Effect of COVID-19 on transportation air pollution by moderation and mediation analysis in Queens, New York

Behzad Ghiasi¹ · Tarkan Alisoltani¹ · Farhad Jalali² · Hamzeh Tahsinpour^{3,4}

Received: 26 September 2020 / Accepted: 29 September 2021 / Published online: 20 November 2021
© The Author(s), under exclusive licence to Springer Nature B.V. 2021

Abstract

The outbreak of the COVID-19 virus in 2020 has left many changes in the quality of life and environment, including air quality in different parts of the world. As a result of lockdown conditions, the level of air pollution has been changed considerably due to topographic, geographical, and cultural conditions as well as traffic restrictions. Thus, this study aimed to investigate the effect COVID-19 outbreak on improving air quality as a result of changes in traffic volume and traffic patterns in Queens, New York, using the moderation and mediation analysis model structure. In this model, COVID-19 outbreak periods were defined as a moderating variable, traffic volume (number of daily vehicles) as an independent variable and mediator, and air pollution concentration parameters (NO_x , $\text{PM}_{2.5}$, and O_3) individually as dependent variables. Three-time periods were selected, each representing the duration and severity of traffic restrictions and prohibitions, and these three periods corresponded to 1 February–4 March, 5 March–21 March, and 22 March–15 May. They represented the normal, aware, and lockdown periods, respectively. The result of the study showed that in 2020 compared to the last five consecutive years, $\text{PM}_{2.5}$ and NO_x pollutants decreased by 39.2% and 35.8% as a result of the traffic ban due to the COVID-19, but an increase of 15.1% in O_3 pollutant was observed in the mentioned period. Although traffic restrictions reduced total traffic volume compared to the same period last year, there has been no significant reduction in the air quality index (AQI). The reduction in NO_x concentration leads to more O_3 ground levels, and this caused the AQI not to decrease significantly. Finally, the moderation and mediation model results showed that the COVID-19 almost has no significant effect on the correlation between daily traffic and the concentration of NO_x , $\text{PM}_{2.5}$, and O_3 pollutants as moderator. However, the COVID-19 has a significant correlation with O_3 and $\text{PM}_{2.5}$ concentration, and the traffic volume mediation effect is negligible. Therefore, the statistical analysis and models show that the COVID-19 pandemic is an effective traffic volume and air quality parameter.

Keywords COVID-19 · Moderation analysis · Mediation analysis · Hayes regression · Air quality index

Introduction

The COVID-19 pandemic has highlighted the importance of ambient air quality and the need for cleaner air, leading to a deeper understanding of environmental threats on a

global scale, such as climate change as a result of increased greenhouse gas emissions. According to the World Health Organization (WHO), the number of deaths attributed to air pollution worldwide reached 4.2 million in 2016 (WHO 2018) and estimates that around 7 million people die every year from exposure to fine particles in polluted air (WHO 2018), while the number of casualties from the COVID-19 pandemic to date is about one million people, approximately 14% of deaths from air polluted (WHO 2020). On the other hand, due to the widespread pandemic and the mandatory quarantine in many industrial cities around the world, the emission of air pollutants from human-made resources has changed. The following map shows the air pollution index contributed to ozone and $\text{PM}_{2.5}$ concentrations in the USA over the first positive COVID-19 test until 15 May (the last day of quarantine in some cities) (Fig. 1). It indicates a

✉ Behzad Ghiasi
Behzad.ghiasi@ut.ac.ir

¹ School of Environment, College of Engineering, University of Tehran, Tehran, Iran

² School of Management, Xian Jiaotong University, Xi'an, China

³ Faculty of Environment and Energy, Science and Research Branch, Islamic Azad University, Tehran, Iran

⁴ Ministry of Education, Tehran, Iran

Fig. 1 Comparing AQI in 2019 and 2020 (1 Feb–15 may (EPA 2020a))

noticeable change and improvement in the air quality index that is particularly obvious in eastern areas with higher population densities.

