

# Assessing the Relationship between COVID-19, Air Quality, and Meteorological Variables: A Case Study of Dhaka City in Bangladesh

## Special Issue:

Special Issue on COVID-19 Aerosol Drivers, Impacts and Mitigation (XIV)

Md Sariful Islam<sup>1\*</sup>, Mizanur Rahman<sup>2</sup>, Tanmoy Roy Tusher<sup>3,5</sup>, Shimul Roy<sup>4,5</sup>,  
Mohammad Arfar Razi<sup>6</sup>

<sup>1</sup> Department of Geography, Virginia Polytechnic Institute and State University, Blacksburg, USA

<sup>2</sup> Department of Geosciences, Florida Atlantic University, Boca Raton, FL, USA

<sup>3</sup> Graduate School of Environmental Studies, Tohoku University, Sendai, Japan

<sup>4</sup> School of Energy and Environment, City University of Hong Kong, Kowloon, Hong Kong, China

<sup>5</sup> Department of Environmental Science and Resource Management, Mawlana Bhashani Science and Technology University, Tangail, Bangladesh

<sup>6</sup> Bengal Institute for Architecture, Landscapes and Settlements, Dhaka, Bangladesh

## ABSTRACT

The novel coronavirus disease 2019 (COVID-19) has become a serious health concern worldwide for almost a year. This study investigated the effects of selected air pollutants and meteorological variables on daily COVID-19 cases in Dhaka city, Bangladesh. Air pollutants and meteorological data for Dhaka city were collected from 8 April to 16 June 2020 from multiple sources. This study implied spearman's correlation to see the correlation between daily COVID-19 cases and different air pollutants and meteorological variables. Besides, multiple linear regression and the Generalized Additive Model (GAM) were used to investigate the association between COVID-19 cases and other variables used in this study. Due to lockdown measures, significant differences between PM<sub>2.5</sub>, SO<sub>2</sub>, NO<sub>2</sub>, CO, and O<sub>3</sub> in 2019 and 2020 were observed in Dhaka city. We used lag-0, lag-7, lag-14, and lag-21 days on daily COVID-19 cases to look at the lag effect of different air pollutants and meteorology. The LRM results showed that the daily COVID-19 cases are significantly correlated with relative humidity (lag-0 days) and pressure (lag-14 days) ( $p < 0.05$ ). Additionally, the GAM model results showed a significant nonlinear association among daily COVID-19 cases and meteorology and air quality variables on different lag days. Therefore, our results suggest that an effective public health intervention measures should be implemented to slowdown the spreading of COVID-19.

**Keywords:** COVID-19, Air quality, Correlation, Meteorology, Dhaka

## 1 INTRODUCTION

COVID-19 is an unprecedented outbreak that has a significant impact on the world's economy and public health. It is highly contagious (Lu *et al.*, 2020; Sohrabi *et al.*, 2020) and has been rapidly propagating across the globe. On February 11, 2020, WHO identified the causative agents as coronavirus-2 (SARS-CoV-2) and named the disease "Corona Virus Diseases 2019 (COVID-19)" (Dong *et al.*, 2020; Lu *et al.*, 2020). Until 10 March 2020, the total confirmed cases of COVID-19 were 137,658, and total deaths due to COVID-19 were 4,299 (Worldometer, 2020a). On 11 March 2020, the WHO declared the outbreak as a pandemic (WHO, 2020a). As of 28 September 2020, the WHO reported a total of 33,362,14 confirmed COVID-19 cases and a total of 1,003,198 deaths related to COVID-19 outbreaks in 215 countries and territories across the world (Worldometer, 2020a).

Bangladesh is one of the most densely populated countries in the world. It is the home of

## OPEN ACCESS



**Received:** October 27, 2020

**Revised:** December 28, 2020

**Accepted:** January 15, 2021

**\* Corresponding Author:**

shariful@vt.edu

**Publisher:**

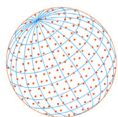
Taiwan Association for Aerosol  
Research

ISSN: 1680-8584 print

ISSN: 2071-1409 online

**© Copyright:** The Author(s).

This is an open access article distributed under the terms of the [Creative Commons Attribution License \(CC BY 4.0\)](https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are cited.



165,084,336 people (as of 28 September 2020), where the population density is 1265 per square kilometer (Worldometer, 2020b). Like other countries, Bangladesh also has been struggling with COVID-19 outbreak. Bangladesh reported the first 3 confirmed cases of COVID-19 on March 08, 2020 (IEDCR, 2020). As of 28 September 2020, Bangladesh has reported 359,148 confirmed cases, and 5,161 confirmed deaths related to COVID-19 outbreaks (WHO, 2020b). The highest number of confirmed cases of COVID-19 have been reported in Dhaka city, the capital of Bangladesh. As of 28 September 2020, a total of 942,19 (26% of total cases in Bangladesh) confirmed cases had been reported in Dhaka (IEDCR, 2020).

To control the propagation of the COVID 19, it is crucial to identify the influential factors associated with the transmission of SARS-CoV-2. It is well documented that respiratory diseases such as asthma, chronic obstructive pulmonary disease (COPD), and lung cancer are associated with air pollution (Ling and van Eeden, 2009; Hoek *et al.*, 2013; Gorai *et al.*, 2016; Guan *et al.*, 2016). Air pollution is also identified as one of the causes of ischemic heart disease and stroke (WHO, 2020c). Wallis and Nerlich (2005) and Cui *et al.* (2003) found that environmental conditions and air pollution had a strong association with the fatality of the severe acute respiratory syndrome (SARS). Accordingly, it is assumed that the COVID-19 has an association with air pollution and meteorological variables. A study by Shi *et al.* (2020) found that meteorological variables had an influence on transmission of COVID-19 in China. Suhaimi *et al.* (2020) conducted a similar study in Kuala Lumpur, Malaysia, and they also found that different air pollutants and meteorological parameters has an association with daily new COVID-19 cases. Different other studies around the world were also found an association between COVID-19 infected cases, meteorological variables, and air pollutants (Bashir *et al.*, 2020; Jiang *et al.*, 2020; Li *et al.*, 2020; Lin *et al.*, 2020).

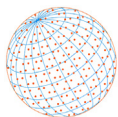
In Bangladesh, air pollution is one of the most critical concerns among all environmental issues. Many deaths have been reported every year due to numerous diseases linked to air pollution in the country (Mahmood, 2011). The Environmental Performance Index (2020) shows the low environmental performance index for Bangladesh (rank: 162/180 countries), mainly resulted from the poor air quality index (EPI, 2020). Dhaka city is consistently ranked as one of the world's top polluted capital cities (Rahman *et al.*, 2019; WHO, 2020d). In Dhaka, an average annual PM<sub>2.5</sub> level is 97.1  $\mu\text{g m}^{-3}$ , making it the second most polluted city in the world (Rodríguez-Urrego and Rodríguez-Urrego, 2020). Many patients in Dhaka are suffering from cardiovascular and Chronic Obstructive Pulmonary Disease (COPD) attributable to air pollution (Gurjar *et al.*, 2008). In recent years, the concentration of PM<sub>10</sub>, PM<sub>2.5</sub>, O<sub>3</sub>, NO<sub>x</sub>, SO<sub>2</sub>, and CO has increased considerably in major cities of the country (Azad and Kitada, 1998; Begum *et al.*, 2004; Salam *et al.*, 2008; Rana and Khan, 2020).

To identify the significant challenges to control the COVID-19 outbreak, explore its impacts on socioeconomic status, and assess the severity of the pandemic in Bangladesh, some studies have been conducted (Alam *et al.*, 2020; Anwar *et al.*, 2020; Shammi *et al.*, 2020). Besides, in our previous study, we investigated the impacts of nationwide lockdown during the COVID-19 outbreak on air quality in major cities in Bangladesh (Islam *et al.*, 2021). It is also essential to observe the association of COVID-19 cases with air quality and meteorological variables. However, there have been no studies conducted in Bangladesh to examine such a relationship. The main scope of this research is to investigate a possible association between daily COVID-19 cases, air pollution, and meteorological parameters in Dhaka city during the studied period. Based on existing research gaps, it is hypothesized that the ambient air pollutants and meteorological variables correlate with COVID-19 cases in Bangladesh. Dhaka city is selected as an ideal location to investigate the hypothesis due to its high COVID-19 cases, high ambient air pollution due to anthropogenic emissions, and seasonal meteorological variation. Therefore, this study explores the potential association between COVID-19 cases, air pollutants, and meteorological variables. We attempt to clarify the roles of air pollutants and meteorological parameters on COVID-19 transmission in Dhaka city of Bangladesh.

## 2 METHODS

### 2.1 Study Area

Dhaka is the capital and most populous city in Bangladesh with an estimated population of



