turn improve the living standard of the people. Besides all the benefits, the industry is polluting the environment of developing and developed countries. Industry discharges some chemicals and gases in manufacturing process which are infecting clean air and water. It created some harmful environmental issues for human health. It is also one of the causes to spread diseases among the people. According to the World Health Organization (2018), "Ambient (outdoor air pollution) in both cities and rural areas was estimated to cause 4.2 million premature deaths worldwide in 2016."[1]

During its productive activities, industry emits various pollutants such as particulate matter, black smoke, carbon dioxide, nitrogen oxide, and sulfur dioxide. These pollutants caused by industrial activities have deleterious effects on life expectancy and infant mortality by adversely influencing respiratory system (Kampa and Castanas 2008; Yuzbekov and Yuzbekov 2015), nervous system (Genc et al. 2012; Lenzi and Bonsanto 2018; Babadjouni et al. 2017), lungs (Gauderman et al. 2004; Seaton et al. 1995), pregnancy outcome (Sram et al. 2005; Stieb et al. 2012), and cardiovascular system (Brook et al. 2010; Dominici et al. 2006). Humans come in contact with these pollutants mainly through ingestion and inhalation, whereas cutaneous contact is the minor path of exposure. Air pollution pollutes water and food, making ingestion the main route of contaminated intake. Inhaling toxic air can cause irritation in nasal cavity resulting in a runny nose

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[1] WHO fact sheet on "Ambient (outdoor) air quality and health (2 May 2018)." http://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

and cough. When these pollutants go down in the lungs, they could trigger the inflammation increasing risk of stroke, cardiovascular diseases, and heart attack. According to Kampa and Castanas (2008), air pollution affects some organs and systems, causing severe and chronic respiratory diseases, which in turn reduce life expectancy.

Although there are many studies (Narayan and Narayan 2008; Correia et al. 2013; Ray and Kumar 2015; Meghisan and Toma 2017) that empirically examined the association between pollution, diseases related to pollution, infant mortality, and life expectancy, these are at micro dimension and for particular region, state, or country. To our best of knowledge, there is not any study that has investigated the linkage between health and pollution using large panel data, and various indicators of health and industrial pollution, simultaneously.

This study aims to unscramble the linkage between health and industrial pollution by using a rich panel dataset of middle-income countries over 1990–2016. The study uses life expectancy and infant mortality as health proxy. Industrial pollution is measured by carbon dioxide emissions and nitrous oxide emissions. The novelty of this study is that, it uses two different panel data sets, one for "health and carbon dioxide (CO_2) emissions" analysis and second for "health and nitrous oxide (N_2O) emissions" analysis. To our knowledge, it is the first study using N_2O as an indicator of industrial pollution. Furthermore, this study attempts to assess the impact of industrial pollution on health separately for lower- and upper-middle-income countries.

The paper is structured as follows: "Literature review" section summarizes previous studies, and "Theoretical framework and econometric model" and "Methodology" sections consist of theoretical framework and methodology. Data is arranged in "Data" section. "Results and discussion" section is about results and discussion. "Conclusion" section covers the concluding remarks.

Literature review

The industry is playing a pivotal role as it boosts up the economic growth of an economy. Akram et al. (2008) investigated the co-integration between health and economic growth in the long run. In addition, it is also the source of water and air pollution that adversely affects the human health. Briggs (2003) proposes that exposure to environmental pollution is a key source of health hazard. Among the determinants of health, environmental pollution accounts for severe public health concerns. Similarly, according to Kampa and Castanas (2008), human health is badly affected by air pollution released from industrial activities by spreading various diseases among the people.

Nevalainen and Pekkanen (1998) asserted that particulate air pollution is associated with an increase in respiratory diseases and mortality. In addition, they maintained that life expectancy is noticeably influenced by particulate air pollution in the countries where the cardiovascular mortality rate is high. They further added that life expectancy is higher in areas with less pollution. Afroz et al. (2003) found that some states are strongly affected by air pollution, and it has a weak impact on human health in other states of Malaysia. By utilizing a quasi-experimental design, Marques and Lima (2011) examined the association between psychological health and residence in industrial area. The results revealed that individuals living in industrial areas tend to have poor psychological health, use lower level of optimism, and employ less coping strategies compared with those living in non-industrial areas.

