Nature Environment and Pollution Technology
An International Quarterly Scientific Journal
p-ISSN: 0972-6268
(Print copies up to 2016)
e-ISSN: 2395-3454
Vol. 22 | No. 2 | pp. 671-680 | 2023
Original Research Paper
https://doi.org/10.46488/NEPT.2023.v22i02.010
Open Access Journal

An Inappropriate Rise in NO_2 During the COVID-19 Pandemic in the Urban Area of Chhattisgarh, India

A. Zeb*, I. U. Khan*, S. Tripathi, M. R. Sahu*** and A. Kumar***†**
*Department of Mathematics, COMSATS University, Islamabad, Abbottabad Campus, Pakistan
**Department of Science and Technology, Government of India, India
***Department of Biotechnology, Government V.Y.T. P.G. Autonomous College, Durg, India
†Corresponding author: A. Kumar; anilkumardurg1996@gmail.com

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 14-08-2022
Revised: 06-10-2022
Accepted: 19-10-2022

Key Words:
Air quality index
COVID-19
Lockdown
Urban area

ABSTRACT

The COVID-19 first case was reported in India on January 30, 2020, and in Chhattisgarh on March 19, 2020, and since then a sharp surge has been noticed. The government of India imposed a nationwide lockdown on March 25, 2020, a complete suspension of human activities, viz., industry, construction, transport, academic institutions, etc., which resulted in an improvement in air quality (a decrease in $PM_{2.5}$ and PM_{10}, alteration in NO_2 and an increase in O_3). But the rate of cases of COVID-19 has increased sharply, and eventually, under economic pressure, the lockdown was withdrawn on June 1, 2020, which further accelerated the exponential growth of COVID-19 cases. We noticed that in the Chhattisgarh State of India, the alteration in the air quality index during the lockdown period is continuing even after the restoration of anthropogenic activities. Among $PM_{2.5}$, PM_{10}, NO_2, and O_3, the behavior of NO_2 was found to be different than others; it was found to increase during the lockdown period but further decreased with the resumption of anthropogenic activities. We conclude that the air quality index has an insignificant impact on COVID-19 infection.

INTRODUCTION

The world has been facing a serious problem with the COVID-19 pandemic since December 2019, and therefore, the problem has threatened human life, not only by its pathogenic impact (Bai et al. 2020, Sohrab et al. 2020), but also by its economic impact (Bai et al. 2020) to a greater extent. Initially, it was reported in Wuhan, a city in the Republic of China, and gradually spread to more than 200 countries through human-to-human transmission. Only in July 2020 did the scientific community recognize that it spreads not only through human-to-human contact but also through the air; the WHO later validated the concept. On July 23, the total number of confirmed COVID-19 cases in India reached 1,238,798 with a death toll of 29,865.

There is no specific treatment known to the scientific community for SARS-CoV-2 infection; therefore, the world was compelled to go under a state of lockdown to prevent human-to-human transmission of the virus, which resulted in the suspension of human movement, vehicular movement, and industrial activities to a greater extent. Environmentalists have predicted a large reduction in greenhouse gas (GHG) emissions to the environment; some of them have predicted the biggest reduction of greenhouse gases after World War II (Global Carbon Project 2020). In several parts of the world, the total lockdown led to a significant reduction in nitrogen dioxide (NO_2), particulate matter, and GHG from the environment, especially in France, Germany, Italy, and Spain (European Space Agency 2020).

More than 91% of the world's population lives in polluted air, which has contributed to adverse impacts on human health, and it is supposed that nearly 8% of total deaths in the world, especially in Asia, Africa, and Europe, are caused by air pollution (World Health Organization, 2016). According to several authors, air pollution causes death through cardiovascular failure regardless of age (Peng et al. 2009, Wong et al. 1999) and respiratory failure (Katanoda et al. 2011, Nakao et al. 2018, Spix et al. 1998). Zhu et al. (2020) have predicted a positive correlation between higher concentrations of air pollution and a higher risk of SARS-CoV-2 infection.

In several studies, it's been predicted that anthropogenic activities are the main contributor to air pollution, viz., industrial emissions, mining, vehicular emissions, and real

ORCID details of the authors:

A. Kumar: https://orcid.org/0000-0002-1667-4419

estate activities. In India, a total lockdown was imposed on March 25 to inhibit SARS-CoV-2 transmission, which resulted in the suspension of all anthropogenic activities and probably the emission of air pollutants. Although the COVID-19 spread wasn't controlled even after the lockdown, India witnessed the world's largest migration of laborers in the meantime. The COVID-19 infection surge was not reduced after 70 days of lockdown, but it caused severe economic strain, forcing the Government of India to lift the lockdown on June 1, 2020. In 2013, Tamrius et al. (2013) reported on the transmission and survival of viruses (influenza and SARS viruses) under the influence of environmental factors. Rahman and MacNee (2000) have concluded that air pollutants create toxicity in the respiratory and cardiovascular systems of people and that some pollutants, viz., ozone, oxides of nitrogen, and suspended particulates, act as potent oxidants by acting directly on lipid or protein or indirectly on intracellular oxidant pathways. Glencross (2020) established a link between environmental pollutants and the immune system, which explains the acceleration of respiratory disorders in the presence of novel coronavirus infection. They have also concluded that the air pollutant can affect different immune cell types such as particle-clearing macrophages, inflammatory neutrophils, and dendritic cells that create adaptive immune responses. Thus, it becomes essential to evaluate the air quality index, particularly particulate matter, ozone, and oxides of nitrogen, to understand the pathogenic impact of the novel coronavirus. In the Indian state of Chhattisgarh, there is Asia's largest steel plant, as well as many thermal power plants and coal mines, which continuously pour particulate matter and oxides of nitrogen, and accelerate O_3 in the atmosphere. In this COVID-19 pandemic, the evolution of the air quality index to understand the pathogenicity of novel coronaviruses is essential and may be helpful for future planning.

In the present paper, we have tried to address the air quality index of the state of Chhattisgarh considering major cities with industrial activities, viz. Bhilai, Durg, Raipur, Bilaspur, Korba, and Raigarh. The air quality index was comparatively examined during the pre-lockdown period, post-lockdown period, and a brief unlocking period. We have also examined the correlation between air quality and a surge of COVID-19 infection in the state of Chhattisgarh, India, to understand the behavior of the air quality index and the infectious nature of SARS-CoV-2.