Rising or falling each of the air pollutants concentrations such as NO_x, PM_{2.5}, CO, O₃, and greenhouse gases such as CO₂ have been in accordance with the culture and lifestyle, the level of industrial activity, geographical conditions, and topography of the areas and also traffic pattern as well as a period of quarantine and forced cessation of industries. For example, NO_x pollutants have been declined by an average of 40% in various cities in China and about 20% in different cities in Europe during the COVID-19 lockdown (Bauwens et al. 2020). NO_x emissions are directly related to transportation and fossil fuels (Chen et al. 2020). Therefore, declining traffic volume leads to its lower level in many parts of the world. However, as ground-level ozone contamination is often eliminated by NO_x, an increased amount of it is

reported in some places (Shi and Brasseur 2020). Another study using the WRF-CAM model examined traffic-related parameters and the number of anthropogenic air pollutants within the Yangtze River in China. The results of this study showed a decrease of 29–47% in NO_x and 47%–27% in PM_{2.5} concentration due to the reduction in industrial activities, the reduction in vehicle miles traveled (VMT) in private cars, and the closure of activities of construction sites (Li et al. 2020). Related studies monitoring PM_{2.5} concentrations via remote sensing in the north of China have shown a 35% reduction in emissions since the quarantine period and after industry closure (Shi and Brasseur 2020). Unlike other places, the result of studies in London reflects an increase in PM_{2.5} due to an increase in cooking, burning household gas, and wood during the quarantine period (E.R. Group 2020). In general, air pollutants, PM_{2.5}, CO, and air quality index (AQI) have decreased less than the three pollutants

PM₁₀, NO₂, and SO₂ (Bao and Zhang 2020). A recent study has investigated the relationship between air quality and the COVID-19 pandemic in New York State. The results showed a significant correlation between air quality with the outbreak of the COVID-19 pandemic (Bashir et al. 2020).

The recent studies have only examined the COVID-19 pandemic effect on air quality in the form of trend and mean comparison analysis and have not used statistical models and analyses (such as statistical relation models and two population tests). Also, these researches have not addressed the reason for changes in air pollution concentrations and their relations.

A moderation and mediation analysis is applied to investigate whether the relationship between two variables depends on a third variable's value. In other words, the presence of a moderator variable can strengthen, weaken, or reverse the nature of a relationship between an independent variable and a dependent variable. Also, a mediator parameter's presence causes a more indirect effect of two parameters on each other (Hayes 2017).

Therefore, this study aims to investigate the COVID-19 pandemic effect on air quality and its relations by moderation and mediation analysis. The different aspects of COVID-19 pandemic effects on air quality and pollutants and traffic volume (as the critical parameter in air quality and COVID-19 pandemic restrictions) have been performed to provide the conceptual and statistical effect of COVID-19 on air quality condition. Also, meteorological, AQI, and traffic volume daily trend compared with previous years and seasonal change effect on air pollutant concentration have been studied. Queens District of New York has been selected as the study area due to the highest rate of COVID-19 virus infection.

Material and methods

Case study

Queens is one of the five boroughs in the east of New York City. According to available data, the first COVID-19 test in this area was performed on 3 March, and the first positive case was recorded on 5 March (Department of Health and Mental Hygiene (DOHMH) 2020). Queens is one of the most critical boroughs with the highest incidence of the COVID-19 virus among other boroughs (DOHMH 2020). Due to the rapid spread of the virus in New York City, it was quarantined and monitored between 22 March and 15 May.

According to available statistics, 95.9% of vehicles in Queens use gas, 3.7% use diesel fuel, and only 0.2% are electric vehicles (Department of Motor Vehicles (DMV) 2020).

Based on the Environmental Protection Agency (EPA) in 2019 Dataset, Queens was 292 days in good condition,

69 days average, and 4 days unhealthy for sensitive people in terms of AQI (EPA 2020b). Of these, the quality parameters NO₂, O₃, and PM_{2.5} were 74, 188, and 103 days, respectively, as the significant parameter of the AQI (EPA 2020b).

Dataset

There are three categories of data used in this study consisting of the concentration of air pollution parameters (including PM_{2.5}, NO_x, O₃, and CO), daily average wind and temperature, and the volume of traffic passing through the Queens borough. Air pollution concentration, meteorological, and traffic data were gathered daily from the EPA and Department of Transportation (DOT). This study's air pollution monitoring station was Queens College in Queens, NY (urban, 40.7° N, 74.0° W). Data on the concentration of air pollution parameters were used on a daily basis during the quarantine period (22 March to 15 May) from 2015 to 2019 and on a daily basis during 1 Feb to 15 May. Daily traffic volume data was also used during 1 Feb to 15 May. This time period is selected for investigating parameters before the first COVID-19 test in Queens.