Jedrychowski and Flak (1998) conducted a study on the relationship between chronic respiratory symptoms and quality of air among children in Krakow (Poland). They found that the prevalence of hay fever, chronic phlegm, and cough is higher among children living in polluted zones. In a study, Kobrossi et al. (2002) found that children living near the fertilizer or cement factories were more prone to experience respiratory problems compared with those living far away in Lebanon. Same but weak results were obtained when compared with children living in non-industrialized areas.

Premaratna et al. (2002) carried out a cross-sectional analysis to assess the effect of industrial pollution on health in Sri Lanka. The results revealed that children living in industrial zone are more prone to rhinitis and cough. Among adult population, probability of headache and cough is higher for those living in industrial areas. Besides, they found no significant differences between two groups regarding disorders related to teeth, miscarriages, eczema, visual defects, or high blood pressure. In a study comprising sample of 250 children (divided in two zones) in Nigeria, Nkwocha and Egejuru (2008) examined the impact of four air pollutants (Sulfur dioxide, carbon mono oxide, particulate matter, and nitrogen) on children's respiratory health with reference to diseases and symptoms. They found a strong relationship between diseases, various symptoms, and industrial air pollution, with the strongest influence on children below 2 years in high polluted zones than in less polluted zones.

Similarly, Loomis et al. (1999) investigated the association between air pollution and infant mortality for Mexico using data during 1993–1995. They found that the level of fine particles, ozone, and nitrogen dioxide is associated with increased infant mortality. Currie and Neidell (2005) also found the inverse effect of air pollution on infant deaths in California. Jerumeh et al. (2015) investigated the impact of pollution (CO_2 emissions) on health in Nigeria during 1971–2011. Results obtained from VECM revealed that pollution has negative influence on health in the short and the long run. Similarly, using data for Spain over 2009–2013, de Keijzer et al. (2017) examined the relationship of greenness and air pollution with life expectancy and mortality using linear regression and Poisson regression respectively. They used NO_2, PM2.5, PM10, and O3 to assess air quality and normalized difference vegetation index to evaluate greenness. They found that air pollution is associated with reduced life expectancy and increased mortality with a stronger influence on life expectancy than mortality. They also found that greenness has a positive influence on health, but in low socioeconomic status areas.

Meghisan and Toma (2017) investigated the effect of greenhouse gas emissions, ozone, and particulate matter air (PM) pollutants on life expectancy at birth and on life expectancy at 65 years old in Romania during 2005–2015. Results obtained from correlation analysis revealed that there is a statistical significant correlation between PM, greenhouse gas emissions, and life expectancy at 65 years and between PM and life expectancy at birth. Results of linear regression reveal that life expectancy at 65 years is influenced by greenhouse gas emissions.

Narayan and Narayan (2008) in a study conducted in 8 OECD countries over 1980–1999 found that in the long run health expenditures are positively and significantly influenced by environmental quality measured by CO_2 and SO_2 emissions. Correia et al. (2013) found that life expectancy increases by 3.5 years if fine particulate matter (PM2.5) declines by 10 $\mu g/m^3$ after controlling the effect of several demographic and socioeconomic variables in 545 US counties during 2000–2007. Monsef and Mehrjardi (2015) conducted a study to scrutinize the determinants of life expectancy in 136 countries during 2002–2010. They found that CO_2 emissions have statistically insignificant impact on life expectancy. Ray and Kumar (2015) investigated the association between economic growth, CO_2 emissions, and health for a sample encompassing low-, middle-, and high-income countries over 1961–2010. The study revealed that CO_2 emissions tend to reduce life expectancy. In addition, they found that in high-income countries adverse impact of CO_2 could be reduced by investing in health expenditures. Sulaiman and Abdul-Rahim (2017) investigated the linkage between life expectancy and air pollution, using dynamic OLS for a sample comprising G-7 countries during 1995–2015. The study revealed that life expectancy is significantly and adversely influenced by air pollution. In these countries, life expectancy can decline by 0.044% due to 1% increase in CO_2 emissions. Chen et al. (2018) investigated the empirical relationship between SO_2 emissions due to industrialization and public health using 161 Chinese municipalities over 2004–2010. Results obtained from 3SLS method indicated that health is significantly and adversely influenced by SO_2 emissions. They found that if SO_2 emissions increase by one million ton, the number of deaths due to lung cancer and respiratory diseases increases by 0.735% and 0.052% (per 100,000 populations), respectively.

