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RESEARCH ARTICLE

# Do environmental pollutants carrier to COVID-19 pandemic? A cross-sectional analysis

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## Abstract

The coronavirus disease (COVID-19) is a highly transmitted disease that spreads all over the globe in a short period. Environmental pollutants are considered one of the carriers to spread the COVID-19 pandemic through health damages. Carbon emissions, PM2.5 emissions, nitrous oxide emissions, GHG, and other GHG emissions are mainly judged separately in the earlier studies in different economic settings. The study hypothesizes that environmental pollutants adversely affect healthcare outcomes, likely to infected people by contagious diseases, including coronavirus cases. The subject matter is vital to analyze the preventive healthcare theory by using different environmental pollutants on the COVID-19 factors: total infected cases, total death cases, and case fatality ratio, in a large cross-section of 119 countries. The study employed the generalized least square (GLS) method for robust inferences. The results show that GHG and CO2 emissions are critical factors likely to increase total coronavirus cases and death rates. On the other hand, nitrous oxide, carbon, and transport emissions increase the case fatality ratio through healthcare damages. The study concludes that stringent environmental policies and improving healthcare infrastructure can control coronavirus cases across countries.

**Keywords** Carbon emissions · GHG emissions · Nitrous oxide emissions · COVID-19 pandemic · GLM approach · Cross-country study

## Introduction

In late December 2019, primary instances of pneumonia from unknown causes were recorded in Wuhan, China. On March 11, 2020, WHO announced COVID-19 as a global epidemic because of its fast spread. It has caused catastrophic losses in socioeconomic sectors and thousands of fatalities throughout the globe (WHO 2019, 2020). In January 2020, researchers recognized the SARS-CoV-2 as the cause of the sickness. SARS-CoV-1 and the new coronavirus have a 70% genome sequence similarity. COVID-19 affects the lungs and is a respiratory virus that has spread from China to numerous other nations through transmission. COVID-19 appears to be spread from one person to another by direct touch or droplets, according to evidence. According to Wang et al. (2020), around 41% of coronavirus transmission occurred through direct human-to-human contact.

The coronavirus disease (COVID-19) is posing a massive danger to world public health. The epidemic spread to over 200 nations and areas, with the number of illnesses and losses of humans increasing day by day. As an unusual

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incidence, the coronavirus outbreak has harmed world economic growth and negatively influenced the environment. COVID-19 is a recent phenomenon, but enormous literature is available now (see Anser et al. 2021a; Sharif et al. 2020; Irfan et al. 2021). The literature review section comprises three sub-sections. The first sub-section deals with environmental pollutants and non-communicable diseases. The second sub-section is related to environmental pollutants and communicable diseases. Lastly, the third sub-section is related to the COVID-19 pandemic and environmental pollutants.

## Environmental pollutants and non-communicable diseases

Using the panel autoregressive distributed lag (ARDL) approach, Badulescu et al. (2019) investigated whether health expenditures are affected by economic growth, non-communicable diseases, and environmental pollution. They showed that health expenditure is affected by economic growth in the long run and the short run. They found the negative effect of CO2 emissions on health expenditure in the short run, but this is not the case; in the long run, it has the opposite impact as in the short run. Further, they found that changes in environmental expenditure lead to changes in non-communication diseases' impact on health expenditure. According to Qu et al. (2020), gestational diabetes mellitus (GDM) is linked to poor short-run and long-term health in parents and their children. Using a confounder-adjusted random effect log-binomial regression model, they assessed the association between immaturity during pregnancy and GDM. Greenness appears to be an effective strategy for lowering GDM. Greenness and domestic closeness to green space should be included in collaborative development to improve maternal health outcomes. Liu et al. (2020) used ecological niche models (ENMs) to investigate the impact of climatic variables on dengue incidence and forecast dengue outbreak areas in mainland China. Using GAM, the econometric analysis revealed a dome-shaped relationship between EASM and dengue outbreaks, having the most significant influence in China's southeast. Furthermore, it has been found that average temperature and the existence of dengue fever have a positive non-linear relationship. Nhung et al. (2017) analyzed that children's respiratory illnesses have been linked to ambient air pollution. Random effect models were used to calculate the pollutant-specific excess risk percentage and confidence intervals. The meta-analysis discovered a link between daily levels of ambient air pollution indicators and pneumonia hospitalization in children. However, the quantitative generalizability is limited due to a paucity of research from low- and middle-income nations, as susceptibilities to the adverse effects of environmental pollution may differ in those groups. In our research, the meta-regression revealed a substantial influence of national income level on heterogeneity. Tao et al. (2014) examined the relationship between respiratory hospitalizations and different air pollution. The Poisson regression model has been applied after controlling for the long-time trend for air pollutants. They found a strong correlation between respiratory hospital admissions and air pollutants and observed a more substantial effect for aged $\geq 65$ years and also for females in Lanzhou.

