Significance between Air pollutants, Meteorological Factors and COVID-19 Infections:

Probable Evidences in India

Mrunmayee Manjari Sahoo*

*Domain of Environmental and Water Resources Engg, SCE, Lovely Professional University,
Phagwara-144411, India, mrunmayee.23405@lpu.co.in

Abstract

SARS-CoV-2 (Coronavirus) disease represents the causative agent with a potentially fatal risk which is having great global human health concern. Earlier studies suggested that air pollutants and meteorological factors were considered as the risk factors for acute respiratory infection, which carries harmful pathogens and affects the immunity. The study intended to explore the correlation between air pollutants, meteorological factors and the daily reported infection cases caused by novel coronavirus in India. The daily positive infected cases, air pollution and meteorological factors in 288 districts were collected from January 30, 2020 to April 23, 2020 in India. Speraman’s correlation and generalised additive model were applied to investigate the correlations of four air pollutants (PM$_{2.5}$, PM$_{10}$, NO$_2$ and SO$_2$) and eight meteorological factors (Temp, DTR, RH, AH, AP, RF, WS and WD) with COVID-19 infected cases. The study indicated that a 10 µg/m$^3$ increase during (Lag0-14) in PM$_{2.5}$, PM$_{10}$ and NO$_2$ was resulted in 2.21% (95% CI: 1.13 to 3.29), 2.67% (95% CI: 0.33 to 5.01) and 4.56 (95% CI: 2.22 to 6.90) increase in daily counts of COVID 19 infected cases respectively. However, only 1 unit increase in meteorological factor levels in case of daily mean temperature and DTR during (Lag0-14) associated with 3.78% (95%CI: 1.81 to 5.75) and 1.82% (95% CI: -1.74 to 5.38) rise of COVID-19 infected cases respectively. In addition, SO$_2$ and relative humidity were negatively associated with COVID-19 infected cases at Lag0-14 with decrease of 7.23% (95% CI: -10.99 to -3.47) and 1.11% (95% CI: -3.45 to 1.23) for SO$_2$ and for relative humidity respectively. The study recommended that there is significant relationship between air pollutants and meteorological factors with COVID-19 infected cases, which
substantially explain the effect of national lockdown and suggested positive implications for control and prevention of the spread of SARS-CoV-2 disease.

Keywords: Air pollution, Meteorological factors, COVID-19, Speraman’s correlation, Generalised additive model

Capsule: The study concludes the significant relationship between air pollutants and meteorological factors with COVID-19 infected cases, which can substantially explain the effect of national lockdown and recommended positive implications for control and prevention of the spread of SARS-CoV-2 disease.

1. Introduction

First strains of human coronavirus were classified in the 1960’s, the virus was responsible for upper respiratory tract infection in young patients (Khan et al., 2020; Shereen et al., 2020; Tyrrell and Myint, 1996). The coronavirus pandemic is an ongoing pandemic as COVID-19 caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). The disease outbreak was first identified in Wuhan, China in the month of December, 2019 (Hellewell et al., 2020; Lu et al., 2020.; Ma et al., 2020; Remuzzi and Remuzzi, 2020; Xu et al., 2020). In consecutive days, the disease spread rapidly in the nearby countries and rest of the world, which became a global human health degrade issue (Breslin et al., 2020; Chong et al., 2020; Her, 2020; Lodigiani et al., 2020; Niu et al., 2020; Segars et al., 2020; Shahzad et al., 2020; Wu et al., 2020). As of 23rd Apr, 2020, a total of 25,44,792 confirmed cases of COVID-19 had been reported globally, including more than 21,700 cases in India, and more than 17,5,690 reported deaths globally (WHO, 2020). As people with the COVID-19 infection arrived in India without ongoing transmission, potential control measures have been enforced within India to try to enclose the spread of the outbreak (WHO, 2020) and to halt transmission. Isolation of infected and suspected patients along with the identification of contacts are the important aspects of control the outbreak, whereas it is still unclear that these efforts will achieve the control of COVID-19 transmission. Most of the patients have infected with SARS-CoV-2 have mild to no symptoms including fever, throat irritation
and dry cough (Cevik et al., 2020; Civil and Morettini, 2020; Moghanibashi-mansourieh, 2020). In addition, some of the patients have severe acute respiratory infections with incurable complications and increasing mortal risk (Giacomelli et al., 2020; Wang et al., 2020).

Like that of influenza virus (SARS) cases, several studies have been conducted to analyse the significant factors affecting the droplets transmission of SARS-CoV-2. The impact of air pollutants and meteorological factors have been demonstrated to evaluate human-to-human contact, which could rise the risk of COVID-19 infections (Auler et al., 2020; Bashir et al., 2020; Briz-redón and Serrano-aroca, 2020; Chan et al., 2020). Besides, the droplets transmission from human to human has a significant effect on increase in number of COVID-9 infected cases, association of air pollutants and meteorological parameters have shown significant correlations with COVID-19 infections (Fattorini and Regoli, 2020; Frontera et al., 2020; Muhammad et al., 2020; Ogen, 2020; Qi et al., 2020; Wang and Su, 2020; Xie and Zhu, 2020). The impact of air pollution in increasing number of COVID-19 cases lacks careful attention and research.