The studies reviewed above employ different indicators of health and pollution, but directly to the identical conclusion that industrial pollution has a detrimental impact on human health. Although there are some studies that explored the impact of pollution on health status, these studies are limited in terms of approach and scope used. This study contributes to the literature on health and industrial pollution in a number of ways: (a) this study is carried out by employing two-panel dataset encompassing 68–89 countries during 1990–2016, (b) different indicators of health and industrial pollution are used, and (c) we have extended our examination to verify whether results are robust to other determinants of health.

Theoretical framework and econometric model

This study intends to estimate the production function for health based on the Grossman's (1972) demand for health model. According to Grossman, health is a capital good and individuals are inherited with an initial stock of health which declines over time. Like human capital, individuals can invest in their stock of health by utilizing medical care. So individual health production functions can be depicted as

$$H = H(X) \tag{1}$$

where H represents health output and X represents a vector of inputs to health. Individual inputs to health may include several variables like recreation, education, housing, income, nutrient intake, community, and individual endowment. Following Fayissa and Gutema (2005), inputs in vector X are divided into economic, social, and environmental factors. So Eq. 1 can be modified as

$$H = H(EF, SF, ENF) \tag{2}$$

where EF, SF, and ENF are used for per capita income, social, and environmental indicators respectively. Each vector contains different variables, but literature has used variables on the basis of sufficient data availability.

For empirical investigation, the variables in economic factors vector includes income (Y) and no. of physicians (NP) as health facilities; social factors vector are restricted in urbanization (URB) and education (EDU); and environmental factors vector include industrial pollution (IP). By substituting the above-mentioned variables into Eq. 2,

$$H = H(Y, NP, URB, EDU, IP) \tag{3}$$

Eq. 3 can be expressed in Cobb Douglas production form, considering health as output and three other input factors.

$$H = (Y)^{\alpha 1}(NP)^{\alpha 2}(URB)^{\alpha 3}(EDU)^{\alpha 4}(IP)^{\alpha 5} \tag{4}$$

Here, health is dependent variable measured by life expectancy and infant mortality.

$$LE = (Y)^{\alpha 1} (NP)^{\alpha 2} (URB)^{\alpha 3} (EDU)^{\alpha 4} (IP)^{\alpha 5} \quad (4.1)$$

$$IM = (Y)^{\beta 1} (NP)^{\beta 2} (URB)^{\beta 3} (EDU)^{\beta 4} (IP)^{\beta 5} \quad (4.2)$$

The industrial pollution, income, physicians, education, and urbanization are independent variables. For investigating the impact of industrial pollution on health, linearizing Eqs. 4.1 and 4.2 by taking the logarithm, the functional form of the models will be

$$lnLE = \alpha_1 lnY + \alpha_2 lnNP + \alpha_3 lnEDU + \alpha_4 lnURB + \alpha_5 lnIP \quad (5.1)$$

$$lnIM = \beta_1 lnY + \beta_2 lnNP + \beta_3 lnEDU + \beta_4 lnURB + \beta_5 lnIP \quad (5.2)$$

Above association between health (LE and IM) and industrial pollution (CO_2 and N_2O emissions) can be expressed in panel form as

$$le_{it} = \alpha_1 y_{it} + \alpha_2 np_{it} + \alpha_3 edu_{it} + \alpha_4 urb_{it} + \alpha_5 co_{it} \quad (6.1)$$

$$le_{it} = \theta_1 y_{it} + \theta_2 np_{it} + \theta_3 edu_{it} + \theta_4 urb_{it} + \theta_5 no_{it} \quad (6.2)$$

$$im_{it} = \beta_1 y_{it} + \beta_2 np_{it} + \beta_3 edu_{it} + \beta_4 urb_{it} + \beta_5 co_{it} \quad (6.3)$$

$$im_{it} = \Phi_1 y_{it} + \Phi_2 np_{it} + \Phi_3 edu_{it} + \Phi_4 urb_{it} + \Phi_5 no_{it} \quad (6.4)$$

where i is used for countries 67 (for health and CO_2) and 87 (for health and N2O) countries, t is used for time (1990–2016), *le* and *im* are used for natural logarithm of life expectancy and infant mortality, y is used for log of income, *np* represents the number of physicians in logarithmic form, log of education is expressed by *edu*, *urb* is for log of urbanization, *co* and *no* are used for CO_2 emissions and N_2O emissions, and α, θ, β, and ϕ are showing elasticity with respect to life expectancy and infant mortality.