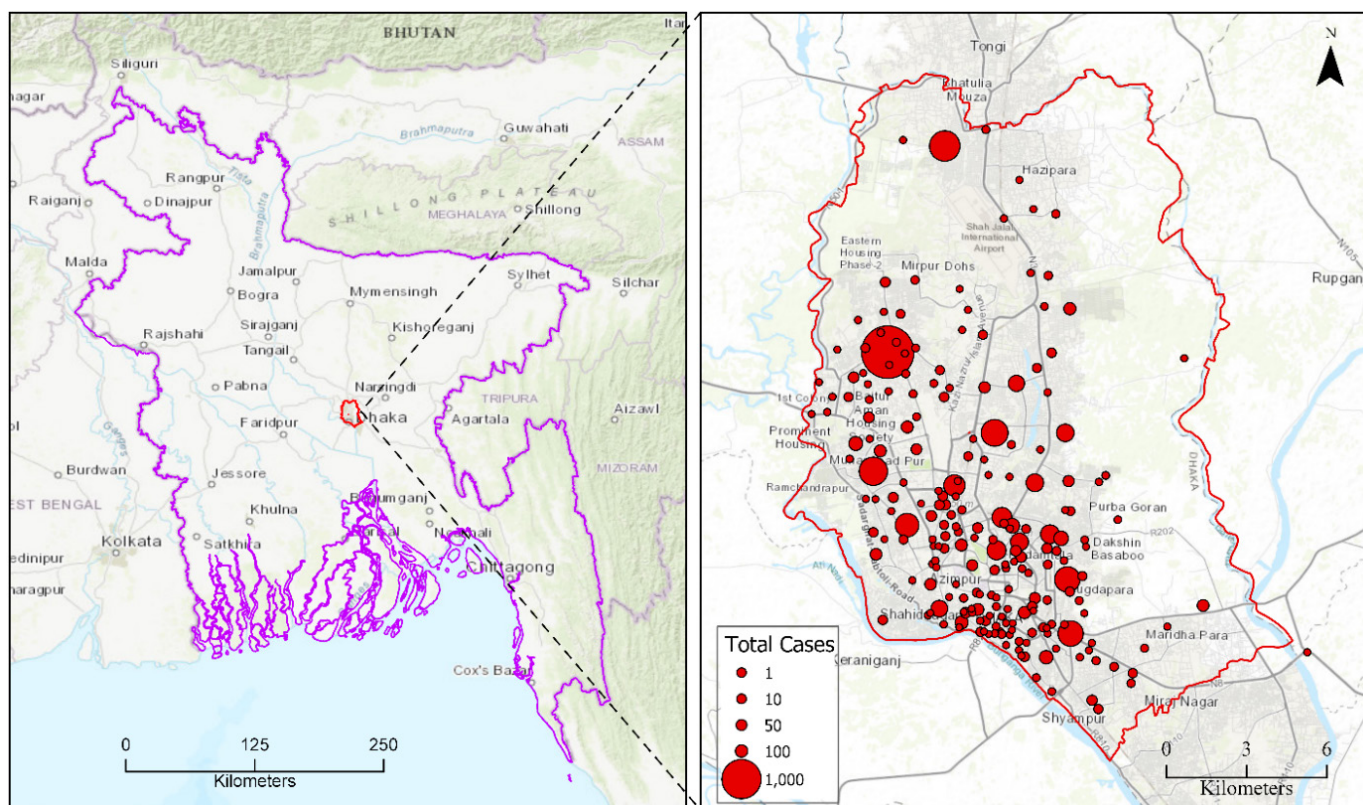
8.9 million living in city area and a population of over 21 million in the greater Dhaka area. According to the United Nations (UN), it is one of the world's 33 megacities as of 2018 (UN, 2020). While the delineation of the Dhaka Megacity is still a matter of debate, the Dhaka City Corporation (DCC) area is considered the central urban hub. The geographical extent of DCC is located between 23.69° and 23.89°N latitudes and 90.33° and 90.44°E longitudes. The city is surrounded by six rivers: Balu and Sitalakhya on the eastern side, Turag and Buriganga on the western side, Tongi Khal to the north, and Dhaleshwari to the south. In 2011, the DCC area was divided into Dhaka North and South City Corporation. The city's climate is typically tropical monsoon with three different seasons, i.e., summer, winter, and monsoon. In Dhaka, 80% of the average annual rainfall falls during the monsoon season. Fig. 1 demonstrates study area overlaid by total COVID-19 cases by location in the city area.

## 2.2 Data

Four different sources of data have been used in this study. Hourly PM<sub>2.5</sub> data for Dhaka city were collected from the Air Now website (<https://www.airnow.gov/>). Additional air pollutants data, including SO<sub>2</sub>, NO<sub>2</sub>, O<sub>3</sub>, and CO were collected from the Google Earth Engine (GEE) platform, collected by the Sentinel-5 mission of the Copernicus programme. We used four different meteorological variables in this study, including temperature, pressure, relative humidity, and wind speed. As such, we collected half-hourly data from Weather Underground. Daily COVID-19 cases data from 8 April to 16 June 2020 were collected from the Institute of Epidemiology, Disease Control and Research (IEDCR), Bangladesh (<https://www.iedcr.gov.bd/>). A detailed description of the datasets used in this study can be found in Table 1.

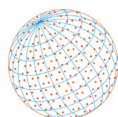
## 2.3 Methodology

Descriptive statistics of all the variables used were reported. In this study, the Spearman correlation ( $\rho$ ) value has been used to look at the correlation between daily COVID-19 cases and other variables. A p-value < 0.05 were considered significant for all statistical analysis. Both the Generalized Additive Model (GAM) and Multiple Linear Regression (MLM) were used to evaluate



**Fig. 1.** Map of the study area overlaid by total COVID-19 cases from 8 April to 30 June at different locations in Dhaka city.



**Table 1.** Summary of the datasets used in this study.

Data source	Parameter	Spatial resolution	Temporal Resolution	Data access link
AirNow	PM <sub>2.5</sub>	-	Hourly	<a href="https://www.airnow.gov/">https://www.airnow.gov/</a>
Sentinel-5	NO <sub>2</sub>	0.01 arc degree	Daily	<a href="https://scihub.copernicus.eu/">https://scihub.copernicus.eu/</a>
Sentinel-5	SO <sub>2</sub>	0.01 arc degree	Daily	<a href="https://scihub.copernicus.eu/">https://scihub.copernicus.eu/</a>
Sentinel-5	CO	0.01 arc degree	Daily	<a href="https://scihub.copernicus.eu/">https://scihub.copernicus.eu/</a>
Sentinel-5	O <sub>3</sub>	0.01 arc degree	Daily	<a href="https://scihub.copernicus.eu/">https://scihub.copernicus.eu/</a>
Weather Underground	Temperature	-	30 minutes	<a href="https://www.wunderground.com/">https://www.wunderground.com/</a>
Weather Underground	Relative Humidity	-	30 minutes	<a href="https://www.wunderground.com/">https://www.wunderground.com/</a>
Weather Underground	Wind Speed	-	30 minutes	<a href="https://www.wunderground.com/">https://www.wunderground.com/</a>
Weather Underground	Pressure	-	30 minutes	<a href="https://www.wunderground.com/">https://www.wunderground.com/</a>
IEDCR, Bangladesh	COVID-19 Cases	-	Daily	<a href="http://www.bbs.gov.bd/">http://www.bbs.gov.bd/</a>

the association between daily COVID-19 cases and other variables. The GAM model explores the nonlinear relationship between air pollutants, meteorological variables, and health outcomes (Ma *et al.*, 2020, Xie and Zhu, 2020). As the effect of meteorological variables can last for several days, and the incubation period of COVID-19 ranges from 1 to 14 day (CDC, 2020). Therefore, it was reasonable to use the lag effect of different air pollutants and meteorological variables in this study. Different studies also used the lag effect to look at the impacts of different air pollutants and meteorology on COVID-19 cases (Adhikari and Yin, 2020; Xie and Zhu, 2020; Zhu *et al.*, 2020). Therefore, in this study, we have used lag-0, lag-7, lag-14, and lag-21 days to look at the effect of air pollutants and meteorological variables on daily COVID-19 cases in Dhaka city, Bangladesh. To implement the Generalized Additive Model (GAM), 'mgcv' package in R statistical software was used. The ArcGIS pro v2.3 was used for mapping.

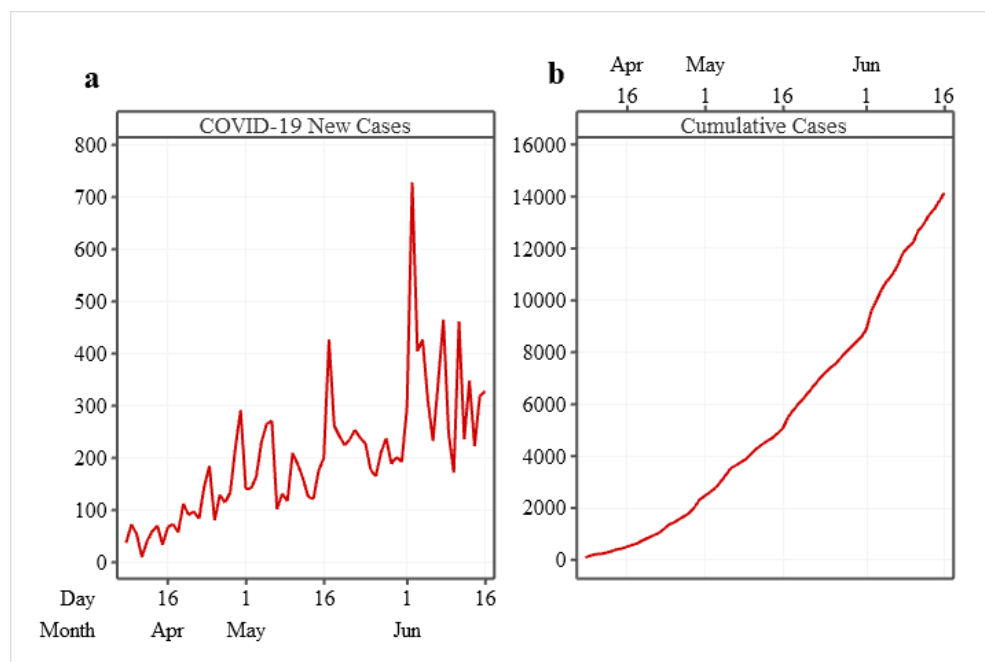
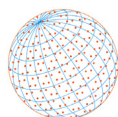
### 3 RESULTS AND DISCUSSION

#### 3.1 Descriptive Statistics of Daily COVID-19 Cases, Meteorological Variables and Air Pollutants

Bangladesh reported the first three confirmed cases of COVID-19 in Dhaka city on 8 March 2020. Until 8 April 2020, there were 78 confirmed COVID-19 cases in Dhaka. Figs. 2(a) and 2(b) shows the variations of daily and cumulative COVID-19 cases in Dhaka from 8 April to 16 June 2020. The study shows that the daily COVID-19 cases increased gradually during the observation period, which ranged from 11 to 728, with the the mean value 200.8, Standard Deviation (SD) 124, and Coefficient Value (CV) 61.76 (Table 2). As of 16 June, cumulative confirmed cases were 14000 in Dhaka city.