Previous researches have recommended that the ambient meteorological factors and air pollutants were acted as the risk factors for acute to severe respiratory infection by carrying fatal micro pathogens and organisms. The micro pollutants and pathogens affect the human body by decreasing the level of immunity and more vulnerable and prone toward the SARS-CoV-2 (Cai et al., 2019; Hernandez et al., 2018; Pettersson et al., 2019).

In this manuscript, we have applied a generalised additive model (GAM) to explore the association between daily reported infected due to COVID-19, and various factors including air pollutants and meteorological conditions in India (Gerling et al., 2020; X. Lin et al., 2018; Ma et al., 2020; Prata et al., 2020; Ravindra et al., 2019). The objectives of the proposed study were i) to investigate the consequences of air pollutants and meteorological factors on COVID-19 infections., ii) to recommend useful significance and correlations to regulate and prevent the spread of the novel SARS-CoV-2 diseases, iii) to correlate the and analyse the inter and intra relationship between four air pollutants,
eight meteorological factors and daily reported COVID-19 infected cases in eight most infected states
having 288 districts in India by using generalised additive model (GAM).

2. Materials and Methodology

2.1 Study Area

The proposed study considered 32 states and Union Territories of India having geographical location
at north of the equator between 8°4' north to 37°6' north latitude and 68°7' to 97°25' east longitude
as shown in Fig. 1. According to Ministry of Health and Family Welfare, Government of India, 21,700 COVID-
19 infected cases have been reported in the whole of the country India as of April 23, 2020. The study
included eight states with high COVID-19 infected cases covering around 65% of the total COVID-19 cases
reported in the country. The analysis focused on 288 districts of the eight most COVID-19 affected States,
Delhi, Uttar Pradesh, Maharashtra, Kerala, Karnataka, Telangana, Madhya Pradesh and Tamil Nadu. The
meteorological, air pollution and COVID-19 infected cases data have collected for these States.
Fig. 1. Locations of 32 states and union territories and cumulative COVID-19 infected cases in each state as of April 23, 2020

2.2 Data Collection

Daily notified infected cases for the selected districts, states and union territories between 30th Jan 2020 to 23rd Apr 2020 were collected from the reports updated by Ministry of Health and Family Welfare, Government of India.

Air pollution data were collected from an online platform (www.openaq.org) monitoring daily and hourly data for air quality. The concentrations of four pollutants such as particulate matters with diameters ≤ 2.5 µm (PM$_{2.5}$), particulate matters with diameters ≤ 10 µm (PM$_{10}$), nitrogen dioxide (NO$_2$) and sulfur dioxide...
(SO$_2$) were extracted. The air pollutants concentration in eight states with respect to wind speed and wind direction were represented in Fig. 2.
Fig 2. The concentration of four air pollutants (PM$_{2.5}$, PM$_{10}$, NO$_2$ and SO$_2$) based on wind speed and wind direction over the eight states and union territories.

Meteorological data on daily diurnal temperature range (DTR), mean temperature, relative humidity (RH), absolute humidity (AH), air pressure (AP), Rainfall (RF), wind speed (WS), wind direction (WD) were collected during the study period from Indian Meteorological Department (www.imd.gov.in). The meteorological parameters except wind speed and wind direction were represented by box plots in Fig. 3 which depicted the maximum, minimum, 1st quartile, median and 3rd quartile values.
NOTE: Name of states and UTs: DL: Delhi, KA: Karnataka, MH: Maharashtra, MP: Madhya Pradesh, TG: Telengana, TN: Tamil Nadu and UP: Uttar Pradesh

Absolute humidity (AH, g/m³), which is considered as the mass of water in a unit volume of air, was estimated through dry bulb temperature, dew point temperature and relative humidity using the derived equation with the assumptions of standard atmospheric pressure of the study area (Qi et al., 2020; H. Xu et al., 2014).
The equation is derived as

\[ AH = \frac{1000 \times (6.11 \times 10^3 \times 100)}{((T_c + 273.16) \times 461.5)} \]

Where, \( T_c = \) The dry bulb temperature, which is considered as the daily mean temperature for the study, and

\[ T_1 = \frac{7.5 \times T_d}{(237.7 + T_d)} \]

Where, \( T_d = \) the dew point temperature. Here, \( T_d \) is calculated from the equation below considering dry bulb temperature and relative humidity. The equation is expressed as:

\[ T_d = \frac{(-430.22 + 237.7 \times \ln E)}{(-\ln E + 19.08)} \]

Where \( E = RH \times \frac{E_s}{100} \), \( E_s = 6.11 \times 10^T_2 \) and \( T_2 = \frac{7.5 \times T_c}{(237.7 + T_c)} \). The 3-dimensional graphical representation of \( AH, T_c \) and RH is shown in Fig. 4.
Fig. 4. 3D association of meteorological parameters, Absolute Humidity, Relative Humidity with Daily mean temperature

2.3 Statistical Analysis

Descriptive statistics were performed to distinguish the environmental factors (absolute humidity, relative humidity, windspeed, air pressure, rainfall, daily mean temperature and diurnal temperature range) at 24 hours interval over the study period. Spearman’s correlation analysis was performed to evaluate the correlations between the air pollutants, meteorological factors and the number of infected cases due to COVID-19.