Methodology

To estimate the parameters specified in Eqs. 6.1 to 6.4, panel data analysis approach is used. The basic approaches to panel data analysis are pooled OLS model, fixed effects model, and random effects model. The choice among these approaches depends upon erogeneity of the independent variables and purpose of the scrutiny.

Pooled OLS model

Key assumption of pooled OLS estimation technique is that intercepts and slope coefficients do not vary across cross-sectional units and over time. Variations across countries and over time are captured by error. The disadvantage of using panel data is that it assumes identical intercept and slope parameters for each countries. This assumption of entities is too restrictive and deforms the true relationship between explained and explanatory variables across entities. That is why one move towards fixed and random effects approaches.

Fixed effects approach

Fixed effects approach is employed when one assess the effect of parameters that does not remain same over time. Fixed effects approach investigates the association between explained and explanatory variables in each cross-sectional unit. Every cross-sectional unit has a number of unique characteristics, which may or may not have an effect on predictor variable. We need to control this impact on predictor variable. Fixed effects estimation technique controls the effect of these time-invariant attributes and can appraise the net impact of explanatory variable on explained variable. This implies that the fixed effects allow variability in intercept to take into account the influence of the unique attributes of each entity.

Hausman test result

Before running estimation, we performed the Hausman test to make a choice between fixed effects (FE) and random effects (RE) estimation approach. The Hausman test is applied to test the following null hypothesis:

H_0 : RE is consistent and efficient

H_1 : FE is consistent and efficient

Results are reported in Table 1. FE approach is preferred to RE as p value is less than 0.01 and significant at a 1% level of significance irrespective of health and industrial pollution proxy used.

Data

This study intends to scrutinize the association between environmental pollution and health status by using panel data covering

Table 1 The Hausman test result

Industrial pollution	Chi-square	Outcome
When LE is used to measure health		
CO_2	$\chi^2(5) = 71.78$ Prob > $\chi^2 = 0.0000$	FE is appropriate
N_2O	$\chi^2(5) = 23.96$ Prob > $\chi^2 = 0.0002$	
When IM is used to measure health		
CO_2	$\chi^2(5) = 52.55$ Prob > $\chi^2 = 0.0000$	FE is good
N_2O	$\chi^2(5) = 55.69$ Prob > $\chi^2 = 0.0000$	

87 countries (for health and nitrogen model) and 67 countries (for health and carbon dioxide model) over 1990–2016. Data on all variables is obtained from World Development Indicators (WDI). According to WDI, GNI per capita of UMIC was \$3956–\$12,235 and GNI was below \$3956 in LMIC. The detail of variables is given in Table 8 in the Appendix.

Dependent variables

Although several indicators can be used to measure health status, in case of cross-country analysis life expectancy (LE) and infant mortality (IM) are the most appropriate indicators of health status, because these are aggregates of individual level measures (Babones 2008). So, we have used LE and IM as the measures of health, which are also used in literature (Siddique et al. 2018). Life expectancy at birth designates the number of years an infant is anticipated to live if the existing pattern of mortality does not change during its life. Infant mortality rate is the number of newborns that die before their first birthday in a year (per 1000 live births).

Independent variables

Industrial pollution is focused independent variable, which adversely influences the environment and human health. According to WHO estimates, "air pollution is responsible for approximately 2% of lung and heart diseases, around 1% of chest infections and 5% of lung cancers". In this study, industrial pollution is measured by carbon dioxide (CO_2) emissions and nitrous oxide (N_2O) emissions.

Carbon dioxide (CO_2) emissions Long-lasting and widespread changes in the environment due to CO_2 emissions are hazardous for health and wellbeing of present and impending generations. CO_2 emissions can influence health in several ways. Higher concentration of CO_2 emissions can damage respiratory function and cause asphyxiation. Exposure to CO_2 emissions can cause deficiency of oxygen in the body, headache, queasiness, and dizziness (Ray and Kumar 2015; Fayissa and Gutema 2005). CO_2 emissions represent emissions from construction and manufacturing industries including the secretion from burning of fuels.