MATERIALS AND METHODS

Research Settings

The present study has been carried out in cities with major business and industrial activities in the state of Chhattisgarh, India, and for this study, we selected Bhilai (21.1938°N, 81.3509°E), Durg (21.1623°N, 81.4279°E), Raipur

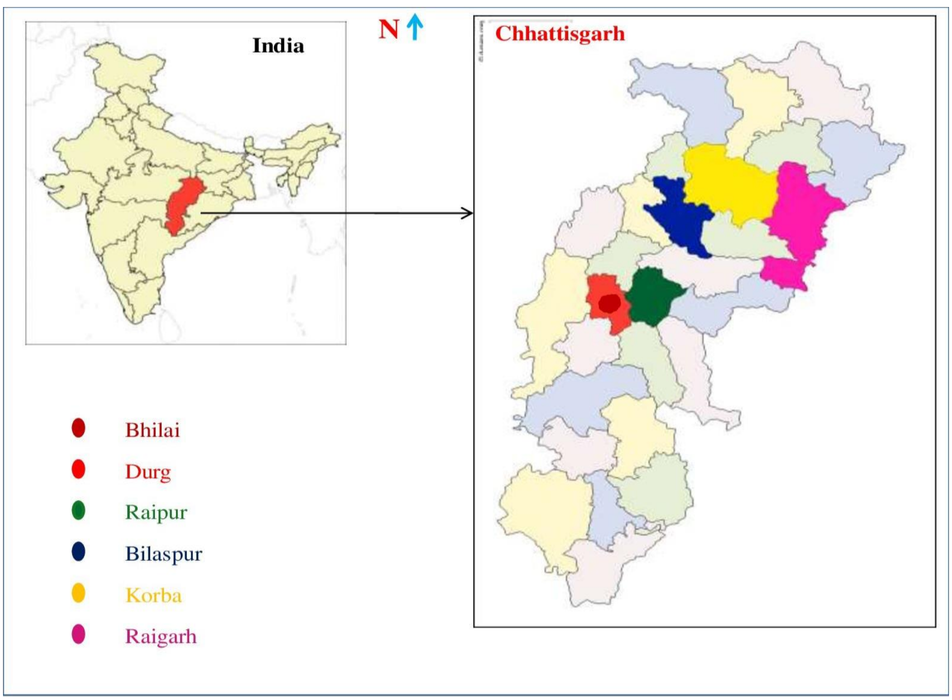

Fig. 1: Selected major cities of Chhattisgarh state of India for the study of Air Quality Index, during COVID-19 pandemic.

(21.2514°N, 81.6296°E), Bilaspur (22.0797°N, 82.1409°E), Korba (22.3595°N, 82.7501°E) and Raigarh (22.0078°N, 83.3362°E) (Fig. 1).

Measures of Variables

For the air quality index study, we considered $PM_{2.5}$, PM_{10}, NO_2, and O_3 right from January 1, 2020, to July 15, 2020, with data collected at an interval of every 15 days. The source of the data was Copernicus Atmospheric Monitoring Service South America Model: GMAI/CPTEC/INDP, through Plume Labs. The cases of COVID-19 infection for the retrospective data were collected from the government site. To perform a comparative study, the data were segmented into three blocks: first, the pre-lockdown period; second, the lockdown period; and third, the unlocking period.

Data Analysis

For each parameter of air quality ($PM_{2.5}$, PM_{10}, NO_2, O_3), a one-way analysis of variance was calculated to test the level of significance. The correlation coefficient of Karl Pearson was calculated to determine the relationship between the air quality index and an increase in COVID-19 infections.

RESULTS AND DISCUSSION

The average air quality index of six cities in Chhattisgarh (Bhilai, Durg, Raipur, Bilaspur, Korba, and Raigarh) was measured for the pre-lockdown period (Jan 1, 2020, to March 15, 2020), the lockdown period (April 1, 2020, to July 1, 2020), and the post-lockdown period (June 15 to July 15, 2020). It was found that during the pre-lockdown period, the average AQI was reported as maximum (111.67 ± 24.83 $\mu g.m^{-3}$) in Bhilai followed by Durg (107.67 ± 20.68 $\mu g.m^{-3}$), Raipur (107.83 ± 20.16 $\mu g.m^{-3}$), Korba (86.33 ± 17.35 $\mu g.m^{-3}$), Bilaspur (86.17 ± 24.14 $\mu g.m^{-3}$) and minimum in Raigarh (85.17 ± 22.81 $\mu g.m^{-3}$). During the lockdown period, the maximum AQI was again reported in Bhilai (97.17 ± 52.17 $\mu g.m^{-3}$), followed by Raigarh (73.6 ± 14.53 $\mu g.m^{-3}$), Raipur (71.2 ± 27.98 $\mu g.m^{-3}$), Korba (71.00 ± 7.61 $\mu g.m^{-3}$), Bilaspur (67.25 ± 7.08 $\mu g.m^{-3}$) and the minimum in Durg (47.25 ± 20.78 $\mu g.m^{-3}$). The AQI was found further improved even after revocation of the lockdown under economic pressure and during this period it was recorded maximum in Bilaspur (40.00 ± 12.12 $\mu g.m^{-3}$) followed by Korba (39.00 ± 12.53 $\mu g.m^{-3}$), Raipur (38.00 ± 3.46 $\mu g.m^{-3}$), Raigarh (33.00 ± 11.53 $\mu g.m^{-3}$) and minimum in Durg (31.67 ± 4.93 $\mu g.m^{-3}$) (Fig. 2).

In our study, we found that the AQI of all the cities improved during the lockdown period and even during the restoration of all anthropogenic activities (post-lockdown period). In Bhilai, where the maximum AQI was reported, it has further improved by 14.5 $\mu g.m^{-3}$ during the lockdown period and 61.17 $\mu g.m^{-3}$ during the post-lockdown period. In Durg, it was improved by 60.47 $\mu g.m^{-3}$ during the lockdown period and by 15.53 $\mu g.m^{-3}$ during the post-lockdown period. In Raipur, it improved by 36.63 $\mu g.m^{-3}$ during the lockdown period and 33.2 $\mu g.m^{-3}$ during the post-lockdown period. In Bilaspur, it was improved by 18.97 $\mu g.m^{-3}$ during the lockdown period and by 27.2 $\mu g.m^{-3}$ during the post-lockdown period. In Korba, it was improved by 15.33 $\mu g.m^{-3}$ during the lockdown period and by 32.00 $\mu g.m^{-3}$ during the post-lockdown period, and similarly, it was found to improve during the lockdown period by 11.57 $\mu g.m^{-3}$ and the post-lockdown period by 40.6 $\mu g.m^{-3}$ in Raigarh. The maximum improvement in the air quality index was reported in Durg (60.47 $\mu g.m^{-3}$) during the lockdown period and in