The Generalised Additive Model (GAM) was applied to correlate the daily infected counts, air pollutants and meteorological parameters (Xiaoping Liu et al., 2019; Prata et al., 2020; Xiao et al., 2019; Xie and Zhu, 2020). The model is an effective approach to determine the effects of air pollutants concentration and change of meteorological factors on health of a human being during the lag period of infection (Hu et al., 2020; M. Lin et al., 2018; Ma et al., 2020; Pearce et al., 2011; Ravindra et al., 2019). As per previous studies, air pollution can be the combination of different gases and particulate matters. Both the short term and long-term exposure to air pollutants can lead to a variety of health problems such as asthma or chronic obstructive pulmonary diseases (COPD) or can cause persistent wheezing or coughing. These studies concluded that the effect of high concentration air pollutants may last for days or week (Cirera et al., 2012; Glick et al., 2019; Hendryx et al., 2019; Hu et al., 2020; Huang et al., 2017; Kersen et al., 2020; Peng et al., 2019; Su et al., 2019). Qi et al., 2019 suggested that meteorological parameters have significant effects on dispersion, dilution and diffusion of air pollutants which ultimately affect the distribution, condensation and concentration of pollutants (Keshavarzian et al., 2020; Lim et al., 2020; Xiaoping Liu et al., 2019; Saha et al., 2018; Tiwari and Kumar, 2020; Junhua Yang et al., 2020; Z. Yang et al., 2020). However, there is an incubation period of 5 to 14 days to show the symptoms of COVID-19 infections as reported by the World Health Organisation and Indian Council of Medical Research (Report, 2020). Following the same, moving
average approach was applied to determine the cumulative lag effect of air pollutants and their association with meteorological factors (Kim et al., 2019; Qiu et al., 2020; Rojas-roa and Rodríguez-villamizar, 2019; Y. Zhang et al., 2019; Zhang et al., 2020; Zhu et al., 2018, 2019). So, Generalised additive model (GAM) with Gaussian distribution was utilised to connect the infected rate due to COVID-19 and air pollutants or meteorological parameters (Chuang et al., 2011; Gao et al., 2019; Ravindra et al., 2019; Sun et al., 2015; Tong et al., 2018; Yoon, 2019; Zhang and Batterman, 2010). The model also used to estimate the correlations between moving average concentrations of air pollutants and meteorological factors at Lag0-7, Lag0-14 and Lag0-21 with daily reported COVID-19 infected cases in India (Charles et al., 2020; Ge et al., 2017; Hao et al., 2019; Liang et al., 2020a; Lin et al., 2013; Jiandong Yang et al., 2020).

The effects of four considered air pollutants (PM$_{2.5}$, PM$_{10}$, NO$_2$ and SO$_2$) and six meteorological factors (Daily mean temperature, DTR, air pressure, relative humidity, absolute humidity and rainfall) were examined in ten separate single pollutant or meteorological model to decrease collinearity or consecutiveness as some considered pollutants or factors were remarkably correlated (Dastoorpoor et al., 2019).

The GAM model was constructed as follows:

$$\log(p_{it}) = \alpha + Q_i + s(\text{temp}_{id}) + s(DTR_{id}) + s(rainf_{id}) + s(rhum_{id}) + s(\text{apres}_{id})$$

$$+ s(\text{ahum}_{id}) + s(\text{wins}_{id}) + \log(p_{i,t-1}) + (\text{time}_{t}) + (\text{day}_{t}) + \varepsilon_{it}$$

where, $\log(p_{it})$ was defined the log-transformed daily infected COVID 19 counts reported on any day, $t$ in any of the district $i$. To avoid considering the logarithm of 0, 1 was added in the list () $\alpha$ is the intercept. $Q_{i,d}$ depicts the linear definite term of $(d + 1)$ day moving average concentration of air pollutants and meteorological factor lag$(0 - d)$ in the district $i$ (Borge et al., 2019; Li, 2017; Liang et al., 2020b; Vidale et al., 2017; Wei et al., 2020). $\log(p_{i,d-1})$ was defined as the log-transformed COVID 19 infected cases reported on day $(d - 1)$ in the district, $i$ to determine the possible sequential correlation in the collected data (W. Liu et al., 2020; Xie and Zhu, 2020). In addition, contemplating
The less correlated meteorological factors during the study period were regulated for the potential cofounding effect, which included the meteorological factors such as, mean temperature ($temp_{id}$), diurnal temperature range ($DTR_{id}$), rainfall ($rainf_{id}$), relative humidity ($rhum_{id}$), air pressure ($apres_{id}$) absolute humidity ($ahum_{id}$) and wind speed ($wins_{id}$). $s(.)$ Refers to the natural smoothing function characterised by natural spline with 3 degrees of freedom ($df$) for meteorological variation to accommodate the daily analysis and trends for the study. Along with air pollutants and meteorological factors, time factor ($time_i$) is added to include the district steady effects to regulate the characteristics such as demographic variation and density, day steady effects ($day$), focusing on time of the day is considered to control uncertain parameters influencing the districts each day before, during and after lockdown (Chen et al., 2019, 2020; M. Lin et al., 2018; Xiaoxiao Liu et al., 2019; Tian et al., 2020; Yáñez et al., 2017).