Nitrous oxide (N2O) emissions N_2O are produce by both man-made and natural sources. Man-made sources come from industrial process, agriculture, and fossil fuel combustion. Human sources are accountable for 38% of emissions. Two main sources of industrial N_2O emissions are the production of adipic and nitric acid (Ussiri and Lal 2012). N_2O emissions contribute to the intensifying greenhouse effect which is responsible for global warming, deification, ecosystem degradation, and decreased resources of fresh water, smog pollution, and ozone depletion. All of these adversely influence health by causing communicable and non-communicable diseases, injuries in calamities, malnutrition in dearth, mortality due to heat waves, etc. (Keatinge and Donaldson 2004; Rossati 2017). N_2O emissions include secretion from industrial production and burning of agricultural biomass.

Income (*Y*) Income plays an imperative role in determining population health. As income increases, the access to adequate education, diet, shelter, health, and other facilities improved (Pritchett and Summers 1996; Kabir 2008; Bayati et al. 2013). Income per capita is measured by GDP per capita, which is a ratio of GDP and population, which is also used in literature (Siddique and Majeed 2015).

No. of physicians (NP) Large number of physicians leads to increase access to health amenities, improved health services, and reduces wait time for treatment and medical attention (Mohan and Mirmirani 2007; Gilligan and Skrepnek 2014). Health care facilities are measured by the number of physicians. Physicians consist of specialist and generalist health practitioners.

Education (EDU) Educated people have greater chances to get good jobs paying high income. Moreover, an educated person has greater knowledge and access to information related to health and stays away from risky behavior (Berger and Leigh 1989; Ross and Wu 1995; Mondal et al. 2009). Tertiary school enrollment is used as an indicator of education (Shahid et al. 2019). Gross enrollment ratio is the fraction of total enrollment to the population corresponding to the particular education level.

Urbanization Urbanization may have a negative or positive influence on health. On the one hand, urbanization may lead to greater admittance to medical facilities and health-related information. In addition, in urban areas, health centers are cost-effective. On the other hand, urbanization is linked with overcrowding and pollution, which have an adverse influence on health (Thornton 2002; Fayissa and Gutema 2005). Urbanization is measured by people residing in the urban vicinity in percentage.

Descriptive analysis

Table 2 shows the summary statistic of the data used for health and CO_2 emissions analysis, while Table 3 carries descriptive stats for health and N_2O emissions analysis. Table 2 reveals that the minimum life expectancy is 41.70 years and the maximum is 79.831 years. The minimum infant mortality rate is 2.9 infant deaths per 1000 and maximum is 132.2. The maximum CO_2 emission is 56.11, and the minimum is zero because of measures adopted by some countries. The mean values of life expectancy and infant mortality are 67.71 and

Table 2 Summary statistics of data used for health-CO_2 emissions analysis

Variables	Obs.	Mean	Std. Dev.	Min.	Max.
LE	1828	67.71	7.52	41.70	79.83
IM	1836	35.38	25.57	2.90	132.20
Y	1809	3700.726	2732.814	193.2445	14,652.24
NP	990	1.82	1.48	0.04	7.52
EDU	1212	27.27	19.25	0.49	118.33
URB	1836	52.62	16.88	15.55	89.04
CO_2	1679	17.67	9.35	0.00	56.12

35.38, respectively. The statistics of all other variables are in Table 2.

Table 3 shows the summary stats of the data used for health and N_2O emissions analysis. Here, summary statistic of only focused dependent variables and independent variable nitrous oxide is discussed. Maximum LE is 79.83 years and minimum is 41.69 years. Minimum number of infant deaths is 2.9 per 1000 and maximum is 132.2. Maximum N_2O emissions rate is 587,166.4 and minimum is 0.07 thousand metric tons. The average values of LE, IM, and N_2O are 67.06, 37.16, and 20,378.79, respectively.

Correlation among variables

Table 4 shows the correlation matrix for "health and industrial pollution" analysis. Negative value shows that if one variable decreases (increase) then the other variable will increase (decrease), whereas positive value points out that both variables move in the same direction.

LE is positively correlated with all control variables, whereas IM is negatively correlated with independent variables. It indicates that as there is an increase in these variables, IM will decrease and LE will increase.