Tian et al. (2019) argued that it is unclear how pneumonia in adults is affected by particulate matter pollution (PM), and national level scientific data is very limited in third world countries. A quasi-Poisson regression model evaluated relationships between particulate matter concentrations and pneumonia hospital admissions for each city. They observed that ambient PM levels are linked to increased pneumonia hospital admissions in Chinese individuals in the near run. These results support the notion that lowering China's particulate matter (PM) concentrations could be an excellent way to cut pneumonia-related hospitalizations. Hales et al. (2002) used logistic regression and the maximum likelihood method to examine the potential influence of population and climatic changes on the worldwide spreading of dengue disease. They found that if no other contributing variables change, climate change would likely expand the extent of an area with weather favorable for dengue fever transmission, putting a substantial proportion of the human population at risk. Marmot and Bell (2019) elaborated that air pollution is becoming alarming for global health day by day. The death rate from air pollution is more than any other type of pollution throughout the world, especially for low-income and middle-income countries compared to developed countries. Low-income groups are more likely to be affected by the pollutants and have a high chance of having such diseases. Area impoverishment is linked to greater exposure to environmental contaminants in the UK, contributing to NCD disparities. Children are affected easily by environmental pollution, such as cognitive development risks from neurotoxicant pollutants like lead, asthma, and respiratory illness risks from transport pollution. Any national strategy to promote health and eliminate non-communicable diseases should include pollution control and poverty alleviation. Horne et al. (2018) examined the short-term elevation of delicate particulate matter (PM2.5) and acute lower respiratory infection, by adopting an observational case-crossover design. They discovered essential links between short-term increases in PM2.5 and increased healthcare usage for acute lower respiratory infection (ALRI) in children and adults in the USA.

The current literature has primarily shown different environmental predictors causing non-communicable diseases, including toxic materials (Folorunso et al. 2021), air pollution (Milanzi et al. 2021), climate change (Vineis et al.

2021), multi-drug resistance (Mahmoud et al. 2021), unhygienic food systems are causing obesity (Cammock et al. 2021), chemical hazards (de Carvalho et al. 2021), dietary issues (Noce et al. 2021), and inadequate healthcare infrastructure (Mwangi et al. 2021). Based on the stated literature, the study proposed the following research hypothesis, i.e.,

*H1: Environmental factors are likely causing more health deterioration leading to susceptible diseases.*

## Environmental pollutants and communicable diseases

The environmental pollutants are considered a carrier to infectious diseases through different mediums. Cai et al. (2015) studied the effect of ambient carbon monoxide (CO) on hospital admission for chronic obstructive pulmonary disease (COPD) in Shanghai, China, by collecting daily data from 2006 to 2008 of COPD admissions in the hospital and CO Concentrations. They found that there is a negative relationship between daily COPD hospitalization and ambient carbon monoxide concentration. Becker and Soukup (1999) studied the impact of nitrogen dioxide ($NO_2$) on respiratory infection in airway epithelial cells and concluded that possible increases in viral clinical indications connected with $NO_2$ are not due to an increase in the weakness of the epithelial cells. However, it may be due to the special effects of $NO_2$ on host defenses that prevent the spread of the virus. Chen et al. (2018) studied the causes of human influenza due to air pollution in Taiwan using weekly data from 2009 to 2015 was collected from 11 cities of Taiwan. Using modified Granger casualty test and concluded that there is a strong relationship between influenza and fine ambient particles.

Yao et al. (2019) studied the ambient air pollution exposures and risk of drug-resistant tuberculosis (DR-TB) using the data of 752 new cases at Jinan (China) from January 1, 2014, to December 31, 2015. They found that exposure to ambient air pollution is associated with an increased risk of DR-TB. Tellier (2006) examined the aerosol spread of influenza A virus and concluded that influenza is spread due to three not mutually exclusive modes, such as aerosols, large droplets, or direct contact with secretions. Brankston et al. (2007) studied influenza as a transmission in human beings by reviewing scholarly literature and found that influenza spread occurs in limited areas rather than long distances. Glencross et al. (2020) studied air pollution and its effects on the immune system and concluded that it weakens many types of immune cells. Therefore, there is a strong relationship between air pollution and the immune system. An increase in air pollution weakens the immune system and increase the number of diseases. Based on the cited literature, the study proposed the hypothesis, i.e.,

*H2: It is the likelihood that infectious diseases can spread from environmental pollutants through the atmosphere.*

## Environmental pollutants and COVID-19 pandemic

The link between environmental air pollution factors and the coronavirus epidemic in California was investigated by Bashir et al. (2020). The findings show that the environmental factors have a strong association with the COVID-19 pandemic in California. The influence of lockout on environmental contaminants and climatic indicators was studied by Shakoor et al. (2020). They observed that under the lockdown scenario caused by this unique pandemic illness, the reduced human activities result in a considerable improvement in air quality by lowering environmental pollutant concentrations. Singh et al. (2021) analyzed the compound risk of environmental pollutants and coronavirus. The aerosol index product was created, and it was discovered that most of the environmental air pollutant concentrations were temporarily lowered during the extended lockdowns. They discovered that these transitory changes have little effect on the seasonality of atmospheric pollutants, implying that observed fluctuations in coronavirus circumstances are most likely connected to environmental air quality. Dettori et al. (2021) studied the impact of air pollutants and the number of deaths by coronavirus and confirmed a link between pollution and the risk of death due to the disease. Espejo et al. (2020) investigated a significant relationship between environmental variables and COVID-19 and positive and negative indirect environmental consequences, with adverse effects being larger and more persistent and made commendations for effectively managing future pandemic concerns. Gautam (2020) studied the impact of coronavirus on environmental air quality in India. Lockdown has been implemented in most of the areas to stop the transmission of the novel coronavirus. Due to this lockdown, significant adverse effects have been noticed in the social and surrounding environment; however, air quality has a positive effect, indicated that 50% of air quality has got better.