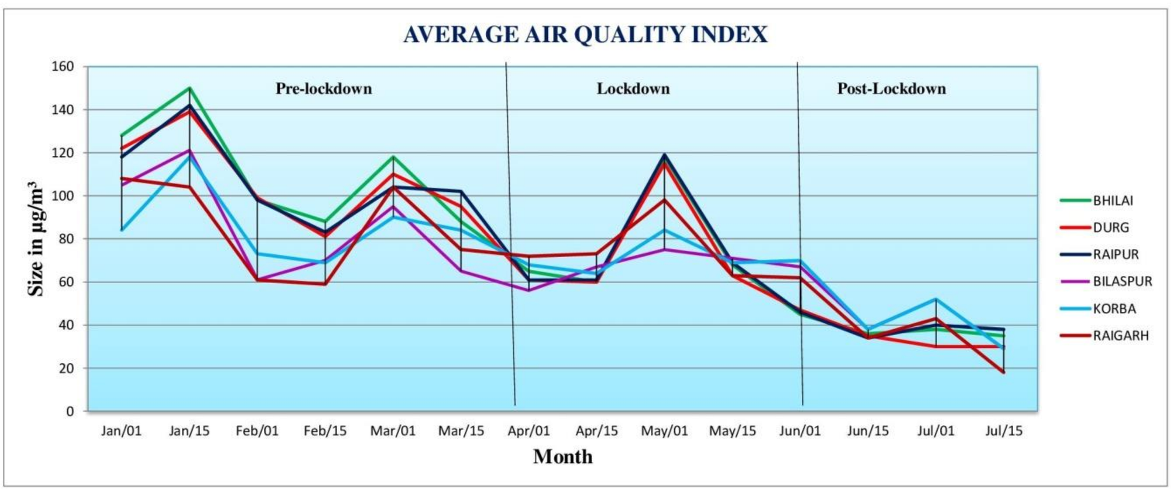

Fig. 2: Average Air Quality Index of the major cities of Chhattisgarh, India.

Table 1: Average Air Quality Index of various cities of Chhattisgarh, India (in μg.m^{-3} from January 1, 2020 to July 15, 2020).

Cities	Pre-lockdown Period						Pre-lockdown Period					Post-lockdown Period		
	Jan 01	Jan 15	Feb 01	Feb 15	March 01	March 15	April 01	April 15	May 01	May 15	June 01	June 15	July 01	July 15
Bhilai	128	150	98	88	118	88	65	160	118	68	45	36	39	33
Durg	122	139	97	81	110	95	61	60	65	31	19	35	34	26
Raipur	118	142	98	83	104	102	61	61	119	69	46	34	40	40
Bilaspur	105	121	61	70	95	65	56	67	75	71	67	38	53	29
Korba	84	118	73	69	90	84	68	64	84	69	70	38	52	27
Raigarh	108	104	61	59	104	75	72	73	98	63	62	34	44	21

Bhilai (61.17 μg.m^{-3}) during the revocation of the lockdown. Out of six cities considered for the study, we found better improvement in AQI in four cities, i.e., Bhilai (61.17 μg.m^{-3}), Bilaspur (27.2 μg.m^{-3}), Korba (32.00 μg.m^{-3}), and Raigarh (40.6 μg.m^{-3}) when the lockdown was revoked and anthropogenic activities were restored. Our findings establish that the AQI improvement during lockdown was not helpful; it occurred in the natural course of the phenomenon (Table 1).

Out of six cities, $PM_{2.5}$ was reported maximum in Raipur (60.5 ± 17.63 μg.m^{-3}) and minimum in Korba (41.83 ± 13.19 μg.m^{-3}) during the pre-lockdown period, and during the lockdown period, it was recorded maximum in Raipur (36.8 ± 18.63 μg.m^{-3}) and minimum in Bilaspur (32.8 ± 3.49 μg.m^{-3}) but during the post-lockdown period, it was reported maximum in Bhilai (24.6 ± 3.60 μg.m^{-3}) and minimum in Durg (9.66±4.61 μg.m^{-3}). During the lockdown and post-lockdown periods, we found a significant improvement in PM 2.5 in all six cities. In Bhilai, an improvement in $PM_{2.5}$ was reported by 22.4 μg.m^{-3} and 11.00 μg.m^{-3} (F = P 0.5 < 7.4945); in Durg by 24.33 μg.m^{-3} and 25.34 μg.m^{-3} (F = P 0.5 < 10.06); in Raipur by 23.7 μg.m^{-3} and 25.14 μg.m^{-3} (F = P 0.5 < 9.1819); in Bilaspur by 13.36 μg.m^{-3} and 15.14 μg.m^{-3} (F = P 0.5 < 7.2875); in Korba by 6.63 μg.m^{-3} and 17.87 μg.m^{-3} (F = P 0.5 < 6.1733) and in Raigarh by 7.76 μg.m^{-3} and 20.4 μg.m^{-3} (F = P 0.5 < 7.8896) during the lockdown and post-lockdown period respectively.

PM_{10} was reported maximum in Raipur (89.5 ± 25.05 μg.m^{-3}) and minimum in Raigarh (70.16 ± 16.59 μg.m^{-3}) during the pre-lockdown period, and during the lockdown period, it was reported maximum in Korba (59.60 ± 5.17 μg.m^{-3}) minimum in Durg (55.81 ± 26.81 μg.m^{-3}). After the lockdown was lifted, it was found to be highest in Bilaspur (26.66 ± 14.84 μg.m^{-3}) and lowest in Durg (13.66 ± 7.23 μg.m^{-3}). The status of PM_{10} in the air was also found to improve during the lockdown and the post-lockdown period compared to the pre-lockdown period. The concentration of PM_{10} was found to improve in Bhilai by 29.43 μg.m^{-3} and 39.4 μg.m^{-3} (F = P 0.5 < 7.477); in Durg 32.19 μg.m^{-3} & 42.15 μg.m^{-3} (F = P 0.5 < 10.1913); in Raipur 31.3 μg.m^{-3} and 40.20 μg.m^{-3} (F = P 0.5 < 8.9965); in Bilaspur 14.53 μg.m^{-3} and 30.14 μg.m^{-3} (F = P 0.5 < 8.7204); in Korba 14.56 μg.m^{-3} and 33.27 μg.m^{-3} (F = P 0.5 < 12.961) and in Raigarh 11.36 μg.m^{-3} and 33.8 μg.m^{-3} (F = P 0.5 < 11.1529) during the lockdown and post-lockdown period respectively.