In regard to the correlation between focused variables, we came to know that LE is positively correlated with CO_2 emissions and negatively correlated with N_2O. With IM, both CO_2 and N_2O emissions are positively correlated, indicating that increases in CO_2 and N2O emissions will increase infant mortality.

Table 3 Summary statistics of data used for health-N_2O emissions analysis

Variables	Obs.	Mean	Std. Dev.	Min.	Max.
LE	2346	67.0687	7.4286	41.6960	79.8310
IM	2403	36.8894	25.4562	2.9000	132.2000
Y	2342	3607.407	2582.310	193.2445	14,652.24
NP	1161	1.6001	1.4686	0.0020	7.5190
EDU	1413	24.4087	19.1756	0.0000	118.3337
URB	2403	48.9802	18.5617	12.9770	89.0430
N2O	2029	19,917.02	57,465.72	0.0791	587,166.4

Table 4 Correlation matrix

Variables	LE	IM	*Y*	NP	EDU	URB	CO_2	N_2O
LE	1.00							
IM	− 0.71	1.00						
Y	0.35	− 0.59	1.00					
NP	0.52	− 0.51	0.26	1.00				
EDU	0.50	− 0.60	0.41	0.70	1.00			
URB	0.39	− 0.53	0.71	0.55	0.52	1.00		
CO_2	0.09	0.03	− 0.01	0.02	0.01	− 0.03	1.00	
N_2O	− 0.15	0.14	0.07	− 0.19	− 0.18	− 0.12	0.26	1.00

Results and discussion

This section reports empirical results based on panel data for MIC over the period 1990 to 2016. "Full sample results" section represents the empirical results obtained from whole sample and "Subsample results" reports the results of subsamples for UMIC and LMIC.

Full sample results

Table 5 shows the results of model 8.1 (LE and CO_2), model 8.2 (life expectancy and N_2O), model 8.3 (IM and LE), and model 8.4 (IM and N_2O) using fixed effects approach.

Table 5 Results of fixed effects model for full sample (MIC)

Model	(8.1)	(8.2)	(8.3)	(8.4)
Variables	Dependent variable: LE		Dependent variable: IM	
Y	0.0401***	0.0374***	− 0.645***	− 0.648***
	(9.48)	(6.98)	(− 19.92)	(− 19.79)
NP	0.0124***	0.0138***	− 0.00588	− 0.0462**
	(3.24)	(3.77)	(− 0.2)	(− 2.06)
EDU	0.0229***	0.0272***	− 0.192***	− 0.168***
	(7.47)	(7.57)	(− 8.21)	(− 7.63)
URB	0.0291*	0.0311*	− 0.0359	− 0.0669
	(1.84)	(1.8)	(− 0.3)	(− 0.63)
CO	− 0.0165***		0.143***	
	(− 4.73)		5.35	
NO		− 0.00299		0.209***
		(− 0.63)		(7.25)
Constant	3.774***	3.754***	8.638***	7.317***
	(65.54)	(54.87)	(19.61)	(17.51)
Obs.	688	691	688	693
R^2	0.579	0.483	0.741	0.718

t values in parentheses: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Table 5 reveals that CO_2 has negative and statistically significant influence on life expectancy that is a 1% increase in CO_2 emissions will cause life expectancy to decrease by 0.0165% (column 1). Column 2 indicates that N_2O emissions has an adverse influence on life expectancy implying that 1% increase in N_2O emissions will reduce life expectancy by 0.0029%, but this effect is statistically insignificant. We found similar results when infant mortality is used as a health measure. Columns 3 and 4 illustrate that estimated coefficients of both CO_2 emissions and N_2O emissions are positive and significant. This indicates that infant mortality increase by 0.143 and 0.209% due to 1% increase in CO_2 and N_2O emissions. These findings are in accordance with Kampa and Castanas (2008), Genc et al. (2012), Gauderman et al. (2004), Radim et al. (2005), and Currie et al. (2009). According to them, increased industrial pollution (CO_2 and N_2O emissions) worsen health status (a) by adversely influencing respiratory system, lung cardiovascular system, and nervous system and (b) by greenhouse effect and global warming.