The environmental impact of COVID-19 was studied by Wang and Su (2020). The findings show that the corona epidemic contributes significantly to world carbon emission reduction and enhances the environmental air quality in China. They discussed how tight quarantine measures could safeguard the population against COVID-19 while also positively affecting the ecosystem. Bashir et al. (2021) investigated the link between environmental and climatic variables and the COVID-19 epidemic in the top ten most afflicted US states. The results showed that the main factors for the coronavirus disease in the top ten most affected states in the USA are PM2.5, humidity, temperature, empirical estimates, environmental quality index, and rainfall. Lin et al. (2020) investigated whether climatic factors and air quality

impacted COVID-19 transmission. The maximum likelihood "removal" approach, which is based on the chain-binomial model, was used. The findings demonstrate that a greater CO content is a risk factor for enhanced new coronavirus transmissibility. However, a higher temperature and air pressure and adequate ventilation limit the virus's communicability. The impact of climatic factors and air pollution differs by area, necessitating considering these concerns in future disease transmissibility models. Fareed et al. (2020) examined the effect of climate on the fatality of coronavirus disease in Wuhan, China, and found a significant correlation between humidity, death, and air quality index. Corona-related fatalities are inversely correlated with humidity, and poor air quality increases this mortality.

The current literature confined economic and environmental sufferings leading to COVID-19 pandemic across different economic settings include Singh et al. (2021), Bilal et al. (2021), Eroğlu (2021), and Bontempi and Coccia (2021). Based on the cited literature, the study proposed the following research hypothesis, i.e.,

*H3: Environmental pollutants likely cause more health sufferings, leading to exposure to coronavirus disease.*

The study's contribution is to test six different environmental pollutants likely to link it to the COVID-19 pandemic, including NO2 emissions, PM2.5, CO2 emissions, carbon embodied transport GHG emissions, and other GHG emissions. The earlier studies, although extensively, surveyed the different types of air pollutants, mainly country-specific (see Wang & Li 2021; Tian et al. 2021; Accarino et al. 2021). At the same time, the need to explore the negative impact of environmental pollutants across the greater number of cross-section countries is highly desirable for sound policy formulation. Moreover, the study used three main outcome variables and the stated environmental pollutants, including the death-to-case ratio, number of infected cases, and total death reported. While the previous studies use the same country-specific factors (see Huang et al. 2021; Elliott et al. 2021; Liu et al. 2021), its generalizability is limited to the specific country. Finally, the empirical contribution of the study is used generalized linear model (GLM) mainly used for count data, which linked it to the linear predictors, linked function, and probability distribution. The earlier studies used different statistical techniques to evaluate the role of governance to absorb economic and healthcare shocks, including structural equation modelling and hierarchical regression (Awan et al. 2018a, b, c; Wang et al. 2021; Awan et al. 2020a, b, c; Purnama & Susanna 2020), cross-sectional regression (Sasmoko et al. 2021), discussion-based findings (Chan et al. 2020; Javed et al. 2020), moderation and mediation analysis (Du et al. 2021, Awan 2019, Irshad et al. 2020, Awan et al. 2021, Ayandele et al. 2021), and time series forecasting (Chimmula & Zhang 2020, Chaurasia and Pal 2020).

Based on the discussion, the study designed the following research questions to evaluate through comprehensive empirical testing, i.e., to what extent do carbon emissions and associated transport emissions provide a carrier to the COVID-19 cases? It is proclaimed that carbon emissions and their associated transport emissions directly affect the healthcare infrastructure, leading to the destruction of patients' immunity, likely to cause coronavirus disease. Hence, the need to evaluate the indirect effect of carbon emissions on increasing coronavirus cases across countries. The second research question is related to the nitrous oxide emissions and PM2.5 emissions, i.e., is NO2 and PM2.5 emissions causing more health damages linked to coronavirus disease? Both the stated emissions cause negative healthcare externalities, which are likely to be infected with the coronavirus. Finally, does GHG emissions and other GHG emissions cause climate change, leading to an increase in the cost of healthcare damages and the susceptibility ratio to link it to coronavirus disease? These questions need to be tested to get a decisive response, which helps to make sustainable healthcare policies across countries. The following research objectives in connection to research questions are as follows:

i) To examine the impact of different environmental pollutants on case fatality ratio across countries
ii) To investigate the negative impact of carbon emissions and GHG emissions on coronavirus cases
iii) To analyze the impact of N2O, PM2.5, and other GHG emissions on coronavirus associated death cases

These objectives are set to understand the lethal aspect of environmental pollutants exposed to coronavirus cases across countries.

## Data and methodology

The study used the following outcome variables in three different modelling frameworks with the same predictors, i.e., case fatality ratio (CFR), the total number of confirmed cases and total death reported served as outcome variables. On the other hand, PM2.5 air pollution, CO2 emissions, CO2 emissions from transportation, nitrous oxide emissions (NO2), GHG emissions, and other GHG emissions served as predictors of the study. The data of COVID-19 factors are taken from the Worldometer (2021) on 5th May 2021. The Worldometer database examines, indorses, and collects data from many sources and makes global corona live information worldwide. On the other hand, the latest available data on the World Bank (2021) of given environmental pollutants

are used for 119 cross-sectional countries for estimation (see Table 7 in Appendix). Table 1 shows the list of variables and their identifications.

Coronavirus is affecting 220 countries and territories. The data has been collected from two different sources, i.e., Worldometer (2021) and World Bank (2021). Due to data availability, 119 counties have been selected. COVID-19 data is almost available for all the countries. However, pollution-related data was rare; thus, we have chosen six pollutants as explanatory variables to find the link between COVID-19 and environmental pollutants in this study. Various researchers have used different approaches to analyze the impact of air pollution on COVID cases, such as techniques to investigate the concentration of air pollution vis-à-vis disease and death of individuals. Some of the basic approaches have been used, like clinical trials and the dosage response counting method. In this study, the generalized linear model (GLM) method has been used to determine the relationship between the variables.