Moderation and mediation analysis

Moderation and mediation analysis has been performed to estimate the effect of the COVID-19 pandemic on the relation between traffic volume and air pollutant parameters. The traffic volume is considered as the independent variable (X), COVID-19 as moderator (M), and air pollutant parameter concentration as dependent variables (Y) in moderation analysis. In the mediation model, the COVID-19 is considered as the independent variable (X), air pollutant parameters concentration as dependent variables (Y), and the traffic volume as mediator.

The conceptual model and statistical diagram are depicted in Figs. 2, 3 and 4.

The moderation and mediation analyses are done based on the Hayes regression procedure (Hayes 2017; Öztürk and Teksöz 2016). The equation of the analysis is given below:

- Moderation analysis:

$$\text{Air pollutant concentration (NO}_x\text{, PM}_{2.5}\text{ and O}_3\text{)} = C + C1 * \text{traffic volume} + C2 * \text{COVID-19} + C3 * (\text{traffic volume} * \text{COVID-19})$$

- Mediation analysis:

$$\begin{aligned} \text{Traffic Volume} &= i1 + a * \text{COVID-19} \\ \text{Air pollutant concentration (NO}_x\text{, PM}_{2.5}\text{ and O}_3\text{)} &= i2 + b * \text{traffic volume} + c' * \text{COVID-19} \end{aligned}$$

Fig. 2 Moderation conceptual model **Fig. 3** Mediation conceptual model **Fig. 4** The statistical model of the moderation analysis

The C , $C1$, $C2$, and $C3$ are the moderation regression coefficients and $i1$, $i2$, a , b , and c' are the mediation regression model coefficients. The moderation and mediation models are done by PROCESS macro in SPSS software.

Results

Investigating the general hypothesis

In order to accurately examine the effect of COVID-19 using the moderation and mediation analysis statistical model,

Table 1 Two-sample mean *t* test analyses of 2020 with 5-year meteorological parameters on 22 March to 15 May period

Year		2015	2016	2017	2018	2019
Temp (deg F)	<i>t</i> value	1.68	1.43	2.10	0.82	2.12
	<i>p</i> value	0.097	0.155	0.038	0.415	0.036
Wind (knots)	<i>t</i> value	−4.38	−3.21	−1.16	−1.39	0.02
	<i>p</i> value	~0	0.002	0.247	0.168	0.988
Relative humidity (%)	<i>t</i> value	2.04	1.15	0.64	−0.73	0.80
	<i>p</i> value	0.044	0.258	0.527	0.468	0.425

Table 2 Mean seasonal comparison of air quality parameters

	NO _x	PM _{2.5}	O ₃	CO
Winter (1 Feb–20 March)	17.1	6.2	0.024	272
Spring (21 March–15 May)	9.1	3.4	0.035	199

three general hypotheses have been investigated to select the best parameters and conceptual structure for this model.

Investigating the meteorological variations

The variations in meteorological parameters are one of the main factors in changing air quality. This issue was examined to determine its effect in 2020 compared to the last 5 years. In this regard, the average daily temperature, wind speed, and relative humidity in the March 22 and May 15 period were investigated by two-sample mean *t* test analyses between 2020 and each year.

Table 1 demonstrates that in the temperature, considering the significance level of 5%, only the 2017 and 2019 average changes compared to 2020 are slightly significant. In the wind, except for 2015 and 2016, which have considerable difference from 2020, the last 3 years are not significantly different from 2020, and there has been little change in this parameter. Relative humidity data also show that, except for 2015, the last 4 years are not significantly different from 2020. Therefore, it can be concluded that meteorological changes in 2020 are not very noticeable and have little impact. The lack of meteorological conditions' strong effect on NO₂ concentration in New York City has also been confirmed in Goldberg et al. (2020) study.

Effect of seasonal change on air pollutant concentration

Meteorological characteristics of each season can affect the air pollution parameter concentration. For this reason, the average concentration of NO_x, PM_{2.5}, O₃, and CO has been calculated in winter (1 Feb–20 March) and spring (21 March–15 May) seasons.