Sensitivity Analyses were supervised to investigate the robustness of the proposed models. To conduct the sensitivity analysis, the state, Maharashtra with 36 districts and the Union territory, Delhi with its 11 districts were excluded from the analysis as the state Maharashtra has highest number of COVID-19 infected cases till the study period. The union territory, Delhi was excluded to avoid the entry of foreign infected nationals through the International airport at Delhi which acted as a connecting link between the COVID-19 infected countries. In other hand, multi-parameter models were designed to differentiate the robustness between single parameter model and multi-parameter model, when supervising the pollutants in the basic constructed model (Baccini et al., 2007; Chen et al., 2018; Phosri et al., 2019; Yang et al., 2015; Zhao et al., 2012).

The hypothesis tests conducted for the study were two tailed with a significance level of 0.05. The effects of air pollutants and meteorological factors were represented as percentage change (%) and corresponding 95% confidence intervals (CIs) of daily mean infected cases due to COVID-19 per unit increase in considered air pollutants concentration (i.e., 10.0 $\mu g/m^3$ increase in PM$_{2.5}$, PM$_{10}$, NO$_2$ and
SO$_2$) and meteorological factors (1 unit increase in daily mean temperature, diurnal temperature range, relative humidity, absolute humidity, air pressure, rainfall).

3. Results and Discussion

3.1 Statistical Representation of Meteorological factors, Air Pollutants, and Infected cases due to COVID-19

Descriptive statistics are represented in Table 1 from 30th Jan 2020 to 23rd Apr 2020 for the air pollutants such as PM$_{2.5}$, PM$_{10}$, NO$_2$ and SO$_2$; meteorological parameters such as Daily mean temperature, DTR, Wind Speed, Rainfall, Relative Humidity, Absolute Humidity, Air Pressure, and COVID-19 infected cases for the first reported place, Kerala and seven in seven other states such as Delhi, Karnataka, Madhya Pradesh, Maharashtra, Tamil Nadu, Telangana and Uttar Pradesh.

During the study period, the 24 hr weighted average concentrations, SD, IQR of the pollutant parameters, PM$_{2.5}$, PM$_{10}$, NO$_2$ and SO$_2$ were represented in Table 1, the concentrations of PM$_{2.5}$ and PM$_{10}$ were reported as higher in seven states out of eight whereas the values of NO$_2$ and SO$_2$ were lesser in seven states out of eight as per National Air Quality Standards, India (The limits for PM$_{2.5}$, PM$_{10}$, NO$_2$ and SO$_2$ were up to 60.0 $\mu$g/m$^3$, 100 $\mu$g/m$^3$, 80.0 $\mu$g/m$^3$ and 80.0 $\mu$g/m$^3$ at Industrial area, Residential area, Rural & other ecologically sensitive areas) (MoEF, 2010). Average temperature of the stations was around 28°C ranging from 24.26 to 29.65 °C, and the average relative humidity was around 47% varying from 32.22 to 68.93% during the period, showing a sub-humid, warm and arrival of summer climate for the considered stations, whereas the average wind speed ranged from 1.82 to 4.07 m/s.

In India, a total of 21,700 infected cases and 720 deaths occurred due to COVID-19, with an average daily average mortality rate of 3.3%.

The daily inter quartile range (IQR) for the air pollutant parameters PM$_{2.5}$, PM$_{10}$, NO$_2$ and SO$_2$ range from 18.62 to 103 $\mu$g/m$^3$, 8.0 to 59.80 $\mu$g/m$^3$, 12.73 to 48.00 $\mu$g/m$^3$, 0.00 to 38.25 $\mu$g/m$^3$ respectively.
with the highest concentrations at Delhi in the case of PM$_{2.5}$, PM$_{10}$ and NO$_2$. However, the highest number of infected and death cases was reported in the State of Maharashtra.

Table 2 represented the spearman’s correlation coefficients between air pollution parameters and meteorological indicators considered for the study. The air pollutants PM$_{2.5}$, PM$_{10}$ and NO$_2$ and the meteorological factors such as wind speed, daily mean temperature, DTR and air pressure had significant positive associations with the infected cases due to COVID19. The air pollutant, SO$_2$ and meteorological factors, Relative Humidity, Rainfall and Absolute Humidity had negative correlation with infected cases of COVID-19. In other hand, the air pollutants (PM$_{2.5}$, PM$_{10}$, NO$_2$ and SO$_2$) had a significant correlation with each other and the pollutants had positive correlations with DTR, air pressure, absolute humidity and rainfall. The parameters such as wind speed, temperature and relative humidity were negatively correlated with the pollutant parameters.