The concentration of NO_2 in the air was also found to be altered during the lockdown and post-lockdown periods in comparison to the pre-lockdown period. It was found maximum in Raipur (89.5 ± 25.05 μg.m^{-3}) and the minimum in Korba (59.33 ± 7.96 μg.m^{-3}) during a pre-lockdown period, and during the lockdown period, it was reported maximum in Raipur (95.6 ± 16.14 μg.m^{-3}) and the minimum in Bilaspur (74.20 ± 10.08 μg.m^{-3}). In the post-lockdown period, it was reported at its maximum in Bhilai (66.33 ± 4.72 μg.m^{-3}) and at its minimum in Raigarh (39.33 ± 7.50 μg.m^{-3}). The NO_2 concentration was found to increase in the air during the lockdown period more than during the pre-lockdown period and to further decrease during the post-lockdown period in all cities except Durg. It was found to increase by 9.17 μg.m^{-3} and decreased by 27.64 μg.m^{-3} (F = P 0.5 < 7.1266) in Bhilai; increased by 23.44 μg.m^{-3} and decreased by 33.27 μg.m^{-3} (F = P 0.5 < 5.7595) in Raipur; increased by 3.37 μg.m^{-3} and decreased by 13.2 μg.m^{-3} (F = P 0.5 < 0.9213) in Bilaspur; increased by 17.67 μg.m^{-3} and decreased by 20.67 μg.m^{-3} (F = P 0.25 < 10.4317) in Korba; increased by 11.9 μg.m^{-3} and decreased by 41.07 μg.m^{-3} during the lockdown and the post-lockdown respectively, but in Durg it was found to decrease by 1.9 μg.m^{-3} and 22.6 μg.m^{-3} (F = P 0.5 < 6.7149) during the lockdown and the post-lockdown period consecutively. The behavior of NO_2 was found to be quite different from that of other pollutants; it was found to increase in the air when anthropogenic activities were almost suspended and to decrease further with the resumption of anthropogenic activities.

The O_3 in the air was also recorded, and it was found that it increased consecutively from the pre-lockdown to the lockdown to the post-lockdown period. The rise of O_3 during this period was reported significantly only in Durg (F = P 0.5 < 6.5815) and in the rest all, viz. Bhilai (F = P 0.5

> 6.5815), Raipur (F = P 0.5 > 6.5815), Bilaspur (F = P 0.5 > 6.5815), Korba (F = P 0.5 > 6.5815) and in Raigarh (F = P 0.5 > 6.5815) it was found to increase at non-significant level (Figs. 3, 4, 5, 6 & Table 2).

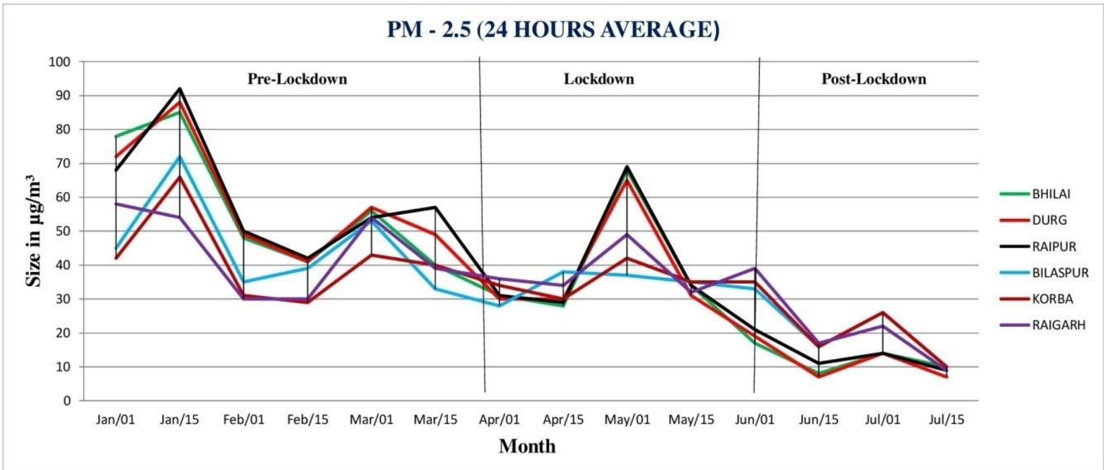

Fig. 3: Level of $PM_{2.5}$ during the pre-lockdown, lockdown, and post-lockdown period.

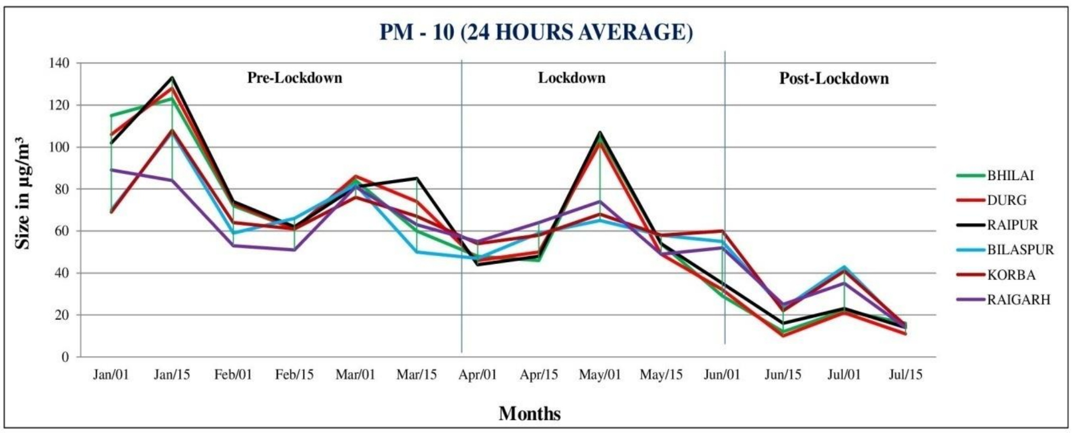

Fig. 4: Level of PM_{10} during the pre-lockdown, lockdown, and post-lockdown period.

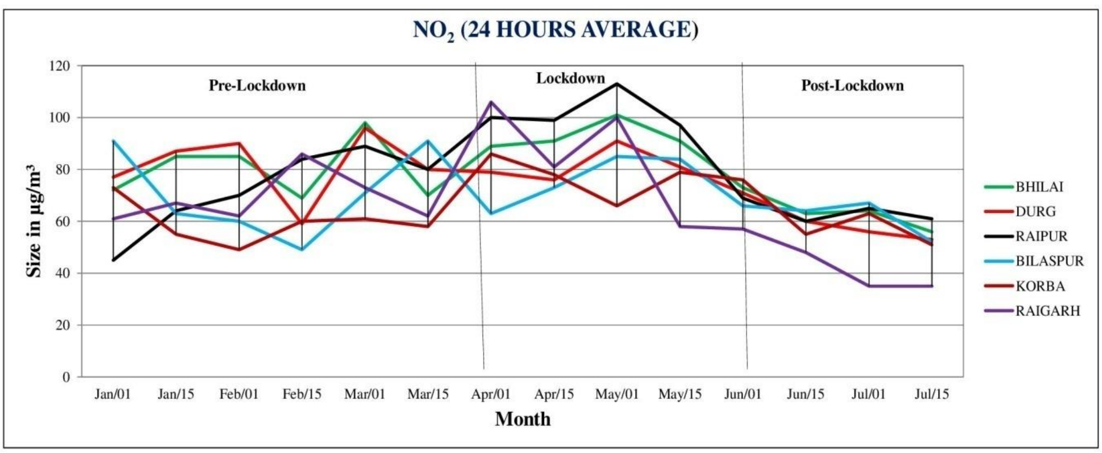

Fig. 5: NO_2 concentration during the pre-lockdown, lockdown and the post-lockdown period.