## Generalized linear model

GLM is a flexible family of models used to handle some problems of the conventional OLS regression model. We can use GLM, if the dependent variable is not normally distributed and the relationship between dependent and independent variables is non-linear. The error term follows a distribution other than standard. The study cannot use GLM if the residual term has an autocorrelation issue.

The GLM has three components, i.e.,

- The linear predictors
- Link function
- Probability distribution

### Linear prediction

Linear prediction is the linear combination of estimated coefficients and regressors.

### Link function

The link function uses to link the linear prediction with the parameter of the distribution.

### Probability distribution

The probability distribution is the link function of the dependent variable.

## Case for GLM

Suppose the dependent variable is continuous and follows a normal distribution and the distribution parameter is a linear function of independent variables. In that case, the GLM model uses the Gaussian family and identity link function. In the CFR case, the dependent variable is continuous with Gaussian distribution and has a non-linear relationship with covariates. Therefore, we have used GLM with the Gaussian family of distribution and log link function.

$$\mathrm{CFR} = \beta_1 + \beta_2 PM2.5_{Airp} + \beta_3 CO2_{EM} + \beta_4 CO2_{TRPT_{EM}} + \beta_5 NO_{EM} + \beta_6 TotalG_EM + \beta_7 \mathrm{Other_EM} + \varepsilon_t \quad (1)$$

For count data, Poisson regression model is the frequently used non-linear regression model. Before estimating the Poisson regression model, it is necessary to check the summary statistic for the count variable. If the mean of the count variable is greater than the variance, then the GLM model will be used with Poisson distribution and log link function. On the other hand, if the variance is greater than the mean, the negative binomial distribution is used along with the log link function. In our case, both daily confirm COVID cases and total death rate, which is count variables, have variances greater than means; therefore, we used GLM with negative binomial distribution and log link function for both of them.

$$\mathrm{T_CASES} = \beta_1 + \beta_2 PM2.5_{Airp} + \beta_3 CO2_{EM} + \beta_4 CO2_{TRPT_{EM}} + \beta_5 NO_{EM} + \beta_6 TotalG_EM + \beta_7 \mathrm{Other_EM} + \varepsilon_t \quad (2)$$

**Table 1** Variables, description, and data sources

| Variables | Symbol | Measurement | Sources |
|---|---|---|---|
| Total cases | T_Cases | (Numbers of total cases) | Worldometer (2021) |
| Total deaths | TD_Cases | (Number of total death cases) | Worldometer (2021) |
| Case fatality ratio | CFR | Deaths to case ratio | Worldometer (2021) |
| CO2 emissions | CO2_EM | kiloton | World Bank (2021) |
| CO2 emissions from transport | CO2_EM_TRPT | % of total fuel combustion | World Bank (2021) |
| Nitrous oxide emissions | NO_EM | Thousand metric tons of CO2 equivalent | World Bank (2021) |
| PM2.5 air pollution | PM2.5_AIRP | Micrograms per cubic meter | World Bank (2021) |
| GHG emissions | TotalG_EM | Kiloton of CO2 equivalent | World Bank (2021) |
| Other greenhouse gas emissions | OtherG_EM | | World Bank (2021) |

$$\begin{aligned} TD_CASES &= \beta_1 + \beta_2 PM2.5_{Airp} + \beta_3 CO2_{EM} + \beta_4 CO2_{TRPT_{EM}} + \beta_5 NO_{EM} \quad (3) \\ &+ \beta_6 TotalG - EM + \beta_7 \text{Other_EM} + \varepsilon_t \end{aligned}$$

## Visual representation

Exploratory data analysis is critical in the empirical study because it provides us with more information just at a glance. It provides information about the structure of data and enables to use of appropriate statistical techniques. In this section, we inspect the visual relationships among variables by using scatter plots.

### Scatter plot of CFR and PM2.5

Figure 1 shows the scatter plot between CFR and PM2.5 for ready reference. The scatter plot shows that CFR and PM25 have a positive relationship, while the problem of heteroskedasticity is due to higher variance between the two stated factors. The scatter plot becomes wide as it moves along the x-axis Fig. 2 3 and 4.

### Scatter plot of CFR and CO2 emission

The scatter plot shows that there is a non-linear relationship between CFR and CO2 emission. Initially, the relationship is positive, and after reaching 200,000, it becomes damaging. The variance is also looking non-constant.

### Scatter plot of CFR and total GHG emissions

The scatter plot shows that there is a positive relationship between CFR and Total gas emission.

### Scatter plot of CFR and NO2 emissions

The scatter plot of CFR and nitrous oxide shows a positive relationship between CFR and nitrous oxide emission. The variance is not constant, and there is a heteroscedasticity problem. Hence, the study cannot use the conventional least-squares regression method.