### 3.2 Lag Analysis of Air Pollutants, meteorological indicators in relation to COVID19 confirmed cases

The moving average lag effects considering single-parameter model with pollutants or meteorological factors were calculated for the above extracted parameters which were correlated with COVID-19 infected cases. The lag effects (Lag0-7, Lag0-14, Lag0-21) of air pollutants and meteorological factors on daily report of COVID-19 confirmed cases were represented in Fig. 5. Significant Positive correlations were observed for the air pollutants, PM$_{2.5}$, PM$_{10}$ and NO$_2$ and meteorological factors, daily mean temperature and DTR with COVID-19 infected cases, whereas significant negative correlations were observed for air pollutant, SO$_2$ and meteorological factor, relative humidity. As per the analysis, a 10 µg/m$^3$ increase during (Lag0-14) in PM$_{2.5}$, PM$_{10}$ and NO$_2$ was resulted in 2.21% (95%CI: 1.13 to 3.29), 2.67% (95% CI: 0.33 to 5.01) and 4.56 (95% CI: 2.22 to 6.90) increase in daily counts of COVID-19 infected cases respectively. However, only 1 unit increase in meteorological factor levels in case of Temperature and DTR during (Lag0-14) associated with 3.78% (95%CI: 1.81 to 5.75)
and 1.82% (95% CI: -1.74 to 5.38) rise of COVID-19 infected cases respectively. On other way, other meteorological parameters such as relative humidity, rainfall and absolute humidity were negatively correlated with COVID-19 infected cases. The air pollutant, SO₂ and meteorological factor, relative humidity were negative associated with COVID 19 infected cases at Lag0-7: -5.12% (95% CI: -7.99 to -2.2523) and Lag0-14: -7.23% (95% CI: -10.99 to -3.47) for SO₂ and at Lag0-7: 0.98% (95% CI: -1.01 to 2.96) and Lag0-14: -1.11% (95% CI: -3.45 to 1.23) for relative humidity.

Table 1: Daily Pollutant Parameters concentrations, meteorological parameters concentrations, and daily infected cases from COVID19 in India.

| Parameters | Descriptive Statistics | Delhi | Karnataka | Kerala | Madhya Pradesh | Maharashtra | Tamil Nadu | Telangana | Uttar Pradesh |
|------------|------------------------|-------|-----------|--------|----------------|-------------|------------|------------|---------------|
| PM₁₅       | Mean                   | 144.21| 74.36     | 80.09  | 75.31          | 128.58      | 81.66      | 49.04      | 95.95         |
|            | Std. Deviation         | 76.86 | 55.68     | 61.21  | 50.65          | 253.49      | 66.32      | 16.97      | 42.81         |
|            | Interquartile Range    | 103.00| 22.42     | 58.50  | 52.75          | 41.25       | 45.73      | 18.62      | 51.50         |
| PM₁₀       | Mean                   | 90.68 | 30.00     | 27.37  | 113.21         | 54.74       | 80.92      | 56.53      | 53.60         |
|          | Std. Deviation | 41.66 | 6.48 | 7.21 | 19.40 | 11.69 | 29.85 | 21.24 | 18.71 |
|----------|----------------|-------|------|------|-------|-------|-------|-------|-------|
| Interquartile Range | 59.80 | 8.00 | 38.50 | 14.00 | 57.63 | 21.36 | 14.52 |
| NO₂      | Mean           | 48.78 | 28.80 | 99.09 | 31.62 | 31.32 | 36.33 | 33.27 | 61.30 |
| Std. Deviation | 28.61 | 22.26 | 37.75 | 22.85 | 31.14 | 12.13 | 21.11 | 7.36  |
| Interquartile Range | 48.00 | 37.28 | 33.30 | 44.76 | 34.09 | 12.73 | 32.90 | 13.06 |
| SO₂      | Mean           | 11.69 | 3.03  | 7.07  | 18.44 | 4.03  | 3.57  | 0.40  | 32.11 |
| Std. Deviation | 8.30  | 3.17  | 1.65  | 6.26  | 0.39  | 2.36  | 0.00  | 41.46 |
| Interquartile Range | 17.06 | 2.39  | 2.40  | 11.88 | 0.51  | 2.19  | 0.00  | 38.25 |