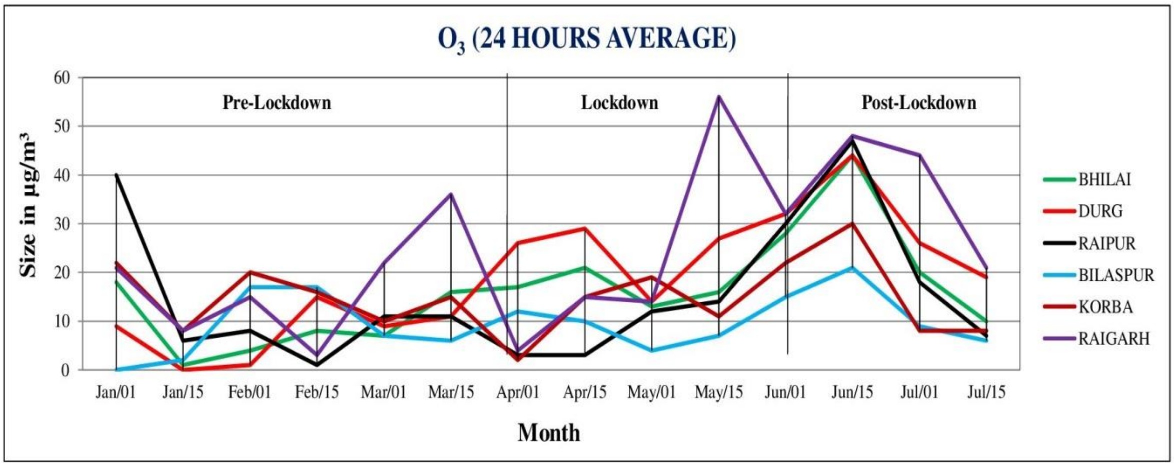

Fig. 6: O_3 concentration during the pre-lockdown, lockdown and the post-lockdown period.

Table 2: Alteration in $PM_{2.5}$, PM_{10}, NO_2, and O_3 during the Pre-lockdown, Lockdown, and Post-lockdown periods.

Cities	Bhilai				Durg				Raipur				Bilaspur				Korba				Raigarh			
	PM 2.5	PM 10	NO_2	O_3	PM 2.5	PM 10	NO_2	O_3	PM 2.5	PM 10	NO_2	O_3	PM 2.5	PM 10	NO_2	O_3	PM 2.5	PM 10	NO_2	O_3	PM 2.5	PM 10	NO_2	O_3
Pre-lockdown period	58.00±19.21	85.83±27.27	79.83±11.47	9.00±6.99	59.33±17.53	88.00±24.81	81.5±12.97	6.66±5.28	60.5±17.63	89.5±25.05	72.16±16.19	12.83±13.81	46.16±14.59	71.33±20.08	70.83±17.13	8.00±7.48	41.83±13.19	74.16±17.13	59.33±7.96	15.16±5.45	44.16±12.75	70.16±1659	68.5±9.69	17.5±11.67
Lockdown period	35.6±21	56.4±28.71	89.00±10.09	19.00±5.78	35.00±17.47	55.81±26.81	79.6±7.40	25.6±6.87	36.8±18.63	58.2±28.13	95.6±16.14	12.40±11.05	32.8±3.49	56.8±6.57	74.20±10.08	9.6±4.27	35.20±4.32	59.60±5.17	77.00±7.21	13.8±7.79	36.4±7.30	58.8±10.18	80.4±22.85	24.2±12.42
Post-lockdown period	24.6±3.60	17.00±5.56	61.33±4.72	24.66±17.47	9.66±4.61	13.66±7.23	57.00±3.60	30.00±12.76	11.66±3.05	18.00±5.29	62.33±3.21	19.00±14.33	17.66±8.62	26.66±14.84	61.00±7.93	12.00±7.93	17.33±8.08	26.33±13.45	56.33±6.11	15.33±12.70	16.00±6.55	25.00±11.00	39.33±7.50	37.66±14.57
F @ < 0.5	7.4945	7.47701	7.1266	3.2038	10.16	10.1913	6.7149	6.5815	9.1819	8.9965	5.7595	0.2008	7.2875	8.7204	0.9213	0.3600	6.1733	12.961	10.4317	0.0505	7.8896	11.1529	6.5969	1.6121

India's first novel coronavirus patient, a student studying at Wuhan University, was reported in Kerala's Thrissur district at a time when more than 7,500 cases were reported in 20 countries around the world. In Chhattisgarh state, the first confirmed case of coronavirus was reported on March 19, 2020, in Raipur, where a girl who returned from London via Mumbai Airport tested positive. Cases of novel coronavirus infection were later reported to be increasing day by day. In the present study, we have summarized the data of novel coronavirus infection in Chhattisgarh as 8 on April 1, 33 on April 15, 40 on May 1, 60 on May 15, 498 on June 1, 1715 on June 15, 2860 on July 1, and 4379 on July 15. Further, it was increased to 5407 on July 20 and 5968 on July 23. In our study (Fig. 7), the air quality index and the increasing trend of COVID-19 cases were found to be negatively correlated ($r = -07688$, $p = 0.0258$).

In less than five months, the COVID-19 outbreak in India has spread to all states and union territories, infecting more than 1,238,798 people, and nearly 29,861 people have lost their lives as of the date of this paper, July 23, 2020. There