The results indicate that the coefficients of income, physicians, and education are statistically significant, signifying that these variables lead improvement in health. The results imply that 1% increase in income, physicians, and education can cause about 0.0401–0.0374, 0.0124–0.0138, and 0.0229–0.0272% increase in life expectancy, respectively, and 0.645–0.648, 0.00588–0.0462, and 0.192–0.168% decrease in infant mortality, respectively. Increasing trend of income leads to better health (Fayissa and Gutema 2008; Messias 2003). With the increase in physician's supply, health is expected to improve as waiting time will decline and availability and accessibility will increase. This result can be supported by Mohapatra (2017).

Education is expected to improve health since well-informed individuals have capability to follow and practice healthy diet and circumvent unhealthy manners. In addition, they have a greater probability to acquire good job and high income. These results are in accordance with Ross and Wu (1995), and Majeed and Gillani (2017). Urbanization has a favorable influence on health; the finding indicates that a 1% increment in urbanization causes 0.0291–0.0311% increase in life expectancy and 0.0359–0.0669% decrease in infant mortality. This result is consistent with the theory that urbanization leads to better health because clinics in urban areas are cost effective, and to easy access to health information and medical services (Bayati et al. 2013; Thornton 2002). However, its effect on infant mortality lacks statistical significance.

In general, other determinants of health (income, physicians, education, and urbanization) have stronger influence on life expectancy and infant mortality than carbon dioxide and nitrous oxide emissions. Yet, policies that focus only on socioeconomic factors and pay no heed to the unfavorable impacts of N_2O and CO_2 pollutants might do little in improving the health status of a country, also may not realize gains in health that can be attained from high socioeconomic level.

Subsample results

We estimated the same models for both upper- and lower-middle-income countries separately. The results attained from fixed effects estimation technique are reported in Tables 6 and 7 for upper- and lower-middle-income countries, respectively.

For UMIC, we found that a 1% increase in CO_2 emissions is expected to decrease life expectancy by 0.0179% and this effect is statistically significant. Similarly, N_2O has a negative coefficient indicating that a 1% increase in N_2O will decrease life expectancy by 0.0042% but this effect is statistically insignificant. With infant mortality as health proxy, we found both CO_2 and N_2O emissions have significant and unfavorable influence on infant mortality indicating that 1% increase in CO_2 and N_2O emissions causes infant mortality to increase by 0.0889% and 0.235%, respectively.

For LMIC, we found that irrespective of proxy used, industrial pollution has expected and statistically significant influence on health. This means that 1% increase in carbon dioxide or nitrous oxide emissions decreases life expectancy by 0.0180% or 0.0123%, respectively, and increases infant mortality by 0.260 and 0.190%, respectively. It can be noted that the adverse impact of industrial pollution on health is greater for lower-middle-income countries. This could be due to

Table 6 Results of fixed effects model for upper-middle-income countries

Model	(8.1)	(8.2)	(8.3)	(8.4)
Variables	Dependent variable: LE		Dependent variable: IM	
Y	0.0382***	0.0366***	− 0.640***	− 0.639***
	(7.04)	(6.42)	(− 15.06)	(− 15)
NP	0.0113	0.0141**	− 0.159***	− 0.135***
	(1.49)	(2.22)	(− 2.67)	(− 2.68)
EDU	0.0211***	0.0245***	− 0.159***	− 0.139***
	(5.37)	(6.25)	(− 5.17)	(− 4.79)
URB	− 0.0058	− 0.0144	− 0.0735	− 0.256*
	(− 0.3)	(− 0.79)	(− 0.49)	(− 1.74)
CO	− 0.0179***		0.0889***	
	(− 4.11)		(2.61)	
NO		− 0.0042		0.235***
		(− 1.21)		(5.33)
Constant	3.935***	3.956***	8.974***	7.833***
	(55.17)	(58.66)	(16.07)	(13.44)
Obs.	423	399	423	401
R^2	0.557	0.491	0.759	0.752

t values in parentheses: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Table 7 Results of fixed effects model for lower-middle-income countries

Model	(8.1)	(8.2)	(8.3)	(8.4)
Variables	Dependent variable: LE		Dependent variable: IM	
Y	0.0491***	0.0475***	− 0.756***	− 0.688***
	(6.91)	(4.73)	(− 14.27)	(− 12.61)
NP	0.00814*	0.0133***	0.0556	− 0.0181
	(1.8)	(2.77)	(1.65)	(− 0.7)
EDU	0.0271***	0.0335***	− 0.198***	− 0.209***
	(4.9)	(4.83)	(− 4.81)	(− 5.56)
URB	0.0674**	0.0389	0.154	0.243
	(2.4)	(1.25)	(0.74)	(1.44)
CO	− 0.0180***		0.260***	
	(− 3.08)		(5.96)	
NO		− 0.0123*		0.190***
		(− 1.67)		(4.77)
Constant	3.571***	3.725***	8.277***	6.620***
	(37.29)	(31.67)	(11.58)	(10.36)
Obs.	265	292	265	292
R^2	0.650	0.507	0.737	0.678

t values in parentheses: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

already poor health condition in lower-middle-income countries.