Table 2 shows that the average concentration of all air pollutants in winter is almost 2 times of spring. So the seasonal changes have a significant effect on the concentration of air pollutants. Also, the whole lockdown period is in the spring season, and there are no seasonal changes in this period.

Effect of COVID-19 on air pollutant concentration

Initially, the impact of the COVID-19 outbreak on air pollution was proposed as the general hypothesis. The difference in averages for each of the air pollutant concentrations, i.e., NO_x, PM_{2.5}, O₃, and CO, have been compared annually between 22 March and 15 May over five consecutive years in comparison with the data for similar parameters in 2020. Nitrogen oxides, carbon monoxide, and PM_{2.5} are three primary air pollutant parameters, and the changes in these parameters can mainly be attributed to the changes in traffic volume and level of services (LOS) and traffic restrictions. Ozone pollution is a secondary pollutant, and its changes are related to changes in NO_x emissions (Jhun et al. 2015). According to Table 3, the ratio of NO_x, PM_{2.5}, and CO pollutants are negative in the last 5 years compared to 2020, and the reduction in emissions of these pollutants in 2020 is because of decreasing in traffic congestions. Also, the positive ratio of ozone concentration in the last 5 years compared

Table 3 Mean difference with 2020 on 22 March to 15 May period

Year	Mean difference (%)					
	2015	2016	2017	2018	2019	5-year-avg
NO _x	−52.1	−36.1	−37.8	−38.5	−23.0	−39.2
PM _{2.5}	−46.1	−37.1	−19.4	−44.1	−24.1	−35.8
O ₃	+27.6	+15.9	+19.7	+5.4	+9.6	+15.11
CO	−15.8	−10.0	−8.6	−19.6	−13.2	−13.5

Fig. 5 Daily traffic volume trend comparison in normal, aware, and lockdown periods between 2019 and 2020 years

Fig. 6 AQI 2019 and 2020 trend comparison in normal, aware, and lockdown periods between 2019 and 2020 years

to 2020 is as a result of the reduction in nitrogen oxide pollution as expected.

The effect of COVID-19 on traffic volume and AQI

In the second part of the hypothesis, the effect of COVID-19 on traffic volume and AQI compared to the same time as the previous year was examined. In this study, the changes in traffic volume are considered in three periods. These changes as the normal time periods, aware mode, and complete quarantine for the Queens borough of New York City are illustrated in Fig. 5. For both 2019 and 2020, there are fluctuations in daily traffic due to the weekend and workday traffic patterns. On the other hand, there is a significant decrease in the average volume of traffic during the period of restrictions compared to the normal period in 2020 and the prevalence of COVID-19. Changes in the AQI over the three-time periods of the normal mode, alert mode, and full quarantine as

well as traffic restrictions for 2019 to 2020 were examined and shown in Fig. 6. According to this graph, there is a low decrease in the air quality index in 2020 compared to 2019, which was the highest difference between AQI changes in the warning period.

The effect of COVID-19 on the determinant parameter of AQI

Due to the significant reduction in traffic congestion and no significant decrease in the air quality index, the AQI parameter status in this period in 2019 and 2020 was also examined.

The air quality index for Queens Borough is determined by the quality index of $PM_{2.5}$, NO_2 , and O_3 parameters. In order to compare the contribution of these three pollutants in determining AQI, the number of days that these parameters were the main factors of AQI in each of the periods 1 February–4 March, 5 March–21 March, and 22 March–15

Table 4 Number of main pollutants in AQI at three period days

Status	2019			2020		
	PM _{2.5}	O ₃	NO ₂	PM _{2.5}	O ₃	NO ₂
1 February–4 March	16	10	7	23	10	0
5 March–21 March	5	7	5	4	13	0
22 March–15 May	8	30	17	5	50	0
Total	29	49	29	32	73	0

Table 5 Results of the O₃ moderation analysis

		Coeff	SE	<i>t</i>	<i>p</i>
Constant	<i>C</i>	0.0409	0.0040	10.12	0.00
Traffic volume (X)	<i>C1</i>	0.0000	0.0000	0.15	0.88
COVID-19 (W)	<i>C2</i>	−0.0059	0.0034	−1.73	0.09
Traffic volume* COVID-19 (XW)	<i>C3</i>	0.0	0.0000	−0.24	0.81