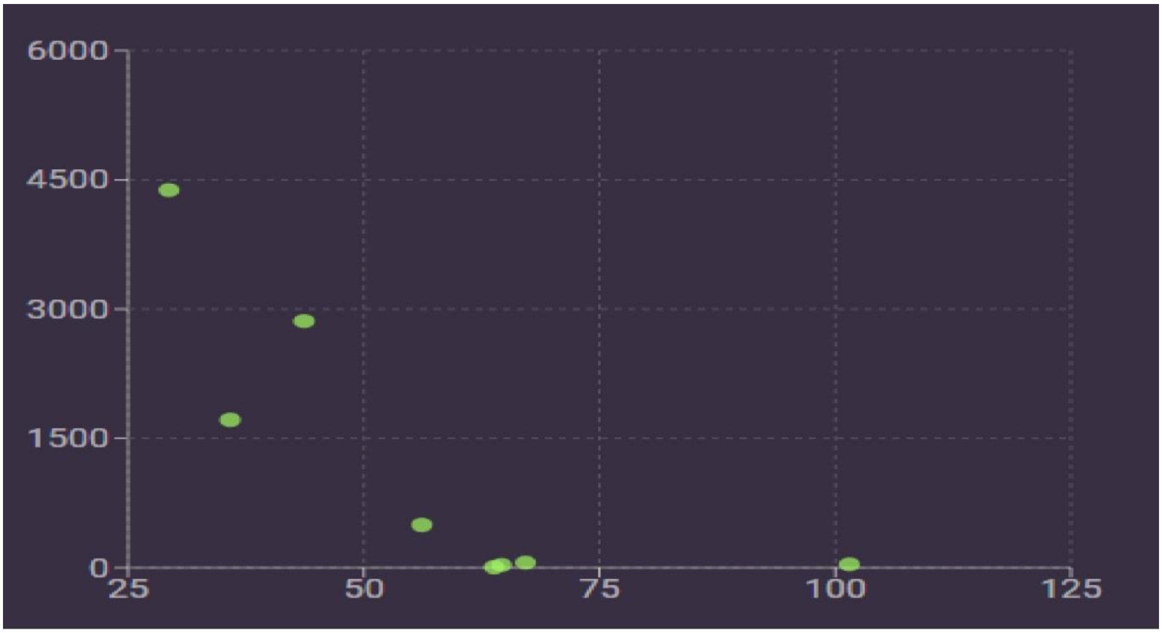

Fig. 7: Negative correlation between average air quality index and increasing cases of COVID-19 (From 1 April to 15 July).

is no sign of a reduction in COVID-19 cases, but we are witnessing that the doubling time of infection was reduced very rapidly. Some of the authors have reported a positive correlation between the air quality index and COVID-19 cases. Zhu et al. (2020) have reported a significant relationship between air pollution and COVID-19 infection and a positive association of $PM_{2.5}$, PM_{10}, CO_2, NO_2, and O_3 with COVID-19 confirmed cases; however, a negative association between SO2 and COVID-19 cases in China was also reported. Fattorini et al. (2020) have also expressed the view that there is a significant correlation between atmospheric pollution and the SARS-CoV-2 outbreak in Italy. It was also reported that high NO_2 concentrations in the atmosphere contribute to fatalities caused by COVID-19, especially in cases such as those observed in Italy, Spain, France, and Germany (Ogen 2020).

In our study, we found that gradually the air quality index from January to the 15th of July improved, but simultaneously the COVID-19 cases also increased during the period. In a systematic study of $PM_{2.5}$, PM_{10}, NO_2, and O_3 for Bhilai, Durg, Raipur, Bilaspur, Korba, and Raigarh, we found a remarkable decrease in $PM_{2.5}$ and PM_{10} during the lockdown and post-lockdown periods, a rise in NO_2 during the lockdown period and a decrease in the post-lockdown period, and a non-significant rise in O_3 during the lockdown and post-lockdown periods consecutively.

The accumulation of NOx in the air and water can cause serious environmental pollution. NO and NO_2 may react with other chemicals to form acid rain, which harms the ecosystem (Akimoto 2003). Nitrogen dioxide (NO_2) is regarded as an indicator of nitrogen oxide and is used to assess environmental pollution levels. The WHO has listed NO_2 as one of the six typical air pollutants (Brunekreef & Holgate 2002). Breathing air containing a high concentration of NO_2 may stimulate the body's respiratory system, but this toxic gas may corrode the body's lung tissue. Short-term exposure to a high concentration of NO_2 can cause respiratory symptoms (e.g., coughing, wheezing, or difficulty in breathing) and aggravate respiratory disease. NO_2 comes from the combustion of oil, coal, natural gas, and other fuels and the exhaust of urban vehicles. It is estimated that anthropogenic pollution worldwide emits approximately 53 million tons of nitrogen oxide per year.

In China, the NO_2 in the atmosphere was measured by the European Space Agency from December 19, 2019, to March 15, 2020, during the lockdown period, and it was reported that during this period, the NO_2 in China was found to be significantly lower than the previous period. The Chinese government resumed industrial activities on February 10, and after that, the NO_2 concentration in the atmosphere increased. Guo et al. (2020) and Mehta et al. (2020) reported that cytokine storm, also known as hypercytokinemia, is one of the major causes of COVID-19 patients due to an uncontrolled release of proinflammatory cytokines (Tisoncik et al. 2012). It is a severe reaction of the immune system, leading to a chain of destructive processes in the body that can end in death, and it has been reported by several authors that the cytokine storm syndrome can be caused by long exposure to air pollutants, especially NO_2. Furthermore, elevated NO_2 exposure has been linked to hypertension (Saeha et al. 2020), heart and cardiovascular disease (Mann et al. 2002, Arden et al. 2004), chronic obstructive pulmonary disease (Abbey et al. 1993), significant deficits in lung function growth in children (Avol et al. 2001), poor lung function in adults, or injury (Bowatte et al. 2017). It has been reported that NO_2 exposure may induce an inflammatory response in the airway by inducing the synthesis of proinflammatory cytokines from pulmonary epithelia (Persinger et al. 2017). Khoder (2002) has reported that high NO_2 concentrations may generate some harmful secondary pollutants, such as nitric acid (HNO_3) and ozone (O_3). WHO (World Health Organization 2016) has warned that NO_2 and its secondary products are the main health issues and that the population should be protected from these pollutants.

Muhammad (2020) has reported that during the COVID-19 lockdown period, NO_2 emission to the atmosphere was reduced by up to 30% in China, Spain, France, Italy (European Space Agency 2016), and the USA (National Aeronautics and Space Administration 2020). As NO_2 is a free radical, it has the potential to deplete tissue antioxidants and cause injury and inflammation. It has also been reported that uric acid and ascorbic acid deplete in bronchoalveolar lavage (BAL) fluid even at low concentrations of antioxidant defenses (Kelly & Tetley 1997). Olker et al. (2004) reported that the release of superoxide radicals from BAL cells decreases under the influence of NO_2 and results in the inhibition of NADPH oxidase and complex III of the respiratory chain and a mild increase in scavenging by enhanced glutathione peroxidase and CuZu-superoxide dismutase mRNA expression and enzyme activities. In cultured human bronchial epithelial cells, NO_2-induced cell membrane damage and increased membrane permeability have been reported by Devalia et al. (1993).

The immunofluorescence studies confirmed that the NO_2 exposed cell increases the level of nitrite, IL-8, IL-β, and TNF-α which further stimulates inflammatory conditions of the bronchial epithelium, leading to asthma and other hyperactive airway diseases. It has also been reported that during the early post-NO_2 period, the cells initiate apoptosis, while necrotic cell death was found to be more prevalent at later time intervals. The NO_2-exposed cell has exhibited increased expression of heme oxygenase-1 (OH-1), a redox-sensitive stress protein, and increased adhesion to neutrophils, which resulted in increased normal human bronchial cell death (Ayyagari et al. 2007). Some structural changes in respiratory cells under the influence of long-term exposure to nitrogen dioxide have also been reported, viz. emphysema-like structural changes, thickening of the alveolar-capillary membrane, loss of the ciliated epithelium, and an increase in lung collagen (EPA Report-No. EPA/600/8-91/049af-cf) (Jarvis et al. 2010).