Table 2 shows that from 8 April to 30 June, the PM<sub>2.5</sub> concentration level ranged from 17.91 to 84.91  $\mu\text{g m}^{-3}$  (Mean = 42.06  $\mu\text{g m}^{-3}$ , SD = 14.26  $\mu\text{g m}^{-3}$ , and CV = 33.91  $\mu\text{g m}^{-3}$ ), the NO<sub>2</sub> concentration level ranged from 0.000021 to 0.000179  $\text{mol m}^{-2}$  (Mean = 0.000065  $\text{mol m}^{-2}$ , SD = 0.000027  $\text{mol m}^{-2}$ , and CV = 41.25  $\text{mol m}^{-2}$ ), the SO<sub>2</sub> concentration level ranged from -0.000281 to 0.000417  $\text{mol m}^{-2}$  (Mean = 0.000063  $\text{mol m}^{-2}$ , SD = 0.000146  $\text{mol m}^{-2}$ , and CV = 234.40  $\text{mol m}^{-2}$ ), the CO concentration level ranged from 0.029060 to 0.059180  $\text{mol m}^{-2}$  (Mean = 0.044227  $\text{mol m}^{-2}$ , SD = 0.005054  $\text{mol m}^{-2}$ , and CV = 11.43  $\text{mol m}^{-2}$ ) the O<sub>3</sub> concentration level ranged from 0.12079 to 0.13665  $\text{mol m}^{-2}$  (Mean = 0.12834  $\text{mol m}^{-2}$ , SD = 0.00436  $\text{mol m}^{-2}$ , and CV = 3.40  $\text{mol m}^{-2}$ ). Fig. 3 shows the daily variations of particulate matter (PM<sub>2.5</sub>) from 1 March to 30 June, and Fig. 4 shows the daily variations of air pollutants in Dhaka from 8 April to 30 June. This study found a gradual decrease in PM<sub>2.5</sub> and CO concentration levels during the observation period. The concentration of O<sub>3</sub> increased gradually until the last week of April and decreased gradually afterward. In contrast, the concentration of NO<sub>2</sub> and SO<sub>2</sub> were static. We believed that these variations in air pollutants' concentration during the observation period were caused by national lockdown measures when transportations and industrial activities were restricted. Islam *et al.* (2021) reported a similar finding in the major cities in Bangladesh because of reduced vehicular and industrial emissions during the national lockdown.

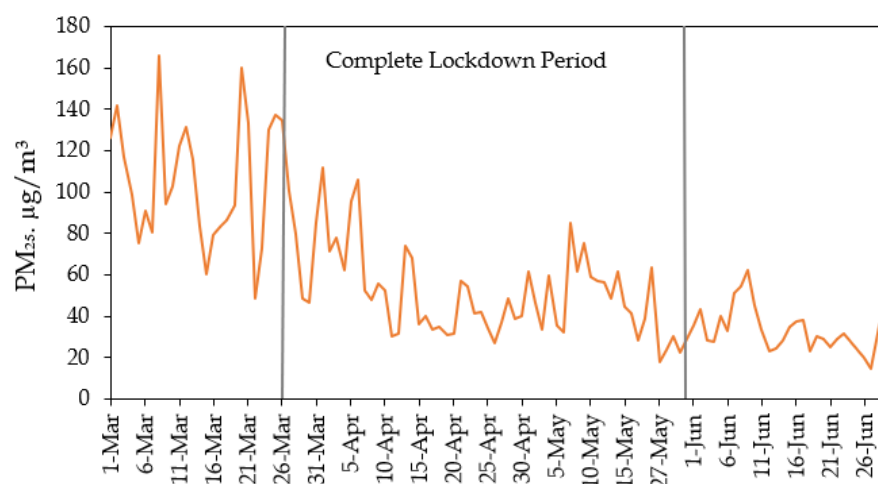
The study shows that temperature ranged from 24.38 to 30.73°C (Mean = 28.247°C, SD = 1.56°C,



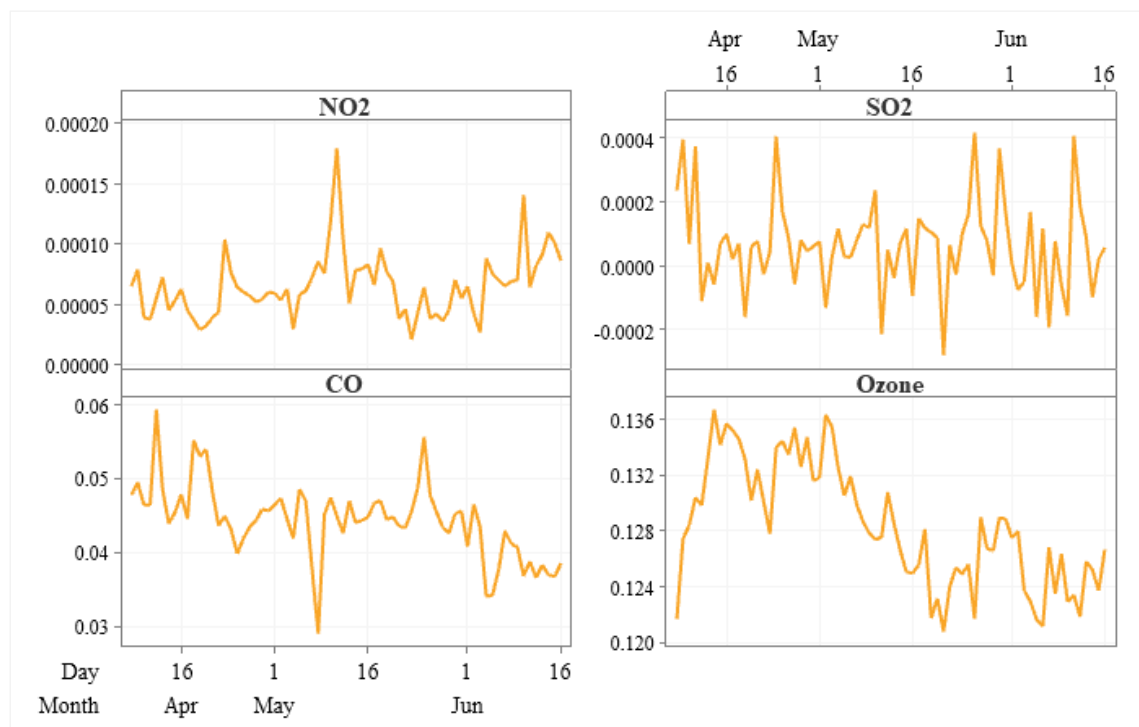
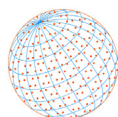
**Fig. 2.** Daily variations of COVID-19 in Dhaka, Bangladesh from 8 April to 16 June 2020. (a) Daily new cases; (b) Cumulative cases.

**Table 2.** Descriptive statistics of the datasets used in this study.

Variable	Minimum	St. Dev	Maximum	Q1	Q3	CV	Mean
COVID-19 Daily Cases	11.0	124.0	728.0	114.5	249.5	61.76	200.8
PM <sub>2.5</sub> ( $\mu\text{g m}^{-3}$ )	17.91	14.26	84.91	31.56	52.85	33.91	42.06
NO <sub>2</sub> ( $\text{mol m}^{-2}$ )	0.000021	0.000027	0.000179	0.000045	0.000077	41.25	0.000065
SO <sub>2</sub> ( $\text{mol m}^{-2}$ )	-0.000281	0.000146	0.000417	-0.000029	0.000118	230.40	0.000063
CO ( $\text{mol m}^{-2}$ )	0.029060	0.005054	0.059180	0.041880	0.046927	11.43	0.044227
O <sub>3</sub> ( $\text{mol m}^{-2}$ )	0.12079	0.00436	0.13665	0.12502	0.13201	3.40	0.12834
Temperature ( $^{\circ}\text{C}$ )	24.380	1.560	30.730	27.223	29.412	5.52	28.247
Relative Humidity (%)	56.810	6.556	88.810	67.630	75.920	9.18	71.432
Wind Speed ( $\text{km h}^{-1}$ )	3.250	5.273	29.390	7.867	13.863	47.23	11.165
Pressure (hPa)	996.0	3.45	1011.6	1003.1	1008.1	0.34	1005.6



**Fig. 3.** Daily variations of particulate matter (PM<sub>2.5</sub>) in Dhaka city between 1 March and 30 June in 2020.

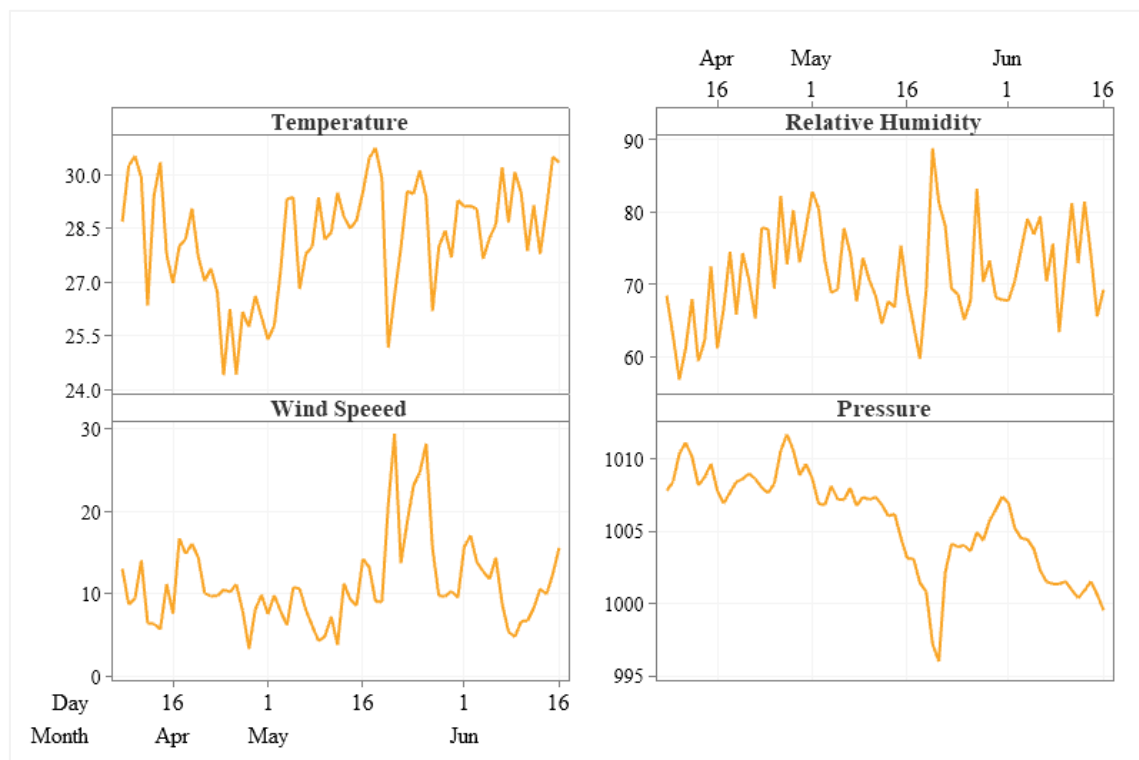
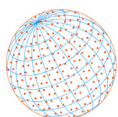


**Fig. 4.** Daily variations of air pollutants in Dhaka city from 8 April to 30 June 2020.

and CV = 5.52°C), the relative humidity ranged from 56.81 to 88.81% (Mean = 71.432%, SD = 6.556%, and CV = 9.18%), the wind speed ranged from 3.25 to 29.39 km h<sup>-1</sup> (Mean = 11.165 km h<sup>-1</sup>, SD = 5.273 km h<sup>-1</sup>, and CV = 47.23 km h<sup>-1</sup>), and the pressure ranged from 996.0 to 1011.6 hPa (Mean = 1005.6 hPa, SD = 3.45 hPa, and CV = 0.34 hPa) during the observation period (Table 2). The daily changes of the meteorological parameters in Dhaka are shown in Fig. 5. The result shows that temperature gradually decreased until the last week of April and gradually increased afterward. Relative humidity increased gradually during the observation period. The wind speeds were found static and the pressure decreased gradually. We assumed that the changes of meteorological variables during the observation period had been seen because of seasonal variation across the country.