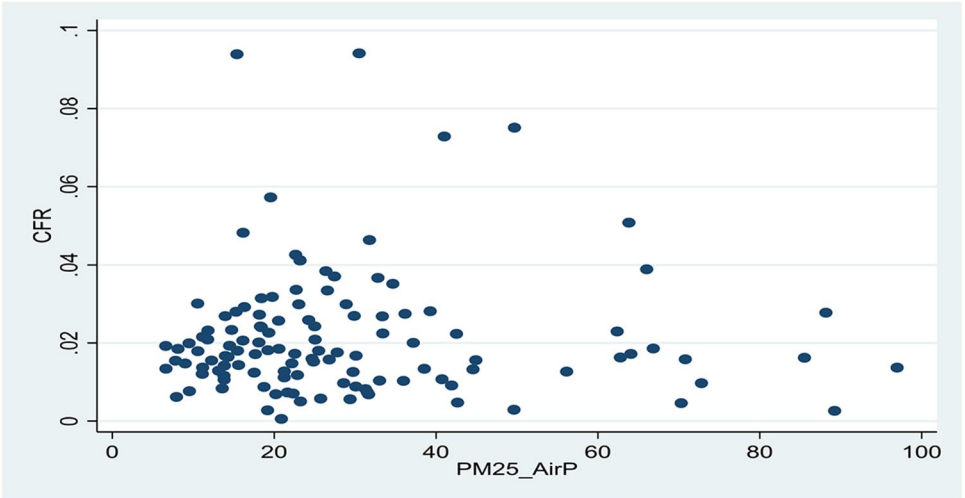


**Fig. 1** Scatter plot between CFR and PM2.5. Source: Author's illustration

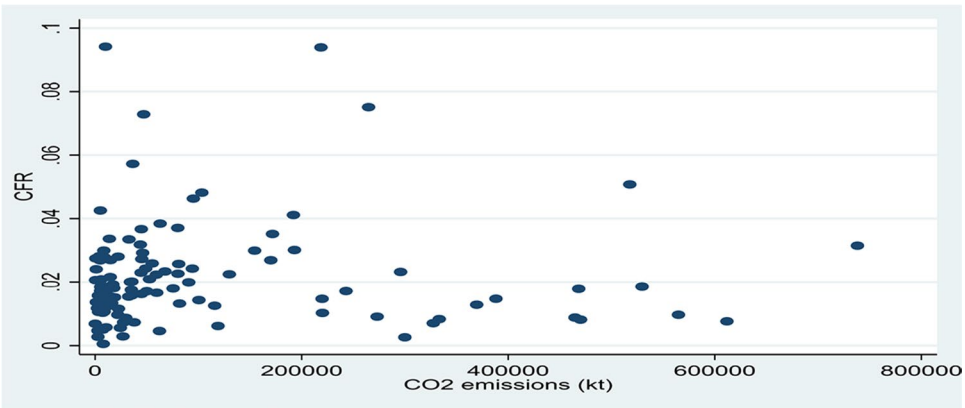


**Fig. 2** Scatter plot between CFR and CO2 emissions. Source: Author's illustration

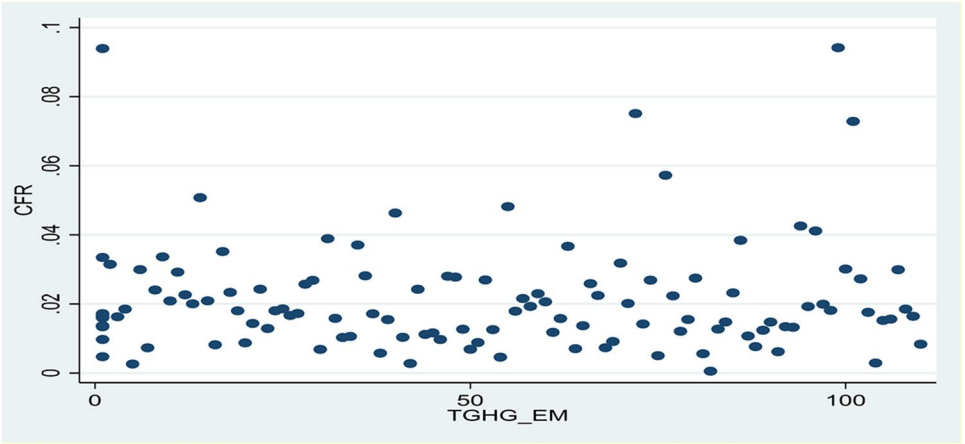


**Fig. 3** Scatter plot between CFR and total GHG emissions. Source: Author's illustration

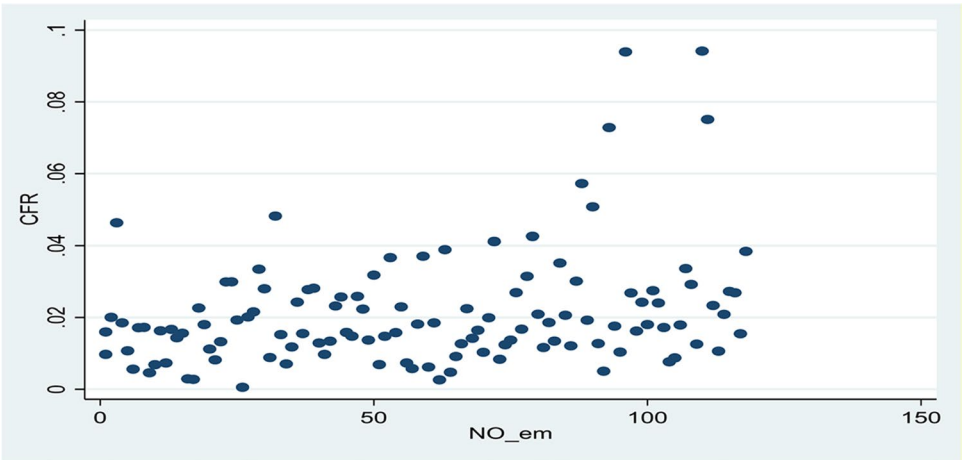


**Fig. 4** Scatter plot between CFR and NO2. Source: Author's illustration

**Table 2** Descriptive statistics

| Variables | Mean | Std. Dev | Max |
|---|---|---|---|
| CFR | 0.021 | 0.016 | 0.094 |
| Total_Cases | 1,462,768.5 | 4,434,332.7 | 34,267,986 |
| Total_Deaths | 31,612.235 | 83,962.354 | 613,575 |
| PM2.5_AirP | 28.91 | 19.101 | 96.963 |
| CO2_Emissions | 540,869.9 | 3,212,264 | 33,683,607 |
| CO2_EM_TRP | 54.176 | 34.21 | 113 |
| NO_EM | 59.008 | 34.482 | 118 |
| OtherG_EM | 53.042 | 31.849 | 110 |
| TotalG_EM | 51.378 | 33.901 | 110 |