Miller et al. (1987) discovered that NO_2 exposure affected pulmonary functions such as end-expiratory volume, vital capacity, and respiratory system compliance. Hussain et al. (2004) reported that even short-term exposure to NO_2 causes enhanced epithelial damage, reduced mucin expression, and increased baseline smooth muscle tone. Garn et al. (2003) investigated the inflammatory response to NO_2 and discovered an increase in the number of inflammatory cells, total protein concentration, and decreased TNF- in bronchoalveolar lavage (BAL), but elevated IL-10, IL-6, and suppressor of cytokine signaling-3 protein. In vitro lipopolysaccharide stimulation of BAL cells reduced TNF- and IL- production while increasing transcription and protein release of IL-10. Besides the above, an elevated level of IL-6, scavenger receptor B, and suppression of cytokine signaling-3 mRNA were also detected in BAL cells of NO_2-exposed animals.

Based on statistics, we discovered a negative correlation between the air quality index and cases of COVID-19 in our study, implying that the air quality index is unrelated to novel coronavirus infection in humans. Our findings disagree with the findings of Zhu et al. (2020) in the context of the scenario of Chhattisgarh, India. The decrease in $PM_{2.5}$ and PM_{10}, and the alteration with NO_2 might be due to the restriction of human activity under fear or precautionary steps against coronavirus.

The rise in the O_3 level in the air was found as a normal course of seasonal changes and might be contributed to the NO_2 increase. NO_2 has been recognized as the most dangerous pollutant, especially for lung damage and dysfunction. SARS-CoV-2 attacks the pulmonary system after entry through the ACE-2 receptor and causes serious, irreversible damage to the pulmonary system. In our study, we found that during the lockdown period, the NO_2 concentration was markedly increased in the state of Chhattisgarh, which has contributed a lot to enhance the pathogenicity of the disease and has created a serious lethal impact on infected persons. Although it is unclear why NO_2 concentrations increased in the atmosphere during the lockdown period, emissions from the Bhilai Steel Plant (one of Steel Authority of India Limited's largest units), the Steel Plant in Raigarh, and the Coal-based Thermal Power Plant in Korba are likely to have contributed because these units were operating at full capacity even during the lockdown period. Based on this study, it is suggested that during such a respiratory problem-based pandemic, the emissions from similar types of industrial units should be under control and evaluated consistently.

CONCLUSION

The first case of novel coronavirus was reported in the Indian state of Chhattisgarh by a migrant from London, and despite all efforts of the government, it has increased exponentially and spread to every corner of the state, prompting a lockdown as per national policy. In our study, we found that the air quality index considering $PM_{2.5}$, PM_{10}, NO_2, and O_3 improved during the lockdown period and continued to improve even during the post-lockdown period. We did not find the effect of the restoration of anthropogenic activities on the air quality index during the post-lockdown period. Our study revealed that the change in air quality was largely influenced by its natural course instead of an absolute anthropogenic impact. We also discovered that the rise in novel Coronavirus infection was not directly related to the air quality index, as previously reported by several authors from around the world. The behavior of NO_2 during the lockdown period in Chhattisgarh was reported quite differently, probably due to the continuation of specified industrial activities, and it has contributed to pulmonary dysfunction in the infected persons. Except for a few cases of cytokine storm-related other organ dysfunction, the majority of infected patients reported severe pulmonary dysfunctions, and both symptoms were likely exacerbated by increased NO_2 in the air. The outcome of the study is that there is a need for NO_2 management not only during novel coronavirus infections but for epidemics related to lung dysfunctions. The findings of the present study may help authorities with NO_2 management during the concerned epidemic period by enforcing steel plants, thermal power plants, and coal-fired units to minimize adverse pulmonary pathogenicity in the future.

ACKNOWLEDGEMENTS

The authors are grateful to Copernicus Atmospheric Monitoring Service Information 2020, the South America Model: GMAI/LPTEC/INDP, and Plum Lab. We are also thankful to Prof. Somali Gupta for her valuable suggestions.

REFERENCES

Abbey, D.E. Colome, S.D. Mills, P.K. Burchette, R. Beeson, W.L. and Tian, Y. 1993. Chronic disease is associated with long-term concentrations of nitrogen dioxide. Journal of Exposure Analysis and Environmental Epidemiology, 3: 181-202.

Akimoto, H. 2003. Global air quality and pollution. Science, 302: 1716-1719.

Arden, P.C. Burnett, R.T. Thurston, G.D. Thun, M.J. Calle, E.E. Krewski, D. and Godleski, J.J. 2004. Cardiovascular mortality and long-term exposure to particulate air pollution. Circulation, 109: 71-77.

Avol, E.L. Gauderman, W.J. Tan, S.M. London, S.J. and Peters, J.M. 2001. Respiratory effects of relocating to areas of differing air pollution levels. American Journal of Respiratory and Critical Care Medicine, 164: 2067-2072.

Ayyagari, V.N. Januszkiewicz, A. and Nath, J. 2007. Effects of nitrogen dioxide on the expression of intercellular adhesion molecule-1, neutrophil adhesion, and cytotoxicity: studies in human bronchial epithelial cells. Inhalation Toxicology, 19: 181-94.

Bai, Y. Yao, L. Wei, T. Tian, F. Jin, D.Y. Chen, L. and Wang, M. 2020. Presumed asymptomatic carrier transmission of COVID-19. Journal of the American Medical Association, 323: 1406-1407.

Bowatte, G. Erbas, B. Lodge, C.J. Knibbs, L.D. Gurrin, L.C. Marks, G.B. Thomas, P.S. Johns, D.P. Giles, G.G. and Hui, J. 2017. Traffic-related air pollution exposure over a 5-year period is associated with an increased risk of asthma and poor lung function in middle age. European Respiratory Journal, 50: 1602357. doi: 10.1183/13993003.02357-2016.

Brunekreef, B. and Holgate, S.T. 2002. Air pollution and health. Lancet, 360: 1233-1242.

Devalia, J.L. Campbell, A.M. Sapsford, R.J. Rusznak, C. Quint, D. Godard, P. Bousquet, J. and Davies, R.J. 1993. Effect of nitrogen dioxide on a synthesis of inflammatory cytokines expressed by human bronchial epithelial cells in vitro. American Journal of Respiratory Cell and Molecular Biology, 9: 271-278.

European Space Agency. 2020. Available online at: http://www.esa.int/Applications/Observing_the_Earth/Coprnicus/Sentinel5P/Coronavirus_lockdown_leading_todrop_in_Pollution_across_Europe (accessed: 4 April 2020).

Fattorini, D. and Regoli, F. 2020. Role of the atmospheric pollution in the Covid-19 outbreak risk in Italy. Environmental Pollution, 264: 114732.

Garn, H. A. Siese, A. Stumpf, S. Barth, P.J. Muller, B. and Gemsa, D. 2003. Shift toward an alternatively activated macrophage response in lungs of NO_2-exposed rats. American Journal of Respiratory Cell and Molecular Biology, 28: 386-396.