### 3.2 Improvement of Air Quality during the Lockdown

The air quality of a region depends on the concentrations of air pollutants, including PM, NO<sub>x</sub>, SO<sub>x</sub>, CO, and O<sub>3</sub>, over a specified averaging period. Due to the complete lockdown (i.e., 26 March 2020 to 30 May 2020), Dhaka's air quality was significantly improved due to the substantial reductions in air pollutants' concentration. The study shows a sharp decrease in PM<sub>2.5</sub>, NO<sub>2</sub>, SO<sub>2</sub>, CO concentrations and an increased O<sub>3</sub> concentration immediately after the nationwide lockdown declaration in April 2020 (Table 3, Figs. 6–9). Mahato *et al.* (2020) also reported decreased PM<sub>2.5</sub>, NO<sub>2</sub>, SO<sub>2</sub>, and CO concentrations and increased O<sub>3</sub> concentration due to the nationwide lockdown in the megacity Delhi (India), particularly in the areas with substantial road-transportation and industrial clusters. Such declining trends in air pollutants' concentrations were also observed in May 2020, except for NO<sub>2</sub> and O<sub>3</sub>, while a sudden increase in NO<sub>2</sub> and reduction in O<sub>3</sub> concentration was observed (Table 3, Figs. 6 and 9). This trade-off relationship between NO<sub>2</sub> and O<sub>3</sub> supports the fact that a decrease in the levels of nitrogen oxides (NO<sub>x</sub>) subsequently increases the levels of O<sub>3</sub> (NO + O<sub>3</sub> = NO<sub>2</sub> + O<sub>2</sub>) (Islam *et al.*, 2021). These variations in NO<sub>2</sub> and O<sub>3</sub> concentrations indicated an increase in vehicular and industrial emissions, attributed to the consequence of lockdown relaxation and reopening of industries maintaining social distancing (Biswas *et al.*, 2020; Hindustan Times, 2020). However, significant spatial variations in NO<sub>2</sub> concentrations were observed in May 2020 (Fig. 6), with high intensity in the south and southeast part of the city. We assumed it might be due to the transboundary effects of local vehicular and industrial emissions from the adjoining



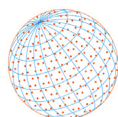
**Fig. 5.** Daily variations of meteorological variables in Dhaka city from 8 April to 30 June 2020.

town (i.e., Narayanganj). It should mention that Narayanganj is known as the country's most industrialized city and is also the worst COVID-19-hit district in Bangladesh (Noman *et al.*, 2016; UNB, 2020).

Interestingly, a reduction in the air pollutants' concentrations was observed in June 2020, indicating less emission activities even after the withdrawal of complete lockdown (Table 3). This scenario can be explained by the effect of 'work from home' practices and the influence of monsoon season (i.e., June–September) in Bangladesh when rainfall helps significantly to washout atmospheric particulates and gaseous pollutant (Rahman *et al.*, 2019). Nevertheless, the comparative analysis revealed that the concentrations of  $\text{PM}_{2.5}$ ,  $\text{NO}_2$ ,  $\text{SO}_2$ , and CO observed in April 2020 were significantly lower than the same period in 2019 (Table 3, Figs. 6–8). On the contrary, the concentration of  $\text{O}_3$  was found higher in April 2020 than that observed in April 2019 (Table 3). Overall analysis exhibited that the concentrations of  $\text{PM}_{2.5}$ ,  $\text{NO}_2$ ,  $\text{SO}_2$ , and CO in April 2020 were found to be decreased by about 17.31, 10.33, 47.92, and 6.07%, respectively, while  $\text{O}_3$  concentration increased by 1.84% (Table 3), reflecting the effectiveness of complete lockdown measures. The study also observed a significant reduction in  $\text{SO}_2$  concentration compared to other pollutants immediately after the complete lockdown declaration. Moreover, our study shows that the average concentrations of  $\text{PM}_{2.5}$ ,  $\text{NO}_2$ ,  $\text{SO}_2$ , and CO were declined by about 17.11, 17.06, 10.93, and 2.15%, respectively, and  $\text{O}_3$  concentration was increased by about 3.99% in 2020 (Table 3), considering the full study period (i.e., March–June). Therefore, a substantial improvement in Dhaka's air quality has been observed due to reducing air pollutants' concentrations during the lockdown period.

### 3.3 Correlation between COVID-19 Cases, Meteorological Variables, and Air Pollutants

Table 4 represents the temporal associations between daily COVID-19 cases and air pollutants or meteorological variables in lag settings. Daily COVID-19 cases showed a significant negative correlation with  $\text{PM}_{2.5}$  at lag-0, with CO at lag-0 and 7, and with  $\text{O}_3$  at lag-0 to 14. However,  $\text{NO}_2$  and  $\text{SO}_2$  did not show any significant relation with daily COVID-19 cases. Bashir *et al.* (2020) also observed a significant negative correlation between  $\text{PM}_{2.5}$  and daily COVID-19 cases. In contrast,

**Table 3.** Variations of different air pollutants in Dhaka city during March to June in 2019 and 2020.

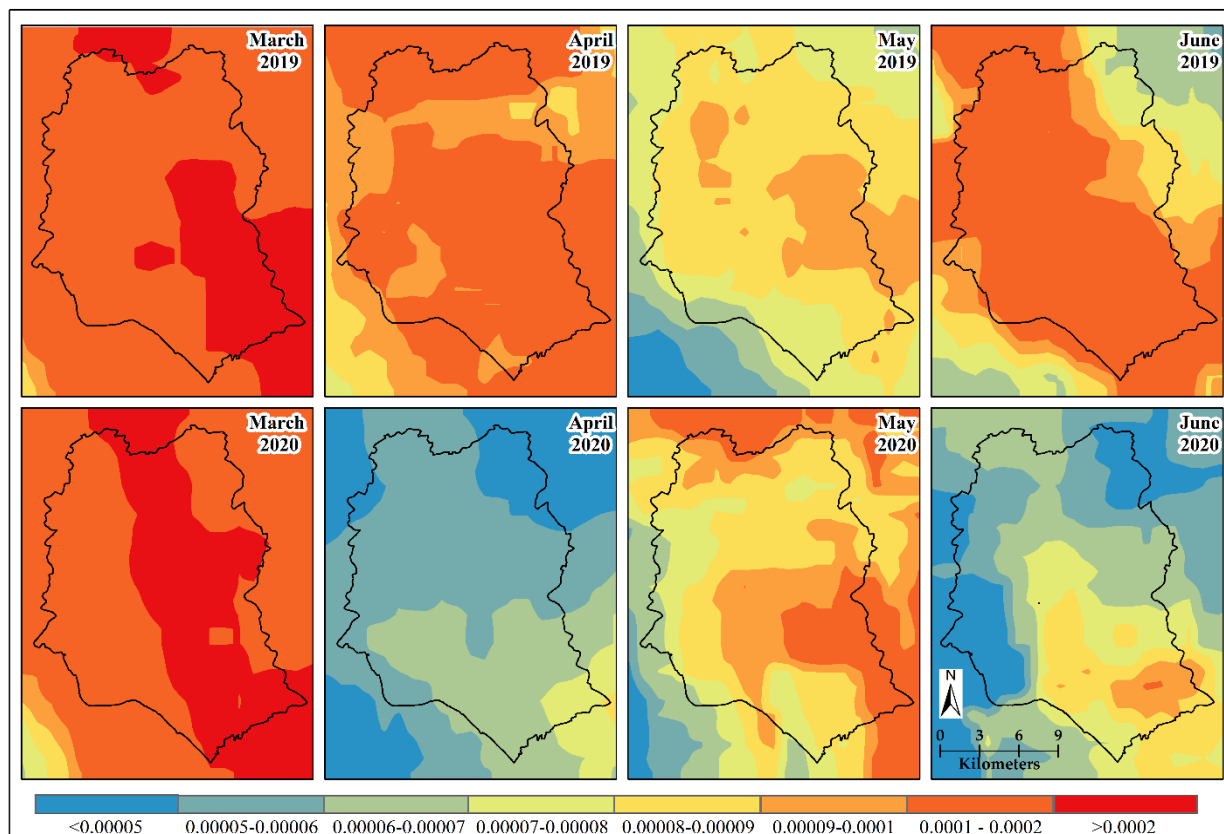
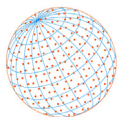
Variables	2019					2020					Average of 2020		Variation between April 2019 and 2020		Variation between 2019 and 2020	
	March	April	May	June	Average of 2019	March	April	May	June	Average of 2020	Net	%	Net	%	Net	%
	122.54	70.67	57.74	31.04	70.50	101.06	52.24	46.97	33.47	58.44						
PM <sub>2.5</sub>	0.000175	0.000105	0.000079	0.000096	0.000114	0.000180	0.000060	0.000071	0.000066	0.000094	-18.43	-17.31	-12.06	-17.11	-17.06	-17.06
NO <sub>2</sub>	0.000224	0.000212	0.000043	0.000017	0.000124	0.000290	0.000070	0.000061	0.000021	0.000111	-0.000045	-10.33	-0.000019	-17.06	-17.06	-17.06
SO <sub>2</sub>	0.048223	0.048026	0.044391	0.043756	0.046099	0.049269	0.047784	0.045053	0.038332	0.045109	-0.000142	-47.92	-0.000014	-10.93	-10.93	-10.93
CO	0.115858	0.124822	0.122448	0.125825	0.122238	0.126782	0.130648	0.127457	0.123593	0.127120	-0.00024	-6.07	-0.000990	-2.15	-2.15	-2.15
O <sub>3</sub>											0.005826	1.84	0.004882	3.99	3.99	3.99

Hoang and Tran (2021) reported a significant positive association between CO and daily COVID-19 confirmed cases in Korea at lag-0 to 21. Ran *et al.* (2020) observed no significant association between daily COVID-19 cases and NO<sub>2</sub>, SO<sub>2</sub>, or CO in China. These regional variations in the associations between air pollutants and daily COVID-19 cases might be attributed to the differences in anthropogenic emission activities (Hoang and Tran, 2021). Moreover, it is evidence that other factors, including population density, social distancing, wearing masks, personal hygiene practices, immunity, policy interventions, etc. might influence the transmission of infection and the associations with regional air pollution.