Table 6 Results of the NO_x moderation analysis

		Coeff	SE	<i>t</i>	<i>p</i>
Constant	<i>C</i>	2.91	7.53	0.39	0.70
Traffic volume (X)	<i>C1</i>	0.0002	0.0004	0.54	0.59
COVID-19 (W)	<i>C2</i>	5.95	6.3	0.94	0.35
Traffic volume* COVID-19 (XW)	<i>C3</i>	0.0	0.0002	−0.20	0.84

May in 2019 and 2020 is shown in Table 4. According to Table 4, the significant pollutant in most time intervals in 2019 and 2020 was O₃ pollution. However, despite the fact that in 29 days of the above period in 2019, NO₂ pollution was an indicator in determining AQI. In 2020, this pollutant was not effective due to reduced concentration and emission due to reduced traffic volume and traffic flow stability. Usually, the increase in unhealthy days with ozone pollutants has been linked to a decrease in NO₂ pollutants. Also, there are virtually no significant changes in 2020 compared to 2019 in terms of PM_{2.5} parameter. Due to zero polluted days with NO₂ parameter in 2020, almost all of these days have become polluted with O₃ because of the inverse relationship between O₃ and NO₂. Therefore, there are no significant changes in the AQI.

Moderation and mediation analysis

According to the proposed hypotheses in the moderator and mediator analytical model, the effect of the COVID-19 on the traffic volume of Queens Borough and the concentration of NO_x, PM_{2.5}, and O₃ pollutant parameters were examined. Moderation and mediation analysis was performed using SPSS software and the Hayes regression plugin. The COVID-19 which has three modes as normal, aware, and lockdown (In three time periods: 1 February–4 March, 5 March–21 March, and 22 March–15 May) was defined as 3, 2, and 1 respectively and selected as moderator. Traffic volume parameter (number of vehicles per day) was defined as the independent variable in moderation model and mediator parameter, and air pollution parameter concentrations (NO_x, PM_{2.5}, and O₃) were defined separately as dependent variables. The results of the moderation analysis were obtained in Tables 5, 6 and 7.

Table 7 Results of the PM_{2.5} moderation analysis

		Coeff	SE	<i>t</i>	<i>p</i>
Constant	<i>C</i>	1.51	1.8	0.84	0.40
Traffic volume (X)	<i>C1</i>	−0.0001	0.0001	−0.68	0.50
COVID-19 (W)	<i>C2</i>	2.36	1.51	1.57	0.12
Traffic volume* COVID-19 (XW)	<i>C3</i>	0.0	0.0	0.17	0.87

Tables 5, 6 and 7 present the results from the Hayes regression analysis examining the moderation impact of COVID-19 on the relationship between traffic volume and O₃, NO_x and PM_{2.5} concentration, respectively.

In the statistical moderation model, the critical parameter is the estimate of *C3* coefficient that reveals the moderation impact of the COVID-19 pandemic. The regression coefficient for *C3* was zero in all three air pollutant parameters. Thus, the COVID-19 has no meaningful linear effect on the traffic volume and O₃, NO_x, and PM_{2.5} concentration relation as a moderator. This means that the relationship between traffic volume and O₃, NO_x, and PM_{2.5} concentration remains the same in the normal situation, starting of the pandemic as well as lockdown period. According to *t* and *p* values, the COVID-19 pandemic is the essential linear parameter in O₃, NO_x, and PM_{2.5} regression models. On the other hand, the COVID-19 pandemic has a significant impact on traffic volume and O₃, NO_x, and PM_{2.5} concentrations separately but does not affect their relationship.

The results of mediation analysis are demonstrated in Tables 8, 9 and 10.