**Meteorological Factors**

| Wind Speed | Mean | 2.16 | 3.15 | 1.82 | 2.03 | 4.07 | 2.85 | 2.54 | 1.98 |
|------------|------|------|------|------|------|------|------|------|------|
| Std. Deviation | 1.07 | 1.18 | 1.30 | 0.96 | 1.52 | 0.72 | 1.00 | 0.93 |
| Interquartile Range | 1.93 | 1.81 | 1.59 | 1.56 | 2.34 | 1.14 | 1.29 | 1.39 |
| Temp Mean | 24.26 | 27.47 | 28.24 | 29.65 | 27.13 | 28.00 | 29.64 | 26.02 |
| Std. Deviation | 4.24 | 0.85 | 0.52 | 2.39 | 1.22 | 0.96 | 1.55 | 4.17 |
| Interquartile Range | 6.56 | 1.54 | 0.79 | 2.89 | 1.21 | 1.45 | 2.56 | 7.53 |
| Diurnal Temp Range Mean | 15.87 | 12.43 | 10.64 | 13.61 | 11.76 | 10.80 | 12.48 | 15.91 |
| Std. Deviation | 2.51 | 1.50 | 1.97 | 1.44 | 1.00 | 1.04 | 0.75 | 2.18 |
|                           | Interquartile Range | 3.35 | 1.98 | 2.47 | 2.62 | 1.58 | 1.98 | 0.99 | 3.09 |
|---------------------------|---------------------|------|------|------|------|------|------|------|------|
| Absolute Humidity Mean    |                     | 1.85 | 2.12 | 2.83 | 1.64 | 2.72 | 2.79 | 2.03 | 1.78 |
| Std. Deviation            |         | 0.17 | 0.18 | 0.12 | 0.30 | 0.18 | 0.11 | 0.23 | 0.22 |
| Interquartile Range       |         | 0.26 | 0.29 | 0.21 | 0.29 | 0.23 | 0.11 | 0.34 | 0.30 |
| Relative Humidity Mean    |                     | 37.56| 40.32| 68.93| 22.79| 67.51| 67.84| 33.71| 32.22|
| Std. Deviation            |         | 11.80| 8.03 | 5.89 | 12.63| 6.01 | 3.94 | 10.01| 13.36|
| Interquartile Range       |         | 21.80| 10.30| 8.92 | 8.93 | 9.25 | 5.76 | 15.32| 18.24|
| Rainfall Mean             |                     | 0.44 | 0.40 | 1.38 | 0.20 | 0.00 | 0.05 | 0.28 | 0.52 |
| Std. Deviation            |         | 1.01 | 0.92 | 2.31 | 0.65 | 0.02 | 0.15 | 0.89 | 1.55 |
| Interquartile Range       |         | 0.24 | 0.12 | 1.87 | 0.04 | 0.00 | 0.00 | 0.00 | 0.10 |
| Air Pressure Mean         |                     | 983.63| 915.31| 1004.18| 953.57| 1010.84| 1008.75| 941.43| 991.76|
| Std. Deviation            |         | 7.28 | 3.11 | 5.03 | 1.17 | 1.36 | 1.00 | 17.44| 2.21 |
| Interquartile Range       |         | 3.12 | 1.00 | 9.33 | 1.31 | 1.60 | 1.31 | 1.60 | 9.82 |
| COVID 19 Cases Infected   |                     | 42.42| 9.44 | 5.15 | 48.24| 116.18| 33.94| 18.11| 28.24|
| Std. Deviation            |         | 72.37| 9.62 | 8.00 | 65.11| 155.18| 40.52| 24.17| 42.66|
3.3 Sensitivity Analysis

The relationships between COVID-19 infected cases and all considered parameters were robust in case of sensitivity analysis as shown in Fig. 6 and Fig 7 when the city Delhi and State Maharashtra were excluded from the data set. Limited fluctuations were observed in the sensitivity analysis considering air pollutants when the city Delhi was excluded from the study, which was examined as the centroid of SARS-CoV-2 transmission in India, whereas there were very less to considerable variations when the state Maharashtra was excluded from the data set, which had the highest number of daily reported COVID-19 infected cases. The multi-parameter models were represented in Fig. 6 (for air pollutants) and Fig. 7 (for meteorological factors). The air pollutants, PM$_{2.5}$ and PM$_{10}$ were formed as multi-parameter model to check the affects the COVID-19 infected cases and was insignificant when effects of NO$_2$ was restricted. Similarly, for SO$_2$, the multi-parameter model was insignificant after adding NO$_2$ but more variation was shown when DTR or relative humidity were added into the multi-parameter model. Similarly, for NO$_2$, the estimation of responses due to COVID-19 infected cases was transformed to be robust when the meteorological parameter, DTR or relative humidity was added in the multi-parameter model. In other hand, the effect of model estimation did not change much after the addition of SO$_2$ or meteorological factors. Subsequently, when controlling for the meteorological parameters, DTR or RH, the association cases could not remain significant after adding the air pollutants.
Table 2. Spearman’s correlation coefficients between air pollutants, meteorological factors across all districts during the study period