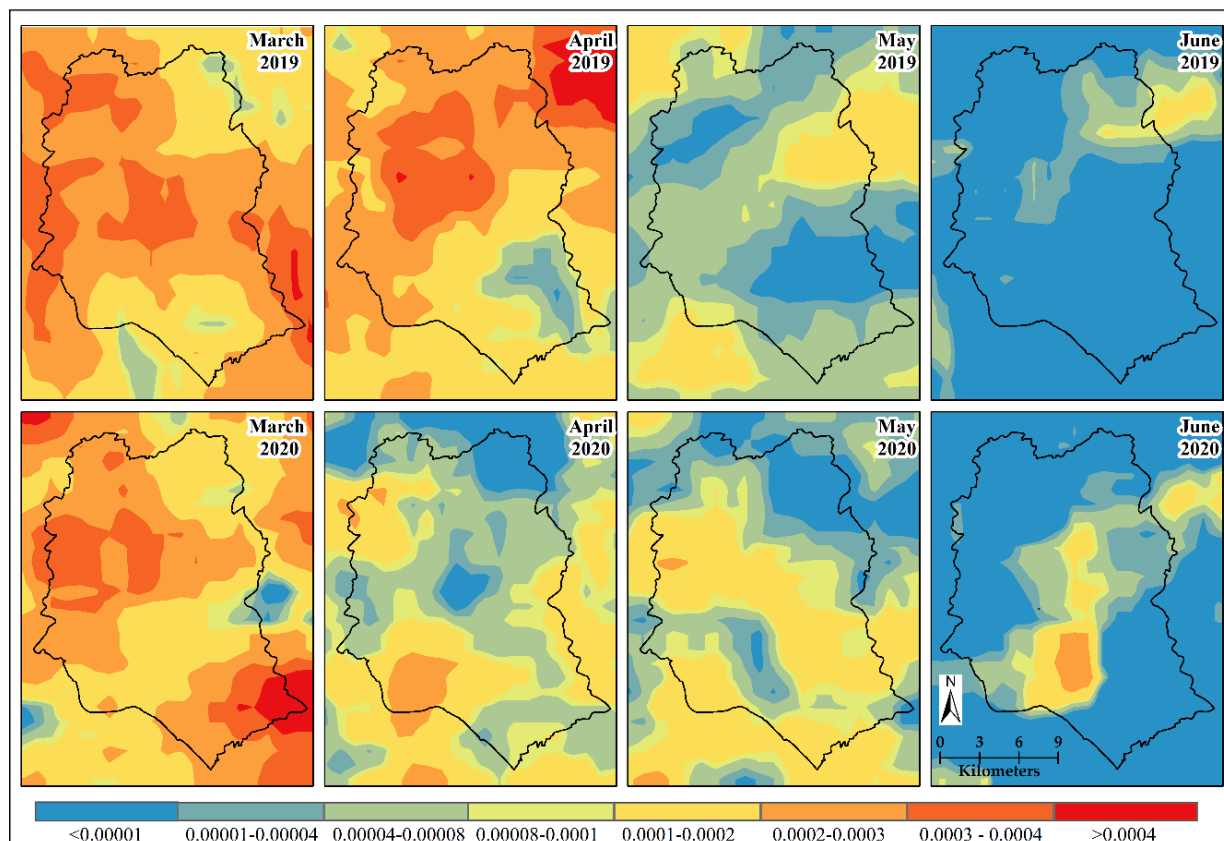
The study also reveals that meteorological variables have a significant correlation with the COVID-19 cases. For instance, relative humidity exhibited a significant positive correlation at lag-0, and atmospheric pressure showed a significant negative correlation at lag-0 to 21. Other studies also showed a significant positive correlation between humidity and daily COVID-19 cases in Mecca and Madina, Saudi Arabia (Alkhowailed *et al.*, 2020), and Buenos Aires, Argentina (Bolaño-Ortiz *et al.*, 2020). Although some studies (Alkhowailed *et al.*, 2020; Rendana, 2020; Rosario *et al.*, 2020) reported that the transmission of COVID-19 is negatively correlated with temperature and wind speed, our study observed no significant ( $p > 0.05$ ) relationship between daily COVID-19 cases and temperature or wind speed (temperature: 24.38–30.73°C, wind speed: 3.25–29.39 km h<sup>-1</sup>). Xie and Zhu (2020) also observed a nonlinear relationship between temperature and COVID-19 confirmed cases at different lag days, with a mean temperature of 26.9°C. It is worth mentioning that the transmission of daily COVID-19 cases could increase during the upcoming winter season (i.e., November–February) like other coronaviruses (e.g., SARS-CoV and MERS-CoV) that had been reported to have better stability at low temperature (Chan *et al.*, 2011). For instance, ~60% of the COVID-19 cases were observed in places with an atmospheric temperature of 5–15°C (Huang *et al.*, 2020).

In addition, associations among and between air pollutants and meteorological variables are presented in Table 4. It is apparent that meteorological conditions influence air pollutants' concentration over a particular region (Liu *et al.*, 2020). In our study, NO<sub>2</sub> showed a significant positive correlation with PM<sub>2.5</sub> at lag-0 to 21 and a significant negative correlation with CO and O<sub>3</sub> at lag-0. However, a significantly positive association was observed between CO and O<sub>3</sub> at lag-0. PM<sub>2.5</sub> showed a significant negative correlation with relative humidity at lag-0 and 7 and with wind speed at lag-0 to 21. In contrast, a significant positive correlation was observed with atmospheric pressure at lag 0. NO<sub>2</sub> showed a significant negative correlation with wind speed at lag-0 to 21 and with atmospheric pressure at lag-0. O<sub>3</sub> represented a significant positive correlation with atmospheric pressure and a significant negative correlation with temperature and wind speed at lag-0 to 21. The temperature showed a significantly negative correlation with relative humidity and atmospheric pressure at lag-0 to 21, while other meteorological parameters showed a significantly negative correlation. Similarly, a significant negative correlation was also observed between wind speed and atmospheric pressure at lag-0 to 21. These results are found to be consistent with the results of other studies (Liu *et al.*, 2020; Hoang and Tran, 2021).

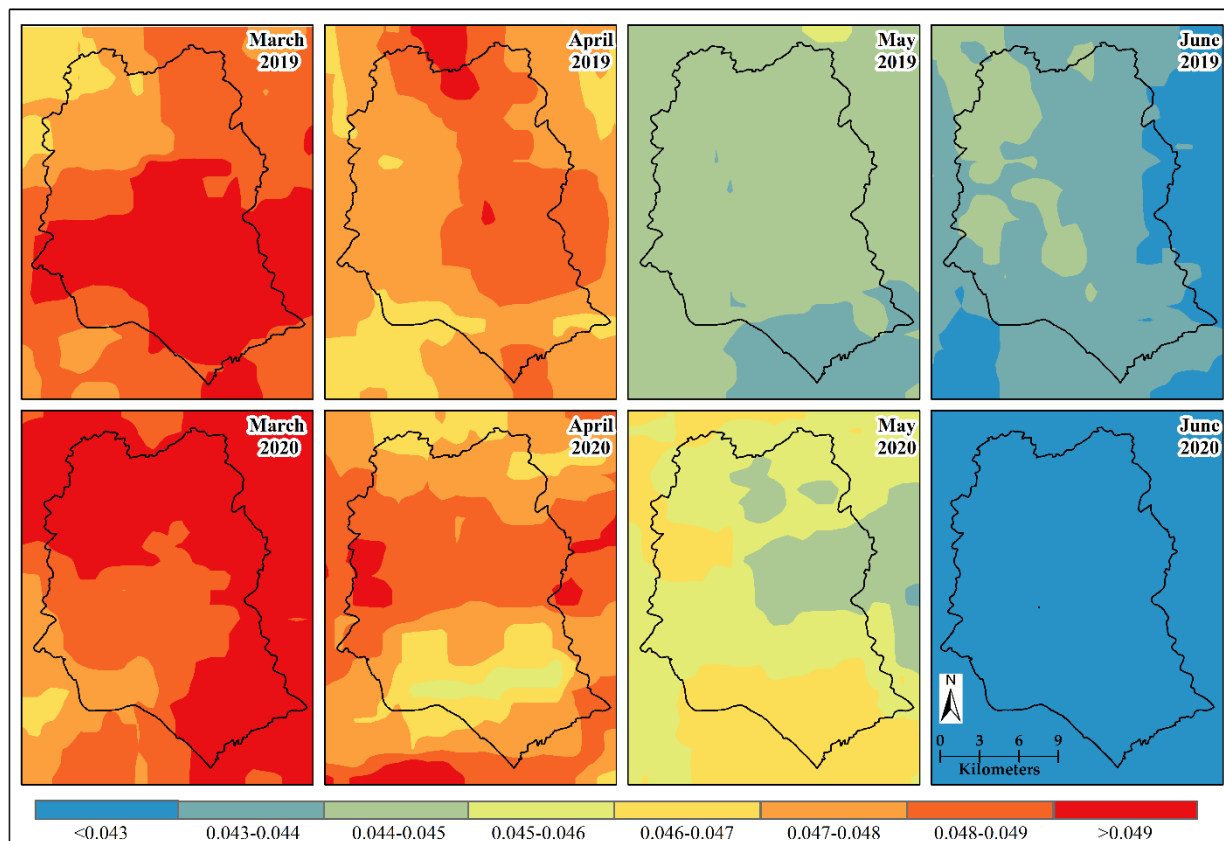
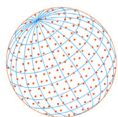