The results of these tables show that according to the coefficient “*a*,” there is a significant correlation between the COVID-19 pandemic and traffic volume. The coefficient

Table 8 Results of the O₃ mediation analysis

		Traffic volume			O ₃ concentration		
		Regression coefficient	SE	<i>p</i>	Regression coefficient	SE	<i>p</i>
Constant	<i>i1</i>	− 5290	1363	< 0.001	<i>i2</i>	0.042	1.5E− 3
COVID-19	<i>a</i>	16,820	681	< 0.001	<i>c'</i>	− 6.5E− 3	1.9E− 3
Traffic volume	−	−	−	−	<i>b</i>	− 9.81E− 9	~ 0.0
	<i>R</i> ²	0.86			<i>R</i> ²	0.50	0.924

Table 9 Results of the NO_x mediation analysis

		Traffic volume			NO _x concentration		
		Regression coefficient	SE	<i>p</i>	Regression coefficient	SE	<i>p</i>
Constant	<i>i1</i>	− 5290	1363	< 0.001	<i>i2</i>	4.320	2.756
COVID-19	<i>a</i>	16,820	681	< 0.001	<i>c'</i>	4.888	3.458
Traffic volume	−	−	−	−	<i>b</i>	1.3E− 4	1.9E− 4
	<i>R</i> ²	0.86				0.25	0.489

Table 10 Results of the PM_{2.5} mediation analysis

		Traffic volume			PM _{2.5} concentration		
		Regression coefficient	SE	<i>p</i>	Regression coefficient	SE	<i>p</i>
Constant	<i>i1</i>	− 5290	1363	< 0.001	<i>i2</i>	1.238	0.651
COVID-19	<i>a</i>	16,820	681	< 0.001	<i>c'</i>	2.569	0.827
Traffic volume	−	−	−	−	<i>b</i>	− 4.7E− 5	4.6E− 5
	<i>R</i> ²	0.86				0.26	0.306

Table 11 The direct and indirect effect of traffic volume on O₃, NO_x, and PM_{2.5} parameters

	O ₃		NO _x		PM _{2.5}	
	Coefficient	<i>p</i>	Coefficient	<i>p</i>	Coefficient	<i>p</i>
Direct effect (<i>c'</i>)	− 6.5E− 3	0.001	4.888	0.161	2.569	0.002
Indirect effect (<i>a*b</i>)	1.65E− 4	0.159	2.190	0.247	− 7.91E− 1	0.154

“*c'*” results illustrate a significant correlation between the COVID-19 pandemic and O₃ and PM_{2.5} concentration, but this relationship is not significant in the NO_x parameter. Coefficient “*b*” indicates the direct effect of traffic volume on the air pollutant concentration, showing that traffic volume almost has no significant relationship with O₃, NO_x, and PM_{2.5} parameters. The direct and indirect effect of traffic volume on air pollutant parameter concentration has been shown in Table 11.

The results of Table 11 demonstrate that the direct effect between COVID-19 and O₃ and PM_{2.5} concentration is significant, and the indirect impact of COVID-19 is much lower than direct effect in O₃ and PM_{2.5} concentration. In other words, the COVID-19 pandemic has a substantial relationship with the concentration of O₃ and PM_{2.5} parameters, and the traffic volume has a low effect as the mediator (Hayes 2017; Öztürk and

Teksöz, 2016). Thus, the COVID-19 pandemic has a direct and significant effect on O₃ and PM_{2.5} concentration without traffic volume effect because their *p* value is lower than 0.05.

Conclusion

Numerous researches have studied the environmental effect of COVID-19 pandemic lockdown in different countries. One of the most critical environmental issues that have been affected by COVID-19 is air pollution. The impact of COVID-19 lockdown on air quality in some parts of the world has been investigated using different methods, such as simple statistical analysis of data, satellite images, and historical maps of contaminated areas. In this study, conceptual moderation analysis models have been made by investigating the dataset

and three general hypotheses. These hypotheses have generally investigated the concentration of pollutant parameters and meteorological dataset since 5 years ago, the trend of changes in the number of vehicles per day, and air quality index in 2020 compared with 2019, as well as the number of days that each pollutant parameter is the main contributor in AQI. The results showed the direct impact of COVID-19 pandemic lockdown on traffic congestion and pollutant concentrations, while due to the inverse relationship between NO_x and O_3 parameters, no significant change was observed in the 2020 AQI compared to 2019 and no significant change in wind and temperature in 2020 comparing to 5 years ago. As a result, in the proposed conceptual model of moderation and mediation analysis, the impact of COVID-19 as the moderator and traffic volume as a mediator on the number of vehicles and its relation to the concentration of pollutants (NO_x , $\text{PM}_{2.5}$, and O_3) in three time periods (1 February–4 March, 5 March–21 March, and 22 March–15 May) based on statistical analysis was examined. Hayes regression results for the three pollutants NO_x , $\text{PM}_{2.5}$, and O_3 were almost identical, showing almost no effect of the COVID-19 pandemic on traffic volume and O_3 , NO_x , and $\text{PM}_{2.5}$ concentration relations as moderator. Also, the COVID-19 pandemic has a significant correlation with traffic volume and $\text{PM}_{2.5}$ and O_3 parameters, and there is no significant mediator effect of traffic volume on COVID-19 and O_3 , NO_x , and $\text{PM}_{2.5}$ concentration relation. Therefore, the statistical analysis and models show that the COVID-19 pandemic is an effective parameter in traffic volume and air quality.