## Results and discussion

Table 2 shows the descriptive statistics of the variables. The average value of CFR is 0.21, and its standard deviation is 0.16 with a minimum value of 0.001 and a maximum value of 0.94. The mean value of total confirmed cases is 1462768.5 in numbers. Some countries have a vast number of cases, just like the USA (34,267,986) followed by India (29,273,338), whereas few of the countries have a smaller number of COVID-19 cases, like Syria (24,723) in the selected countries. The USA has the maximum number of deaths cases, i.e., 613,575, followed by India, i.e., 363,097, and the least number of cases is in Singapore, i.e., 34. A report said there had been only six death cases in the last 6 months. Pollution concentration data is measured in μ/m^3. From Table 2, it can see that the average value of PM 2.5 concentration is 28.91, with a maximum of 96.963. CO2 emissions from transport, NO2, other gas emissions, and total gas emission averages are 54.176, 59.008, 53.042, and 51.378.

Table 3 shows the correlation matrix. Most of the variables are positively correlated with the case fertility ratio except other GHG emissions ($r = -0.146$). Most important variable PM2.5 air pollution ($r = 0.350$) is positively correlated with CFR and negatively correlated with COVID-19 confirmed cases ($r = -0.153$) and total deaths ($r = -0.169$). Carbon emission is positively correlated with CFR ($r = 0.068$) and negative with the total cases ($r = -0.036$) and total deaths ($r = -0.042$). Carbon emission from

**Table 3** Correlation matrix

| Variables | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| **(1) CFR** | 1.000 | | | | | | | | |
| **(2) Total_Cases** | 0.007 | 1.000 | | | | | | | |
| **(3) Total_Deaths** | 0.215 | 0.923 | 1.000 | | | | | | |
| **(4) PM25_AirP** | 0.350 | -0.153 | -0.169 | 1.000 | | | | | |
| **(5) CO2emissions** | 0.068 | -0.036 | -0.042 | 0.178 | 1.000 | | | | |
| **(6) CO2_EM_TRPT** | 0.064 | 0.038 | 0.057 | -0.141 | -0.157 | 1.000 | | | |
| **(7) NO_EM** | 0.301 | 0.107 | 0.121 | -0.081 | 0.019 | -0.052 | 1.000 | | |
| **(8) OtherG_EM** | -0.146 | -0.149 | -0.193 | -0.015 | -0.133 | 0.304 | -0.058 | 1.000 | |
| **(9) TotalG_EM** | 0.037 | 0.084 | 0.054 | -0.187 | -0.055 | 0.137 | 0.065 | 0.294 | 1.000 |

transport is positively correlated with CFR ($r=0.064$), total cases ($r=0.038$), and total deaths ($r=0.057$). Nitrous oxide emission is positively correlated with the CFR ($r=0.301$), total COVID cases ($r=0.107$), and total deaths ($r=121$). Other GHG emissions have negatively correlated to the CFR, total cases, and total deaths, whereas and total GHG emissions are positively correlated to the COVID-19 factors.

Table 4 shows the impact of different types of environmental factors on CFR. The results show that NO2 emissions, carbon emissions, and associated transport emissions positively affect the CFR, implying that these pollutants will likely cause an increasing death-to-case ratio across countries. On the other hand, PM2.5 and total GHG emissions show positive impact of CFR; however, this result is statistically insignificant. The results are in line with the earlier studies that confirmed the negative impact of environmental pollutants on increasing CFR in different economic settings, for instance, Rendana (2021), Anser et al. (2020), and Anser et al. (2021b). The results supported the transformative healthcare policies, where coronavirus cases are likely to decline by the sustainable transformation of environmental legislation, including carbon pricing, command-and-control mechanism, incentive-based regulations, and healthcare reforms that help mitigate adverse environmental externalities worldwide.

Table 5 shows the GLM estimates for COVID-19 cases. In this case, the outcome variable is a count variable with a variance greater than the mean. Therefore, the study used the GLM with the distribution family as negative binomial and link function as a natural logarithm. The results show that total GHG emissions and carbon emissions are the critical variables likely causing coronavirus cases. On the other hand, PM2.5 and other GHG emissions would likely cause coronavirus cases, contrary to the findings of Frontera et al. (2020) and Zhu et al. (2020a, b). The number of earlier studies supported the findings that the carbon emissions and GHG emissions causing more health damages, leading to increase the susceptibility rate of coronavirus cases across

**Table 4** GLM estimates for CFR model

| CFR | Coef | St.Err | *t* value | *p* value | [95% Conf | Interval] | Sig |
|---|---|---|---|---|---|---|---|
| PM25_AirP | 0.003 | 0.003 | 1.05 | 0.292 | −0.003 | 0.010 | |
| TotalG_EM | 0.003 | 0.002 | 1.21 | 0.228 | −0.002 | 0.007 | |
| OtherG_EM | −0.005 | 0.002 | −2.16 | 0.031 | −0.009 | 0.000 | ** |
| NO_EM | 0.007 | 0.002 | 3.52 | 0.000 | 0.003 | 0.011 | *** |
| CO2_EM_trpt | 0.004 | 0.002 | 1.88 | 0.060 | 0.000 | 0.008 | * |
| CO2emissions | 0.013 | 0.001 | 0.91 | 0.363 | 0.000 | 0.000 | |
| Constant | −4.559 | 0.298 | −15.30 | 0.000 | −5.142 | −3.975 | *** |
| Mean dependent var | | 0.021 | | SD dependent var | | 0.016 | |
| Number of obs | | 119.000 | | Chi-square | | 20.918 | |
| Prob > chi2 | | 0.002 | | Akaike crit. (AIC) | | −653.107 | |