| Parameters            | Infected Cases | PM$_{2.5}$ | PM$_{10}$ | NO$_2$ | SO$_2$ | Wind Speed | Temperature | DTR | Relative Humidity | Air Pressure | Rainfall | Absolute Humidity |
|-----------------------|----------------|------------|-----------|--------|--------|------------|-------------|-----|-------------------|--------------|----------|-------------------|
| Infected Cases        | 1              |            |           |        |        |            |             |     |                   |              |          |                   |
| PM$_{2.5}$            | 0.23*          | 1          |           |        |        |            |             |     |                   |              |          |                   |
| PM$_{10}$             | 0.33*          | 0.87*      | 1         |        |        |            |             |     |                   |              |          |                   |
| NO$_2$                | 0.21*          | 0.59*      | 0.58*     | 1      |        |            |             |     |                   |              |          |                   |
| SO$_2$                | -0.26*         | 0.32*      | 0.34*     | 0.47*  | 1      |            |             |     |                   |              |          |                   |
| Wind Speed            | 0.02*          | -0.22*     | -0.16*    | -0.13* | -0.03* | 1          |             |     |                   |              |          |                   |
| Temperature           | 0.22*          | 0.30*      | 0.33*     | -0.13* | 0.22*  | -0.03      | 1           |     |                   |              |          |                   |
| DTR                   | 0.27*          | 0.42*      | 0.46*     | 0.24*  | 0.33*  | 0.19       | -0.12*      | 1   |                   |              |          |                   |
| Relative Humidity     | -0.28*         | -0.33*     | -0.41*    | -0.36* | -0.47* | 0.01       | -0.09*      | 0.19 | 1                 |              |          |                   |
| Air Pressure          | 0.03*          | 0.08*      | 0.06*     | 0.25*  | -0.19* | 0.02       | 0.15*       | 0.15 | 0.73*             | 1            |          |                   |
| Rainfall              | -0.13*         | 0.01*      | 0.03*     | 0.41*  | 0.05*  | -0.33*     | -0.08       | 0.18 | 0.40*             | 0.08         | 1        |                   |
| Absolute Humidity     | -0.02*         | 0.21*      | 0.27*     | 0.22*  | 0.12*  | 0.03       | -0.01       | 0.57*| 0.96*             | 0.67*        | 0.38*    | 1                 |
Fig. 5. Percentage Change (%) and 95% CI of daily infected COVID-19 cases correlated with a unit increase in air pollutant and meteorological concentration using single-parameter models.

NOTE: 10 \( \mu \text{g/m}^3 \) increase in PM\(_{2.5} \), PM\(_{10} \), NO\(_2 \) and SO\(_2 \) and 1 unit increase in meteorological factors (DTR: diurnal temp range, Temp: daily mean temperature, RH: relative humidity, AH: absolute humidity, AP: air pressure, RF: rainfall)
Fig. 6
Fig. 7. Percentage Change (%) and 95% CI of daily infected COVID-19 cases correlated with a unit increase in air pollutant and meteorological concentration using single-parameter models after excluding Delhi and Maharashtra from the analysis.

NOTE: 10 µg/m³ increase in PM$_{2.5}$, PM$_{10}$, NO$_2$ and SO$_2$ and 1 unit increase in meteorological factors (DTR: diurnal temp range, Temp: daily mean temperature, RH: relative humidity, AH: absolute humidity, AP: air pressure, RF: rainfall), MH: The state, Maharashtra, DL: The union territory, Delhi.

4. Discussion
To find out the correlation between daily reported COVID-19 infected cases and air pollutants concentration at variations of meteorological factors, GAM (generalised additive model) was applied for the proposed study. The analysis resulted in positive correlations of air pollutants, PM$_{2.5}$, PM$_{10}$, NO$_2$ and the meteorological factor, DTR with COVID-19 infected cases, while SO$_2$ and other meteorological factors such as daily mean temperature, air pressure, absolute humidity, relative humidity and wind speed were negatively correlated with daily counts of COVID-19 infected cases. These findings may suggest some evidences that air pollutants at meteorological variations act as important risk factors for infection in COVID-19 (Fig. 8).
Fig. 8. Percentage Change (%) and 95% CI of daily infected COVID-19 cases correlated with a unit increase in air pollutant and meteorological concentration using single and multi-parameter models

NOTE: 10 µg/m³ increase in PM_{2.5}, PM_{10}, NO₂ and SO₂ and 1 unit increase in meteorological factors (DTR: diurnal temp range, RH: relative humidity)

The respiratory infection and pneumonia caused by microorganisms are driven by air pollutants and are closely interrelated with air pollution as per recent evidences (Hachem et al., 2019; Kim et al., 2018; Rojas-roa and Rodríguez-villamizar, 2019; L. Thi et al., 2019; N. Thi et al., 2019; Y. Zhang et al., 2019). Most of air quality studies reported that short-term exposure to particulate matter, PM_{2.5}, can be related to acute lower respiratory infection (Bates et al., 2018; Li et al., 2020; G. Liu et al., 2020; Martins and Carrilho, 2020; Tan et al., 2019; Wu, 2019). However, not only PM_{2.5}, but PM_{10} was also found to have a significant relation with hospitalization due to the respiratory illness and pneumonia (Cheng et al., 2020; Chew et al., 2020; Ge et al., 2018; J. Liu et al., 2020; Luong et al., 2016; Mäkelä et al., 2019; Nephew et al., 2020; Pun et al., 2017; Rooij et al., 2019; J. Zhang et al., 2019).