References

- Bao R, Zhang A (2020) Does lockdown reduce air pollution? Evidence from 44 cities in northern China. *Sci Total Environ* 731:139052. <https://doi.org/10.1016/j.scitotenv.2020.139052>
- Bashir MF, Ma B, Komal B, Bashir MA, Tan D, Bashir, M (2020) Correlation between climate indicators and COVID-19 pandemic in New York, USA. *Sci Total Environ* 728:138835
- Bauwens M, Compernelle S, Stavrou T, Müller J F, Van Gent J, Eskes H, ... Zehner C (2020) Impact of coronavirus outbreak on NO_2 pollution assessed using TROPOMI and OMI observations. *Geophys Res Lett* 47(11):e2020GL087978. <https://doi.org/10.1029/2020GL087978>
- Chen K, Wang M, Huang C, Kinney PL, Anastas PT (2020) Air pollution reduction and mortality benefit during the COVID-19 outbreak in China. *Lanc Planet Health* 4(6):e210–e212. [https://doi.org/10.1016/S2542-5196\(20\)30107-8](https://doi.org/10.1016/S2542-5196(20)30107-8)
- Department of Health and Mental Hygiene (2020) COVID-19 daily data, Available at: <https://www.data.gov>
- Department of Motor Vehicles (2020) COVID-19 daily data, Available at: <https://www.data.gov>
- Environmental Protection Agency (2020a) Air quality maps—Archive, Available at: <https://cfpub.epa.gov/airnow>
- Environmental Protection Agency (2020b) Air quality dataset, Available at: <https://www.epa.gov>
- Environmental Research Group, The Effect of Covid-19 Lockdown Measures on Air Quality in London in 2020. Report (King's College London, 2020), https://www.assets.ctfassets.net/9qe818412nz4/2TM8WJU2w1cHeedjkVIRQ/2e5a91667d676b3c63f1e748156b68c4/ERG_response_to_Defra.pdf
- Goldberg DL, Anenberg SC, Griffin D, McLinden CA, Lu Z, Streets DG (2020) Disentangling the impact of the COVID-19 lockdowns on urban NO_2 from natural variability. *Geophys Res Lett* 47(17):e2020GL089269. <https://doi.org/10.1029/2020GL089269>
- Hayes AF (2017) Introduction to mediation, moderation, and conditional process analysis: a regression-based approach. Guilford publications
- Jhun I, Coull BA, Zanobetti A, Koutrakis P (2015) The impact of nitrogen oxides concentration decreases on ozone trends in the USA. *Air Qual Atmos Health* 8(3):283–292
- Li L, Li Q, Huang L, Wang Q, Zhu A, Xu J, ..., Azari M (2020) Air quality changes during the COVID-19 lockdown over the Yangtze River Delta Region: an insight into the impact of human activity pattern changes on air pollution variation. *Sci Total Environ* 732:139282. <https://doi.org/10.1016/j.scitotenv.2020.139282>
- Öztürk N, Teksoz G (2016) The impact of affective constraints on shaping environmental literacy: model testing using mediator and moderator variables. *Int Electron J Environ Educ* 6(2):54–75
- Shi X, Brasseur GP (2020) The response in air quality to the reduction of Chinese economic activities during the COVID-19 outbreak. *Geophys Res Lett* 47(11):e2020GL088070. <https://doi.org/10.1029/2020GL088070>
- World Health Organization (2018) Mortality and burden of disease from ambient air pollution: situation and trends. https://www.who.int/airpollution/data/AAP_BoD_results_May2018_final.pdf
- World Health Organization (2020) WHO Coronavirus Disease (COVID-19) Dashboard, Available at: <https://covid19.who.int/>

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.