Glencross, D.A. HO, T.R. Camina, N. Catherine, M. Hawrylowicza, C.M. and Pfeffer, P.E. 2020. Air pollution and its effects on the immune system. Free Radical Biology and Medicine, 151: 56-68.

Global Carbon Project. Available online at http://www.globalcarbonproject.org/carbonbudget/index.html. (accessed date: 4 April 2020).

Guo, Y.R. Cao, Q.D. Hong, Z.S. Tan, Y.Y. Chen, S.D. Jin, H.J. Tan, K.S. Wang, D.Y. and Yan, Y. 2020. The origin, transmission and clinical therapies on coronavirus disease 2019 (COVID-19) outbreak- an update on the status. Military Medical Research, 7: 11.

Hussain, I. Jain, V.V. O'Shaughnessy, P. Thomas R. Businga, T.R. and Kline, J. 2004. Effect of nitrogen dioxide exposure on allergic asthma in a murine model. Laboratory and Animal Investigations, 126: 198-204.

Jarvis, D.J. Adamkiewicz, G., Heroux, M.E., Rapp, R., Frank, J. and Kelly, F.J. 2010. WHO Guidelines for indoor air quality: selected pollutants. Copenhagen: World Health Organization, Regional Office at Europe, pp. 201-248.

Katanoda, K. Sobue, T. Satoh, H. Tajima, K. Suzuki, T. and Tominaga, S. 2011. An association between long-term exposure to ambient air pollution and mortality from lung cancer and respiratory diseases in Japan. Journal of Epidemiology, 21: 132-143.

Kelly, F. and Tetley, D.T. 1997. Nitrogen dioxide depletes uric acid and ascorbic acid but not glutathione from lung lining fluid. Biochemical Journal, 325: 95-99.

Khoder, M.I. 2002. Atmospheric conversion of sulfur dioxide to particulate sulfate and nitrogen dioxide to particulate nitrate and gaseous nitric acid in an urban area. Chemosphere, 49: 675-684.

Mann, J.K. Tager, I.B. Lurmann, F. Segal, M. Quesenberry, C.P. Lugg, M.M. Shan, J. and Eeden, S.K.V.D. 2002. Air pollution and hospital admissions for ischemic heart disease in persons with congestive heart failure or arrhythmia. Environmental Health Perspectives, 110: 1247-1252.

Mehta, P. McAuley, D.F. Brown, M. Sanchez, E. Tattersall, R.S. and Manson, J.J. 2020. COVID- 19: consider cytokine storm syndromes and immunosuppression. Lancet, 395: 1033-1034.

Miller, K.G. Janecek, T.R. Katz, M.E. and Keil, D.J. 1987. Stable carbon and oxygen isotope record of benthic foraminifera from Paleocene-Eocene sediments. Pangaea, doi:10.1594/Pangaea.726768.

Muhammad, S. Long, X. and Salman, M. 2020. COVID-19 pandemic and environmental pollution: A blessing in Disguise. Science of the Total Environment, 728: 138820.

Nakao, M. Ishihara, Y. Kim C.H. and Hyun, I.G. 2018. The impact of air pollution, including asian sand dust, on respiratory symptoms and health-related quality of life in outpatients with chronic respiratory disease in Korea: A panel study. Journal of Preventive Medicine & Public Health, 51: 130-130.

National Aeronautics and Space Administration. 2020. Available online at https://neo.sci.gsfc.nasa.gov/view.php?datasetId=AURA_ NO_2. (accessed date: 5 May 2020).

Ogen, Y. 2020. Assessing nitrogen dioxide (NO_2) levels as a contributing factor to coronavirus (COVID-19) fatality. Science of the Total Environment, 726: 138605.

Olker, C. Siese, A. Stumpf, S. Müller, B. Gemsa, D. and Garn, H. 2004. Impaired superoxide radical production by bronchoalveolar lavage cells from NO_2-exposed rats. Free Radical Biology and Medicine, 37: 977-987.

Peng, R.D. Bell, M.L. Geyh, A.S. McDermott, A. Zeger, S.L. Samet, J.M. and Dominici, F. 2009. Emergency admissions for cardiovascular and respiratory diseases and the chemical composition of fine particle air pollution. Environmental Health Perspectives, 117: 957-963.

Persinger, R.L. Poynter, M.E. Ckless, K. and Janssen-Heininger, Y.M.W. 2002. Molecular mechanisms of nitrogen dioxide induced epithelial injury in the lung. Molecular and Cell Biochemistry, 234: 71-80.

Rahman, I. and MacNee, W. 2000. Oxidative stress and regulation of glutathione in lung inflammation. European Respiratory Journal, 16: 534-554.

Saeha, S. Bai, Li. Oiamo, T.H. Brunet. R.T. Scott, W. Jerrett, M. Kwong, J.C. Goldber. M.S. Copes, R. Kopp, A. and Chen, H. 2020. Association between road traffic noise and incidence of diabetes mellitus and hypertension in Toronto, Canada: a population-based cohort study. Journal of the American Heart Association, 9: 013021.

Sohrab, C. Alsaf, Z. O'Neill, N. Khan, M. Kerwan, A. Al-Jabir, A. Iosifidis, C. and Agha, R. 2020. World Health Organization declares global emergency: A review of the 2019 novel coronavirus (COVID-19). International Journal of Surgery, 76: 71-76.

Spix, C. Anderson, H.R. Schwartz, J. Vigotti, M.A. Leterttre, A. Vank, J.M. Touloumi, G. Balducci, F. Piekarski, T. and Bacharova, L. 1998. Short-term effects of air pollution on hospital admissions of respiratory diseases in Europe. Archives of Environmental Health, 53: 54-64.

Tamrius, J.D. Shaman, J. Alonso, W.J. Bloom Feshbach, K. Uejio, C.K. Comrie, A. and Vibond, C. 2013. Environmental predictors of seasonal influenza epidemics across the temperate and tropical climates. PLoS Pathology, 9: 1003194.

Tisoncik, J.R. Korth, M.J. Simmons, C.P. Farrar, J. Martin, T.R. and Katze, M.G. 2012. Into the eye of the cytokine storm. Microbiology and Molecular Biology Reviews, 76: 16-32.

Wong, T.W. Lau, T.S. Yu, T.S. Neller, A. Wong, S.L. Tam, W. and Pang, S.W. 1999. Air pollution and hospital admissions for respiratory and cardiovascular diseases in Hong Kong. Occupational Environmental Medicine, 56: 679-683.

World Health Organization. 2016. Available online at: http://www.who.int/heath-topic/air-pollution#tab=tab_1 (accessed: 5 April 2020).

Zhu, Y. Xie, J. Huang, F. and Cao, L. 2020. Association between short-term exposure to air pollution and COVID-19 infection: Evidence from China. Science of the Total Environment, 727: 138704.