*Note: *** p < 0.01, ** p < 0.05, * p < 0.01*

**Table 5** GLM estimates for total COVID-19 cases

| Total cases | Coef | St.Err | *t* value | *p* value | [95% Conf | Interval] | Sig |
|---|---|---|---|---|---|---|---|
| PM25_AirP | −0.015 | 0.005 | −3.35 | 0.001 | −0.024 | −0.006 | *** |
| TotalG_EM | 0.0012 | 0.003 | 3.57 | 0.000 | 0.005 | 0.019 | *** |
| OtherG_EM | −0.020 | 0.004 | −5.64 | 0.000 | −0.027 | −0.013 | *** |
| NO_EM | 0.004 | 0.003 | 1.36 | 0.174 | −0.002 | 0.010 | |
| CO2_EM_trpt | −0.001 | 0.003 | −0.28 | 0.778 | −0.007 | 0.005 | |
| CO2emissions | 0.008 | 0.002 | −3.24 | 0.001 | 0.000 | 0.000 | *** |
| Constant | 14.61 | 0.405 | 36.10 | 0.000 | 13.82 | 15.41 | *** |
| Mean dependent var | 1,462,768.521 | | | SD dependent var | | 4,434,332.684 | |
| Number of obs | 119.000 | | | Chi-square | | 88.057 | |
| Prob > chi2 | 0.000 | | | Akaike crit. (AIC) | | 3554.956 | |

*Note: *** p < 0.01*

countries (see Shakil et al. 2020; Kareem et al. (2021),, and Lembo et al. (2021). The results align with the healthcare signalling theory, which argued that environmental policies should be fair enough to control contagious diseases—the positive signalling received by the community members from the healthcare physicians helpful to reduced mental illness.

Table 6 shows the impact of environmental pollutants on the total COVID-19 death cases. The dependent variable is a count variable with a variance higher than the mean; therefore, the study used GLM with negative binomial family and log link function. The results show that total GHG emissions and carbon emissions are the critical factors increasing coronavirus cases. The carbon and GHG emissions are likely to increase more health damages, leading to increased death rates associated with coronavirus disease. On the other hand, PM2.5 and other GHG emissions have a negative and significant effect on COVID-19 death cases. The results are also in contrast with the results of Wu et al. (2020). The earlier studies confirmed the negativity of the environmental pollutants leading to COVID-19 deaths, i.e., Sarfraz et al. (2021), Cicala et al. (2021), and Magazzino et al. (2020). The stated studies argued that ecological factors, including environmental pollutants, provide a channel to exacerbate coronavirus cases, requiring stringent environmental regulations and sound healthcare policies to improve community health Table 7.

The results are generally supported by the "preventive healthcare theory," where community health is the prime responsibility of the governments to make necessary arrangements for reducing adverse healthcare outcomes from any contagious disease (Rad et al. 2021; Anser et al. 2021c, d; Joarder et al. 2020; Bashirian et al. 2020). The Delta variant form of coronavirus cases is more contagious that need to be limited by sustainable healthcare policies (Twohig et al. 2021; Bari et al. 2021). The environmental pollutants are considered a carrier of coronavirus pandemic via adverse community healthcare infrastructure (Sharma et al. 2021; Suthar et al. 2020). The study results validate the nexus between environmental pollutants and coronavirus

**Table 6** GLM estimates for total COVID-19 death cases

| Total deaths | Coef | St.Err | *t* value | *p* value | [95% Conf | Interval] | Sig |
|---|---|---|---|---|---|---|---|
| PM25_AirP | −0.015 | 0.005 | −3.33 | 0.001 | −0.024 | −0.006 | *** |
| TotalG_EM | 0.008 | 0.003 | 2.39 | 0.017 | 0.001 | 0.014 | ** |
| OtherG_EM | −0.023 | 0.004 | −6.15 | 0.000 | −0.031 | −0.016 | *** |
| NO_EM | 0.004 | 0.003 | 1.41 | 0.158 | −002 | 0.011 | |
| CO2_EM_trpt | 0.000 | 0.003 | 0.01 | 0.992 | −0.006 | 0.006 | |
| CO2emissionskt | 0.000 | 0 | −2.99 | 0.003 | 0.000 | 0.000 | *** |
| Constant | 11.09 | 0.413 | 26.84 | 0.000 | 10.3 | 11.9 | *** |
| Mean dependent var | | 31,612.235 | | SD dependent var | | 83,962.354 | |
| Number of obs | | 119.000 | | Chi-square | | 87.522 | |
| Prob > chi2 | | 0.000 | | Akaike crit. (AIC) | | 2640.559 | |

*Note: *** p < 0.01 and ** p < 0.05*

pandemic in a large cross-section of countries, which enlighten the need to reduce pandemics through adopting healthcare and environmental-based policies.