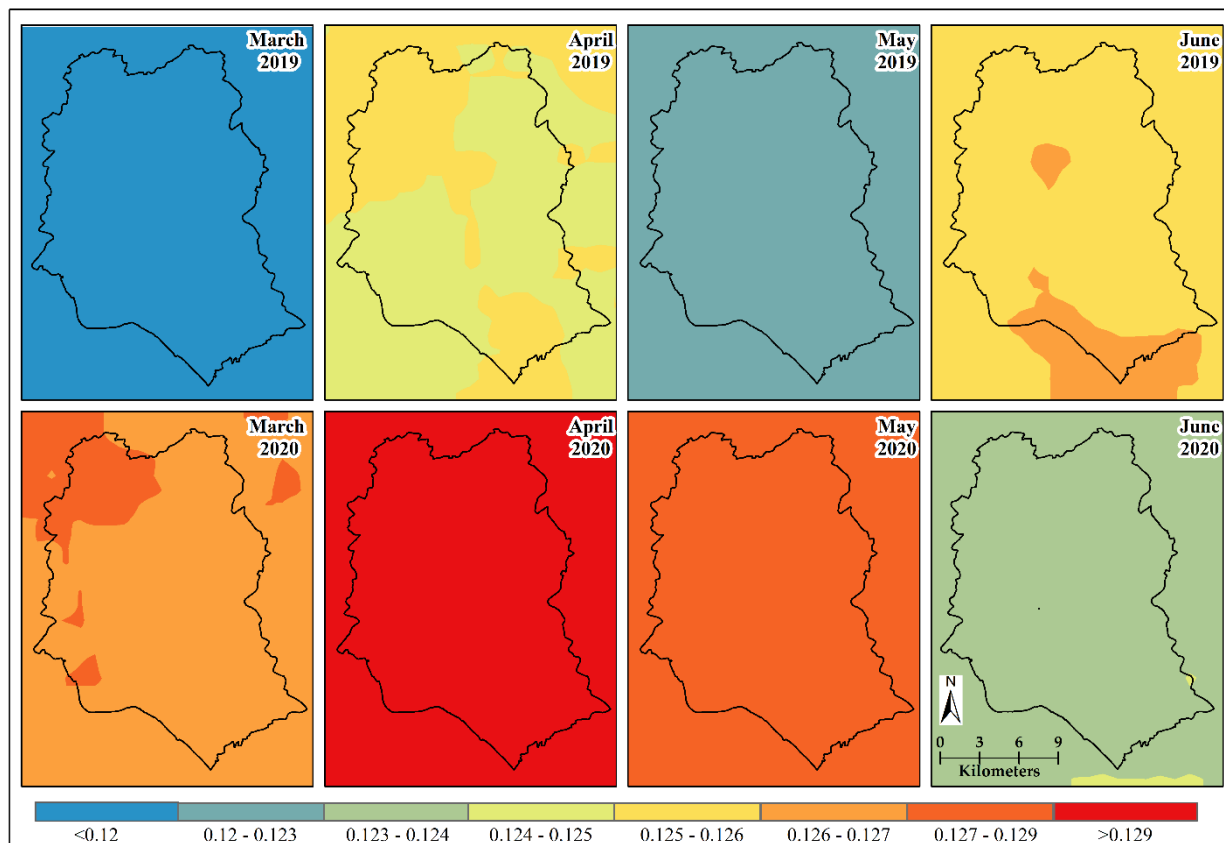
**Fig. 6.** Variations in NO<sub>2</sub> concentrations in Dhaka city from March to June in 2019 and 2020.



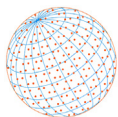
**Fig. 7.** Variations in SO<sub>2</sub> concentrations in Dhaka city from March to June in 2019 and 2020.



**Fig. 8.** Variations in CO concentrations in Dhaka city from March to June in 2019 and 2020.



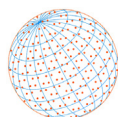
**Fig. 9.** Variations in O<sub>3</sub> concentrations in Dhaka city from March to June in 2019 and 2020.

**Table 4.** Pairwise Spearman's correlation of daily COVID-19 cases, meteorology, and air pollutants.

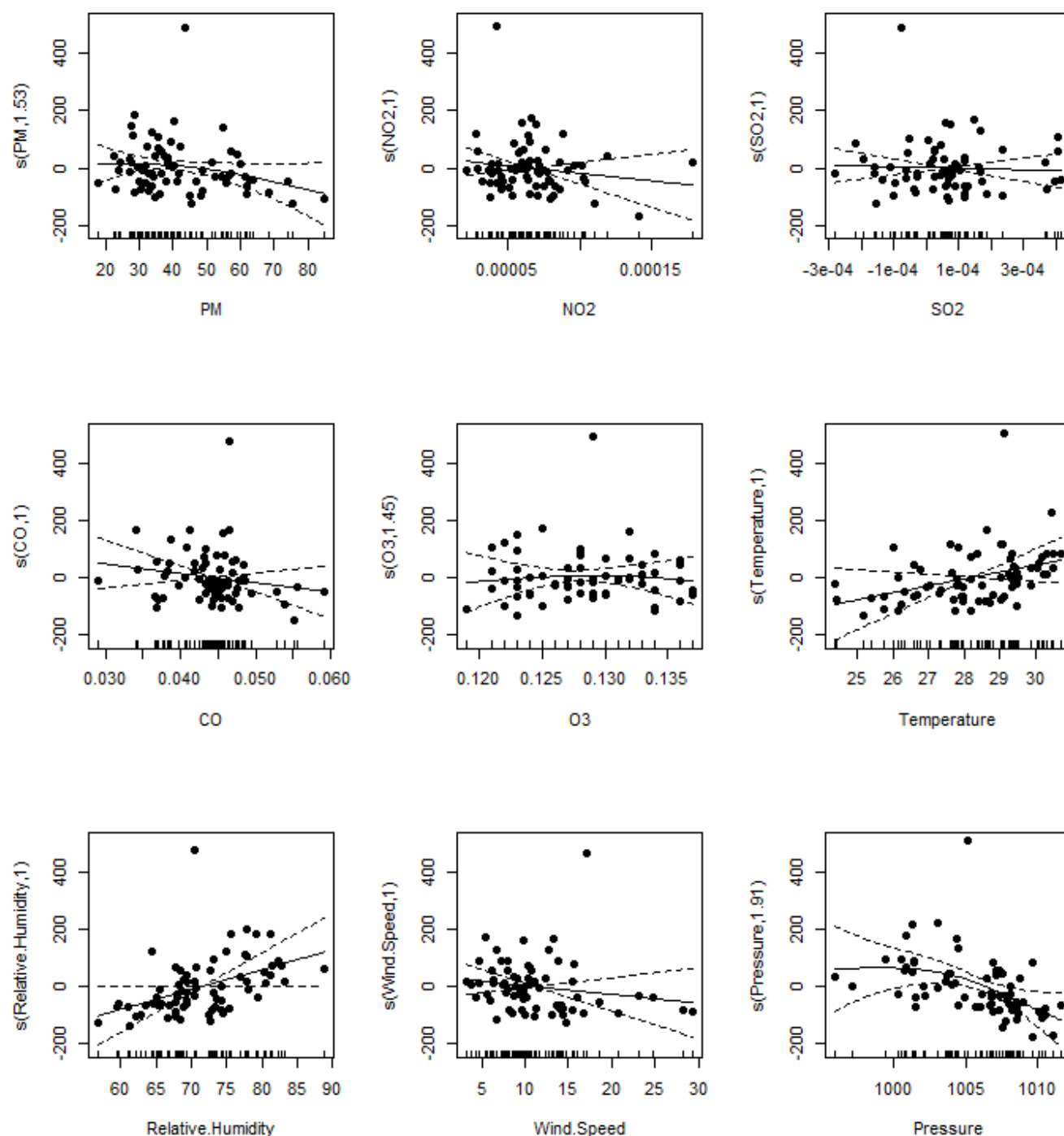
Variable	by Variable	Spearman $\rho$			
		Lag-0	Lag-7	Lag-14	Lag-21
PM <sub>2.5</sub>	COVID-19 cases	-0.28*	-0.16	-0.13	0.05
NO <sub>2</sub>	COVID-19 cases	0.21	0.21	-0.07	0.21
NO <sub>2</sub>	PM <sub>2.5</sub>	0.25*	0.40**	0.40**	0.41**
SO <sub>2</sub>	COVID-19 cases	-0.06	0.02	0.04	-0.05
SO <sub>2</sub>	PM <sub>2.5</sub>	-0.10	-0.07	-0.01	0.11
SO <sub>2</sub>	NO <sub>2</sub>	0.13	0.23	0.24	0.26
CO	COVID-19 cases	-0.40***	-0.38**	-0.13	-0.19
CO	PM <sub>2.5</sub>	0.05	-0.08	-0.10	-0.23
CO	NO <sub>2</sub>	-0.40***	-0.25*	-0.18	-0.21
CO	SO <sub>2</sub>	0.06	0.07	0.03	0.0005
O <sub>3</sub>	COVID-19 cases	-0.56***	-0.45***	-0.41**	-0.27
O <sub>3</sub>	PM <sub>2.5</sub>	0.21	0.142	0.11	0.02
O <sub>3</sub>	NO <sub>2</sub>	-0.31**	-0.20	-0.15	-0.20
O <sub>3</sub>	SO <sub>2</sub>	-0.12	-0.13	-0.22	-0.25
O <sub>3</sub>	CO	0.34**	0.18	-0.04	-0.11
Temperature	COVID-19 cases	0.17	0.02	0.12	0.23
Temperature	PM <sub>2.5</sub>	0.20	0.23	0.19	0.18
Temperature	NO <sub>2</sub>	0.15	0.05	0.03	0.04
Temperature	SO <sub>2</sub>	-0.03	0.02	0.11	0.17
Temperature	CO	0.03	0.14	0.22	0.25
Temperature	O <sub>3</sub>	-0.37***	-0.38**	-0.41**	-0.43**
Relative humidity	COVID-19 cases	0.32**	0.16	0.03	0.004
Relative humidity	PM <sub>2.5</sub>	-0.28*	-0.25*	-0.19	-0.19
Relative humidity	NO <sub>2</sub>	-0.01	-0.04	-0.08	-0.03
Relative humidity	SO <sub>2</sub>	0.01	-0.05	-0.08	-0.09
Relative humidity	CO	-0.28*	-0.27*	-0.23	-0.25
Relative humidity	O <sub>3</sub>	-0.12	-0.07	0.08	0.08
Relative humidity	Temperature	-0.66***	-0.68***	-0.72***	-0.73***
Wind speed	COVID-19 cases	0.18	0.04	0.20	0.006
Wind speed	PM <sub>2.5</sub>	-0.58***	-0.65***	-0.62***	-0.69***
Wind speed	NO <sub>2</sub>	-0.37**	-0.42***	-0.44***	-0.44**
Wind speed	SO <sub>2</sub>	-0.02	0.002	-0.04	-0.01
Wind speed	CO	0.19	0.21	0.24	0.28
Wind speed	O <sub>3</sub>	-0.28*	-0.31*	-0.33*	-0.33*
Wind speed	Temperature	0.03	0.01	0.05	0.07
Wind speed	Relative humidity	0.10	0.16	0.11	0.10
Atmospheric pressure	COVID-19 cases	-0.71***	-0.52***	-0.60***	-0.33*
Atmospheric pressure	PM <sub>2.5</sub>	0.24*	0.16	0.20	0.10
Atmospheric pressure	NO <sub>2</sub>	-0.35**	-0.21	-0.16	-0.27
Atmospheric pressure	SO <sub>2</sub>	0.02	0.02	-0.06	-0.08
Atmospheric pressure	CO	0.41***	0.25	0.07	0.04
Atmospheric pressure	O <sub>3</sub>	0.77***	0.72***	0.65***	0.59***
Atmospheric pressure	Temperature	-0.35**	-0.32*	-0.29*	-0.31*
Atmospheric pressure	Relative humidity	-0.14	-0.10	-0.03	-0.005
Atmospheric pressure	Wind speed	-0.25*	-0.31*	-0.39**	-0.35*