We also found that income, physicians, and education are positively correlated with health, whereas urbanization has mixed effect that is statistically insignificant in most models.

The results summarized that industrial pollution is detrimental to human health and the impact of industrial pollution is greater in lower-middle-income countries. This could be due to the fact that developing countries are experiencing an intense process of industrialization and urbanization in short time and are becoming the countries with the largest air pollution burden in comparison with developed countries where the process of industrialization has completed. So, residents in these counties are more prone to lethal effects of industrial pollutants (Mannucci and Franchini 2017).

Conclusion

In this study, we scrutinized the impact of industrial pollution measured by CO_2 emissions and N_2O emissions on health in middle-income countries. Covering time period 1990 to 2016, the study utilized fixed effects estimation approach (chosen on the bases of the Hausman test) to attain the objectives. The study developed a model based on Grossman (1972) health production function. The analysis is carried out using full sample (upper- and lower-middle-income countries) and subsamples of upper- and lower-middle-income countries separately. The foremost conclusions drawn from the current study are given below.

The study confirms that increased industrial pollution has an adverse influence on health. There is negative relationship between CO_2 emissions, N_2O emissions, and life expectancy, while positive association between CO_2 emissions, N_2O emissions, and infant mortality. These results confirm that industrial pollution deteriorates health. Short- or long-term exposure to industrial pollutants has toxic effects on respiratory, neuropsychiatric, cardiovascular, reproductive, and immunologic system. Besides these problems, industrial pollutants influence environment and health by increasing temperature. Another important finding of the study is that the adverse impact of CO_2 emissions and N_2O emissions is greater in lower-middle-income countries in comparison with upper-middle-income countries.

The study also found that income, physicians supply, and education have significant and favorable effect in improving health status, whereas urbanization has mixed effect on health, lack of statistical significance in some case. It means that urbanization has trivial or insignificant impact on health in these countries.

Limitations

This study has numerous limitations: First, this study pays no attention to chronic diseases. The health measures used in this study consider the quantity of life but not quality. So, it is necessary to create a comprehensive and a single measure of health. Second, industrial pollution not only deteriorates physical health but is also harmful for mental health; this study does not take into account the impact of pollution on mental health. So, advance investigation can be conducted by using suitable measures of physical and mental health. Third, this study is conducted by using two measures of industrial pollution (CO_2 and N_2O); further research can be conducted using numerous other measures of industrial pollution.

Policy recommendations

On the basis of our findings, the following recommendations are advised. Firstly, policies that ensure to reduce industrial pollution must be prioritized for several health benefits are associated with them. Although reduction in pollution is associated with improvement in quality of environment, many other benefits emanate from abating it. Secondly, technologies that generate less industrial pollution should be utilized to decrease the emissions rate of pollutants from industrious activities. Lastly, policies related to economic growth, healthcare facilities, education, and urbanization must be prioritized as this study has confirmed that these variables are associated with improvement in health status.

Appendix

Table 8 Summary of variables and data sources

Variable	Indicator	Source
Dependent variable (health status)		
Health	Life expectancy at birth, total (years)	WDI 2018
	Mortality rate, infant (per 1000 live births)	WDI 2018
Focused independent variable (industrial pollution)		
Industrial pollution	CO_2 emissions from manufacturing industries and construction (% of total fuel combustion)	WDI 2018
	Nitrous oxide emissions (thousand metric tons)	WDI 2018
Independent variable (control variables)		
Income	Per capita gross domestic product (constant 2010 US$)	WDI 2018
Health facilities	Physicians (per 1000 people)	WDI 2018
Education	School enrollment, tertiary (% gross)	WDI 2018
Urbanization	Urban population (% of total)	WDI 2018

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