## Conclusions

The environmental pollutants directly affect the healthcare sustainability agenda, increasing the susceptibility to infectious diseases. The COVID-19 pandemic is a highly transmittable disease that spreads through close connections. The study analyzed the impact of six environmental pollutants that are likely to be a carrier of coronavirus disease. The study builds three models with different outcome variables and the same predictors to evaluate the stated objectives of the study in a large, cross-sectional of 119 countries. The study used the GLM model for all three models. For the first model, the outcome variable is CFR, a continuous variable with a mean greater than variance; therefore, the study uses the Gaussian distribution and log link function. The predictor variables are count variables with variance greater than means; therefore, the study used a negative binomial distribution family and log link functions. The estimated result for CFR shows that NO2 emissions, carbon emissions, and their associated transportation emissions are likely to increase the death-to-case ratio. On the other hand, total GHG and carbon emissions are the crucial factors likely to increase coronavirus cases and deaths accordingly. The PM2.5 and other GHG emissions are not likely found to be a carrier of spreading coronavirus cases and deaths in a given period. The results align with the healthcare signalling theory, transformative health care theory, and preventive healthcare theory, which confirmed the adversity of the lethal air pollutants causing greater healthcare damages, leading to sensitive coronavirus cases. The following policies recommended improving air quality indicators and healthcare infrastructure to contain coronavirus cases, i.e.,

i) The command-and-control mechanism should be improved to enhance air quality levels. The incentive-based regulations and carbon pricing are pivotal for cleaning the environment. The increased healthcare costs and ease of environmental regulations sabotaged the sustainability agenda, leading to worse healthcare outcomes to get infectious diseases. The COVID-19 pandemic is likely to spread in the atmosphere through environmental pollutants; hence, it is desirable to make green and clean eco-friendly policies and give the familiar people social distancing to avoid contact with the contagious disease.
ii) The episodes of climate change negatively affect human health, reducing immunity in the patients who are more likely to be exposed to contagious diseases than healthy people. The exacerbated GHG emissions cause high carbon content in the atmosphere, leading to climate change, limited by achieving energy efficiency and green production. The healthcare costs are likely to be decreased because of healthcare reforms, which help to build its infrastructure to avoid any epidemic.
iii) The electrified vehicles build a green transportation mechanism and help attain a clean and green environment, reducing the healthcare burden and achieving economic sustainability. The social distancing and void contact between economic agents are the only remedial measures to avoid the COVID-19 pandemic. Further, an increase in the COVID-19 testing capacity to detect earlier coronavirus disease helps to reduce the spread of the virus, while its vaccines help to avoid contact with the coronavirus disease and improve the immune system by building antibodies that resist it.

Thus, it is critical to comply with the standardized operating procedures for the prevention of coronavirus disease. The people should avoid large public gatherings, maintain social distancing between them, wear a mask, frequently use hand sanitizers and soaps, and get vaccinated earlier to prevent themselves and others in the community from the coronavirus disease. The matter is serious as the Delta variant spreading with the third and fourth wave of the virus is spreading in the world with an enormous speed. Hence the standard global policies should be spread in a way to escape this disease. The implications for future research and opportunities to more work on the stated topic by adding some essential factors to get more insights about the stated relationships, as earlier studies widely used in different schematic fashions, i.e., healthcare supply chain (Finkenstadt & Handfield, 2021), environmental governance indicators (Umar et al., 2021, Awan et al. 2020b), coronavirus tests (Guglielmi, 2021), ecosystem prevention and its restructuring (Bar 2021; Awan, 2020a), technological innovations (Brem et al. 2021), institutional factors (Lee and Jung 2021; Awan et al. 2020c), and sustainable system and policies (Nhamo and Ndlela 2021; Awan 2020b). These factors would be likely to be considered in future studies for more robust policy inferences.

## Appendix

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**Author contribution** SS: conceptualization, methodology, writing—reviewing and editing. KZ: software, formal analysis, methodology. BU: visualization, methodology, formal analysis. AAN: supervision,

**Table 7** List of countries

| |
|---|
| Afghanistan, Albania, Algeria, Angola, Argentina, Armenia, Australia, Austria, Azerbaijan, Bahrain, Bangladesh, Belarus, Belgium, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Bulgaria, Cambodia, Cameroon, Canada, Chile, China, Colombia, Costa Rica, Croatia, Cuba, Cyprus, Czech Republic, Denmark, Dominican Republic, Ecuador, Egypt, Arab Rep., Estonia, Ethiopia, Finland, France, Georgia, Germany, Ghana, Greece, Guatemala, Honduras, Hungary, India, Indonesia, Iran, Iraq, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Kuwait, Kyrgyz Republic, Latvia, Lebanon, Libya, Lithuania, Luxembourg, Madagascar, Malawi, Malaysia, Maldives, Malta, Mexico, Moldova, Mongolia, Montenegro, Morocco, Mozambique, Myanmar, Namibia, Nepal, Netherlands, Nigeria, North Macedonia, Norway, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Portugal, Qatar, Romania, Russian Federation, Rwanda,Saudi Arabia, Senegal, Serbia, Singapore, Slovak Republic, Slovenia, South Africa, Spain, Sri Lanka, Sudan, Sweden, Switzerland, Syrian Arab Republic, Thailand, Tunisia, Turkey, UAE, Uganda, UK, Ukraine, Uruguay, USA, Uzbekistan, Venezuela, RB., Zambia, and Zimbabwe |

resources, software. MH: formal analysis, resources, validation. MMQA: resources, visualization, formal analysis.

**Data availability** The data is freely available at Worldometer (2021) at https://www.worldometers.info/coronavirus/ and World Development Indicators published by World Bank (2021) at https://databank.worldbank.org/source/world-development-indicators

## Declarations

**Ethics approval** Not applicable.

**Consent to participate** All authors are equally participated in the study.

**Consent for publication** All authors allow the publication of the paper.

**Competing interests** The authors declare no competing interests.

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