### 3.4 Association between COVID-19 Daily New Cases, Meteorological Variables, and Air Pollutants

We initially conducted a multiple linear regression model (LRM) for different lag days to assess the effects of air pollutants and meteorological variables on daily COVID-19 cases. The LRM result showed that all variables except relative humidity (lag-0 days) and atmospheric pressure (lag-14

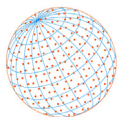


days) exhibited insignificant results with daily COVID-19 cases. As our LRM didn't indicate any strong relation, we used Generalized Additive Model (GAM) to look at the association between COVID-19 cases and air pollutants and meteorological variables. Fig. 10 presents the exposure-response for the mean value of different air pollutants and meteorological variables used with the log-transformed of COVID-19 cases on lag-0 days. The GAM model suggests that on lag-0 days, there was a significant nonlinear relationship between daily relative humidity and pressure ( $p < 0.05$ ) with daily COVID-19 cases. This model explained about 48% of deviance. On lag-7 days,  $PM_{2.5}$  ( $p < 0.01$ ), CO ( $p < 0.05$ ), wind speed ( $p < 0.0001$ ), and pressure ( $p < 0.001$ ) were found to be significantly nonlinear associated with daily COVID-19 cases. The model for lag-7 days



**Fig. 10.** Plots from GAM model in which daily COVID19 cases (lag-0) has been modeled as a smooth function of different air pollutants and meteorological variables.





explained about 67% of deviance. Additionally, on lag-14 days, only atmospheric pressure ( $p < 0.0001$ ) showed a strong nonlinear relationship with daily COVID-19 cases. The adjusted  $R^2$  value for this model was 0.38. Furthermore, on lag-21 days, none of the variables exhibited any significant association with daily COVID-19 cases. This model explained about 41% of deviance.

## 4 CONCLUSIONS

This study investigates how meteorological parameters and air quality variables profoundly impact COVID-19 cases in Dhaka city and evaluate lockdown measures' effectiveness due to COVID-19. The main conclusions are as follows:

- A considerable reduction in  $PM_{2.5}$ ,  $NO_2$ ,  $SO_2$ , and CO, and increased  $O_3$  concentration has been observed due to the complete lockdown from 26 March 2020 to 30 May 2020, which results in significant improvement in air quality in Dhaka city.
- The study revealed that relative humidity among the meteorological parameters showed a significant positive correlation, and atmospheric pressure exhibited a significant negative correlation with daily COVID-19 cases. In contrast, no significant ( $p > 0.05$ ) relationship has been observed between daily COVID-19 cases and temperature or wind speed.
- Regarding the air pollutants, daily COVID-19 cases showed a significant negative correlation with  $PM_{2.5}$ , CO, and  $O_3$  at different lag settings (i.e., lag-0, lag-7, and lag-14, respectively). At the same time, no significant correlation was observed between  $NO_2$  or  $SO_2$  with daily COVID-19 cases. Besides, the GAM model showed a significant nonlinear relationship between meteorological parameters and daily COVID-19 cases at lag-0, lag-7, and lag-14.

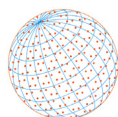
Further studies should be conducted in other cities located in the northern and southern parts of Bangladesh, where the meteorological conditions (e.g., humidity, wind speed, etc.) may vary compared to Dhaka due to various geographic features such as proximity to ocean and hills. Future studies should also consider the seasonal influence on the meteorological condition and COVID-19 cases, as Bangladesh has distinct seasonal variation, and the COVID-19 situation has already passed through different seasons.

## ACKNOWLEDGMENTS

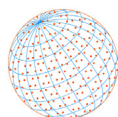
We would like to thank VT's OASF for their APC support.

## REFERENCES

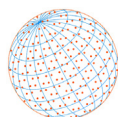
- Adhikari, A., Yin, J. (2020). Short-term effects of ambient ozone,  $PM_{2.5}$ , and meteorological factors on COVID-19 confirmed cases and deaths in Queens, New York. *Int. J. Environ. Res. Public Health* 17, 4047. <https://doi.org/10.3390/ijerph17114047>
- Alam, M., Alam, M., Nazir, K., Bhuiyan, M. (2020). The emergence of novel coronavirus disease (COVID-19) in Bangladesh: Present status, challenges, and future management. *J. Adv. Vet. Anim. Res.* 7, 198–208. <https://doi.org/10.5455/javar.2020.g410>
- Alkhawailed, M., Shariq, A., Alqossayir, F., Alzahrani, O.A., Rasheed, Z., Al Abdulmonem, W. (2020). Impact of meteorological parameters on COVID-19 pandemic: A comprehensive study from Saudi Arabia. *Inf. Med. Unlocked* 20, 100418. <https://doi.org/10.1016/j.imu.2020.100418>
- Anwar, S., Nasrullah, M., Hosen, M.J. (2020). COVID-19 and Bangladesh: Challenges and how to address them. *Front. Public Health* 8, 154. <https://doi.org/10.3389/fpubh.2020.00154>
- Azad, A.K., Kitada, T. (1998). Characteristics of the air pollution in the city of Dhaka, Bangladesh in winter. *Atmos. Environ.* 32, 1991–2005. [https://doi.org/10.1016/S1352-2310\(97\)00508-6](https://doi.org/10.1016/S1352-2310(97)00508-6)
- Bashir, M.F., Ma, B.J., Bilal, Komal, B., Bashir, M.A., Farooq, T.H., Iqbal, N., Bashir, M. (2020). Correlation between environmental pollution indicators and COVID-19 pandemic: A brief study in Californian context. *Environ. Res.* 187, 109652. <https://doi.org/10.1016/j.envres.2020.109652>
- Begum, B.A., Kim, E., Biswas, S.K., Hopke, P.K. (2004). Investigation of sources of atmospheric aerosol at urban and semi-urban areas in Bangladesh. *Atmos. Environ.* 38, 3025–3038. <https://doi.org/10.1016/j.atmosenv.2004.02.042>



- Biswas, R.K., Huq, S., Afiaz, A. (2020). Relaxed lockdown in Bangladesh during COVID-19: Should economy outweigh health? *Int. J. Health Policy Manage.* 9, 488–490. <https://doi.org/10.34172/ijhpm.2020.98>
- Bolaño-Ortiz, T.R., Pascual-Flores, R.M., Puliafito, S.E., Camargo-Caicedo, Y., Berná-Peña, L.L., Ruggeri, M.F., Lopez-Noreña, A.I., Tames, M.F., Cereceda-Balic, F. (2020). Spread of COVID-19, meteorological conditions and air quality in the city of Buenos Aires, Argentina: Two Facets observed during its pandemic lockdown. *Atmosphere* 11, 1045. <https://doi.org/10.3390/atmos11101045>
- Centers for Disease Control and Prevention (CDC) (2020). Interim Clinical Guidance for Management of Patients with Confirmed Coronavirus Disease (COVID-19). <https://www.cdc.gov/coronavirus/2019-ncov/hcp/clinical-guidance-management-patients.html> (accessed 27 August 2020).
- Chan, K.H., Peiris, J.S.M., Lam, S.Y., Poon, L.L.M., Yuen, K.Y., Seto, W.H. (2011). The Effects of Temperature and Relative Humidity on the Viability of the SARS Coronavirus. *Adv. Virol.* 2011, e734690. <https://doi.org/10.1155/2011/734690>
- Cui, Y., Zhang, Z-F., Froines, J., Zhao, J., Wang, H., Yu, S.Z., Detels, R. (2003). Air pollution and case fatality of SARS in the People's Republic of China: An ecologic study. *Environ. Health* 2, 15. <https://doi.org/10.1186/1476-069X-2-15>
- Dong, E., Du, H., Gardner, L. (2020). An interactive web-based dashboard to track COVID-19 in real time. *Lancet Infect. Dis.* 20, 533–534. [https://doi.org/10.1016/S1473-3099\(20\)30120-1](https://doi.org/10.1016/S1473-3099(20)30120-1)
- Environmental Performance Index (2020). Yale Center for Environmental Law & Policy, New Haven. <https://epi.yale.edu/epiresults/2020/component/air> (accessed 19 July 2020).
- Gorai, A., Tchounwou, P., Tuluri, F. (2016). Association between ambient air pollution and asthma prevalence in different population groups residing in eastern Texas, USA. *IJERPH* 13, 378. <https://doi.org/10.3390/ijerph13040378>
- Guan, W.J., Zheng, X.Y., Chung, K.F., Zhong, N.S. (2016). Impact of air pollution on the burden of chronic respiratory diseases in China: time for urgent action. *Lancet*, 388, 1939–1951. [https://doi.org/10.1016/S0140-6736\(16\)31597-5](https://doi.org/10.1016/S0140-6736(16)31597-5)
- Gurjar, B.R., Butler, T.M., Lawrence, M.G., Lelieveld, J. (2008). Evaluation of emissions and air quality in megacities. *Atmos. Environ.* 42, 1593–1606. <https://doi.org/10.1016/j.atmosenv.2007.10.048>
- Hindustan Times (2020). Covid-19: Bangladesh reopens factories, risking new cases. <https://www.hindustantimes.com/world-news/covid-19-bangladesh-reopens-factories-risking-new-cases/story-eOzvdvRDpCP0D1ThAnrfql.html> (accessed 20 June 2020).
- Hoang, T., Tran, T.T.A. (2021). Ambient air pollution, meteorology, and COVID-19 infection in Korea. *J. Med. Virol.* 93, 878–885. <https://doi.org/10.1002/jmv.26325>
- Huang, Z., Huang, J., Gu, Q., Du, P., Liang, H., Dong, Q. (2020). Optimal temperature zone for the dispersal of COVID-19. *Sci. Total Environ.* 736, 139487. <https://doi.org/10.1016/j.scitotenv.2020.139487>
- IEDCR (2020). Bangladesh Coronavirus (COVID-19) Update. <https://www.iedcr.gov.bd/> (accessed 27 June 2020).
- Islam, M.S., Tusher, T.R., Roy, S., Rahman, M. (2021). Impacts of nationwide lockdown due to COVID-19 outbreak on air quality in Bangladesh: A spatiotemporal analysis. *Air Qual Atmos. Health* 14, 351–363. <https://doi.org/10.1007/s11869-020-00940-5>
- Jiang, Y., Wu, X.J., Guan, Y.J. (2020). Effect of ambient air pollutants and meteorological variables on COVID-19 incidence. *Infect. Control Hosp. Epidemiol.* 41, 1011–1015. <https://doi.org/10.1017/ice.2020.222>
- Li, H., Xu, X.-L., Dai, D.-W., Huang, Z.-Y., Ma, Z., Guan, Y.-J. (2020). Air pollution and temperature are associated with increased COVID-19 incidence: A time series study. *Int. J. Infect. Dis.* 97, 278–282. <https://doi.org/10.1016/j.ijid.2020.05.076>
- Lin, S., Wei, D., Sun, Y., Chen, K., Yang, L., Liu, B., Huang, Q., Paoliello, M.M.B., Li, H., Wu, S. (2020). Region-specific air pollutants and meteorological parameters influence COVID-19: A study from mainland China. *Ecotoxicol. Environ. Saf.* 204, 111035. <https://doi.org/10.1016/j.ecoenv.2020.111035>
- Ling, S.H., van Eeden, S.F. (2009). Particulate matter air pollution exposure: Role in the development and exacerbation of chronic obstructive pulmonary disease. *Int. J. COPD* 4, 233–243. <https://doi.org/10.2147/copd.s5098>



- Liu, Y., Zhou, Y., Lu, J. (2020). Exploring the relationship between air pollution and meteorological conditions in China under environmental governance. *Sci. Rep.* 10, 14518. <https://doi.org/10.1038/s41598-020-71338-7>
- Lu, R., Zhao, X., Li, J., Niu, P., Yang, B., Wu, H., Wang, W., Song, H., Huang, B., Zhu, N., Bi, Y., Ma, X., Zhan, F., Wang, L., Hu, T., Zhou, H., Hu, Z., Zhou, W., Zhao, L., Chen, J., *et al.* (2020). Genomic characterisation and epidemiology of 2019 novel coronavirus: implications for virus origins and receptor binding. *Lancet* 395, 565–574. [https://doi.org/10.1016/S0140-6736\(20\)30251-8](https://doi.org/10.1016/S0140-6736(20)30251-8)
- Ma, Y., Zhao, Y., Liu, J., He, X., Wang, B., Fu, S., Yan, J., Niu, J., Zhou, J., Luo, B. (2020). Effects of temperature variation and humidity on the death of COVID-19 in Wuhan, China. *Sci. Total Environ.* 724, 138226. <https://doi.org/10.1016/j.scitotenv.2020.138226>
- Mahato, S., Pal, S., Ghosh, K.G. (2020). Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India. *Sci. Total Environ.* 730, 139086. <https://doi.org/10.1016/j.scitotenv.2020.139086>
- Mahmood, S.A.I. (2011). Air pollution kills 15,000 Bangladeshis each year: The role of public administration and governments integrity. *JPAPR* 3, 129–140. <https://doi.org/10.5897/JPAPR.9000004>
- Noman, A.H.Md., Mia, M.A., Banna, H., Rana, Md.S., Alam, A.S.A.F., Gee, C.S., Isa, C.R., Er, A.C. (2016). City profile: Narayanganj, Bangladesh. *Cities* 59, 8–19. <https://doi.org/10.1016/j.cities.2016.05.020>
- Rahman, M.M., Mahamud, S., Thurston, G.D. (2019). Recent spatial gradients and time trends in Dhaka, Bangladesh, air pollution and their human health implications. *J. Air Waste Manage. Assoc.* 69, 478–501. <https://doi.org/10.1080/10962247.2018.1548388>
- Ran, J., Zhao, S., Han, L., Peng, Z., Wang, M.H., Qiu, Y., He, D. (2020). Initial COVID-19 transmissibility and three gaseous air pollutants (NO<sub>2</sub>, SO<sub>2</sub>, and CO): A nationwide ecological study in China. *Front. Med.* 7, 575839. <https://doi.org/10.3389/fmed.2020.575839>
- Rana, M.M., Khan, M.H. (2020). Trend characteristics of atmospheric particulate matters in major urban areas of Bangladesh. *Asian J. Atmos. Environ.* 14, 47–61. <https://doi.org/10.5572/ajae.2020.14.1.047>
- Rendana, M. (2020). Impact of the wind conditions on COVID-19 pandemic: A new insight for direction of the spread of the virus. *Urban Clim.* 34, 100680. <https://doi.org/10.1016/j.uclim.2020.100680>
- Rodríguez-Urrego, D., Rodríguez-Urrego, L. (2020). Air quality during the COVID-19: PM<sub>2.5</sub> analysis in the 50 most polluted capital cities in the world. *Environ. Pollu.*, 266, 115042. <https://doi.org/10.1016/j.envpol.2020.115042>
- Rosario, D.K.A., Mutz, Y.S., Bernardes, P.C., Conte-Junior, C.A. (2020). Relationship between COVID-19 and weather: Case study in a tropical country. *Int. J. Hyg. Environ. Health* 229, 113587. <https://doi.org/10.1016/j.ijheh.2020.113587>
- Salam, A., Hossain, T., Siddique, M.N.A., Alam, A.M.S. (2008). Characteristics of atmospheric trace gases, particulate matter, and heavy metal pollution in Dhaka, Bangladesh. *Air Qual Atmos. Health* 1, 101–109. <https://doi.org/10.1007/s11869-008-0017-8>
- Shammi, M., Bodrud-Doza, Md., Towfiqul Islam, A.R.Md., Rahman, Md.M. (2020). COVID-19 pandemic, socioeconomic crisis and human stress in resource-limited settings: A case from Bangladesh. *Heliyon* 6, e04063. <https://doi.org/10.1016/j.heliyon.2020.e04063>
- Shi, P., Dong, Y., Yan, H., Zhao, C., Li, X., Liu, W., He, M., Tang, S., Xi, S. (2020). Impact of temperature on the dynamics of the COVID-19 outbreak in China. *Sci. Total Environ.* 728, 138890. <https://doi.org/10.1016/j.scitotenv.2020.138890>
- Sohrabi, C., Alsafi, Z., O'Neill, N., Khan, M., Kerwan, A., Al-Jabir, A., Iosifidis, C., Agha, R. (2020). World Health Organization declares global emergency: A review of the 2019 novel coronavirus (COVID-19). *Int. J. Surg.* 76, 71–76. <https://doi.org/10.1016/j.ijsu.2020.02.034>
- Suhaimi, N.F., Jalaludin, J., Latif, M.T. (2020). Demystifying a possible relationship between COVID-19, air quality and meteorological factors: Evidence from Kuala Lumpur, Malaysia. *Aerosol Air Qual. Res.* 20, 1520–1529. <https://doi.org/10.4209/aaqr.2020.05.0218>
- UNB (2020). COVID-19: Narayanganj EPZ, BSCIC workers at greater risk. UNB News, 4 May 2020. <https://unb.com.bd/category/Bangladesh/covid-19-narayanganj-epz-bscic-workers-at-greater-risk/51088>
- United Nations (UN) (2020). World Urbanization Prospects: The 2018 Revision. United Nations



- Population Division. <https://population.un.org/wup/> (accessed 19 July 2020).
- Wallis, P., Nerlich, B. (2005). Disease metaphors in new epidemics: The UK media framing of the 2003 SARS epidemic. *Soc. Sci. Med.* 60, 2629–2639. <https://doi.org/10.1016/j.socscimed.2004.11.031>
- World Health Organization (WHO) (2020a). Coronavirus Disease 2019 (COVID-19): Situation Report—1. World Health Organization, Geneva. [https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200121-sitrep-1-2019-ncov.pdf?sfvrsn=20a99c10\\_4](https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200121-sitrep-1-2019-ncov.pdf?sfvrsn=20a99c10_4) (accessed 23 September 2020).
- World Health Organization (WHO) (2020b). WHO global urban ambient air pollution database (update 2016). <https://www.who.int/airpollution/data/cities-2016/en/> (access 20 June 2020).
- World Health Organization (WHO) (2020c). WHO coronavirus disease (COVID-19) dashboard. <https://covid19.who.int/region/searo/country/bd> (accessed 28 September 2020).
- World Health Organization (WHO) (2020d). Mortality and burden of disease from ambient air pollution. [https://www.who.int/gho/phe/outdoor\\_air\\_pollution/burden\\_text/en/](https://www.who.int/gho/phe/outdoor_air_pollution/burden_text/en/) (accessed 20 July 2020).
- Worldometer (2020a). COVID-19 coronavirus pandemic. <https://www.worldometers.info/coronavirus/> (accessed 28 September 2020).
- Worldometer (2020b). Annual population data of Bangladesh. <https://www.worldometers.info/world-population/bangladesh-population/> (accessed 28 September 2020).
- Xie, J., Zhu, Y. (2020). Association between ambient temperature and COVID-19 infection in 122 cities from China. *Sci. Total Environ.* 724, 138201. <https://doi.org/10.1016/j.scitotenv.2020.138201>
- Zhu, Y., Xie, J., Huang, F., Cao, L. (2020). Association between short-term exposure to air pollution and COVID-19 infection: Evidence from China. *Sci. Total Environ.* 727, 138704. <https://doi.org/10.1016/j.scitotenv.2020.138704>