Similarly, several studies had been conducted to find the association of air pollutants such as NO₂, SO₂ and other particulate matters with the increased risk of respiratory infections and mortality rates (Ã et al., 2005; Ashikin et al., 2014; Galy-lacaux et al., 2016; Lau et al., 2020; Mason et al., 2019; Pan et al., 2010; Sahoo et al., 2017; Wang and Su, 2020; Jiandong Yang et al., 2020). It had been concluded from several researches that, exposure to critical air pollutants such as PM_{2.5}, NO₂ and SO₂ were harmful to human health and led to persistent and increased risk of respiratory illness (Chen et al., 2019).
2019, 2020; Dastoorpoor et al., 2019; Gao et al., 2019; Hu et al., 2020; J. Liu et al., 2020; Naclerio et al., 2020; Oh et al., 2020; Sangkharat et al., 2019; Thi et al., 2018; Yao et al., 2020). Alternatively, it can be said that all the four air pollutant parameters considered for the study are harmful and risk factors for respiratory diseases and death (Çapraz et al., 2017; Liu et al., 2016, 2017; Zhao et al., 2017). There had been a series of researches suggested that the association between infectious diseases and air pollution particularly by NO\textsubscript{2}. These studies investigated that the increased level of NO\textsubscript{2} up to 70 µg/m\textsuperscript{3} caused the incidence of croup due to influenza virus (Chauhan and Johnston, 2003; Coccia, 2020; Hao et al., 2019; Xu et al., 2013). However, as per the proposed study, SO\textsubscript{2} had a negative correlation with COVID-19 infected cases, which may be the possible reason of low wind frequency along WSW-NW Winds (Cuesta-mosquera et al., 2020; Cuhadaroglu and Demirci, 1997; Mallik et al., 2019; Sangeetha and Sivakumar, 2019).

The Speraman’s correlation analysis examined positive associations with DTR, air pressure, absolute humidity and rainfall with air pollutants concentration, whereas the study demonstrated negative association of wind Speed, daily mean temperature and relative humidity with COVID-19 infected cases (Lee et al., 2019; J. Liu et al., 2020; Xie et al., 2016; Zhen et al., 2017). Some previous studies have reported that the mortality rate due to respiratory diseases increased with low temperature (Lin et al., 2013; Wang et al., 2007). In addition, some other studies have suggested that both high and low temperature might show the health effects on respiratory tracts and pneumonia mortality (Bachur et al., 2019; Brendish et al., 2019; Miao et al., 2017; Tian et al., 2020; Z. Xu et al., 2014; Zhen et al., 2017). Liang et al., 2009 also found the relationship between DTR and emergency room admissions in hospitals for chronic obstructive pulmonary diseases in Taiwan. The study suggested a significant negative correlation with daily average temperature and a strong positive correlation between DTR and rate of pulmonary diseases reported (Kersen et al., 2020; Peng et al., 2019; Yin et al., 2019). In another study, it was concluded that the risk of incidence of respiratory syncytial virus increased by 3.30% with every 1°C increase of DTR (Onozuka, 2020).
As per Lowen and Steel, 2014, the transmission of virus was found to be dependent on both daily mean temperature and relative humidity. The study found that the transmission rate was high at low temperature and was blocked or very low to inefficient at temperatures equivalent to room temperature. However, in case of relative humidity, average outdoor relative humidity is higher in winter than in summer, which excluded the outdoor relative humidity as a possible reason of virus transmission. In other hand, when indoor humidity is lowest during winter months and exposure to cold air outside or dry air inside during colder or flu months increase the transmission rate of virus (Lowen and Steel, 2014; Steel et al., 2011). Gralton et al., 2011 suggested that the association between aerosolized viruses and relative humidity might be a probable combination of properties of virus and interaction among virus, solutes and water molecules, where relative humidity is a function of ambient temperature which determined the saturation vapour pressure of water (Herfst et al., 2017; Marr et al., 2019).

Similarly, some other study suggested that the seasonality of the influenza epidemic was linked to meteorological factors such as decreasing level of ambient humidity and temperature. Exposure to low humidity led to impaired function of trachea, and tissue repair mechanism of airway epithelial cells, resulted in susceptible to virus spread and faster lethality (Kudo et al., 2019).

Consistent with these mentioned reviews, the results of the proposed study indicated that the risk of COVID-19 infected cases increases with decreased relative humidity in colder months. In addition, the study suggested some hypothesis for the prevention and spread of COVID-19. The environmental scientists and pollution management team should focus on the regions with high air pollutants ranges. The regions affected more with pollution might be the regions to suffer more with COVID-19 epidemic. In other words, decreased level of air pollutants excluding SO\textsubscript{2} could be an effective way to prevent infections caused by COVID-19.

Furthermore, researches are still needed to focus on effects of outdoor as well as indoor air pollution on virus diseases and infections. The reviews and present analysis suggested the challenges for the
epidemiologists and clinical scientists must go beyond the short-term triggering cause and evidences regarding the susceptibility to air pollutants in relation to viral infections and mortality. The mechanisms by which temperature and humidity effected the infection rate due to COVID-19 remain unclear but may combine multiple consequences at the level of the host, the lag effects on virus and the respiratory droplets. There is another gap in the research that the data in the proposed study had not included gender or age specific confirmed cases due to COVID-19 because of which the sub group analyses were not investigated. In addition, the study had not related other countries cities and states. Future researches are needed to overcome the research gap and limitations.

5. Conclusions

The proposed study suggested that there was significant correlation between air pollutants, meteorological factors and daily reported COVID-19 infected cases in India. However, it can be said that short term exposure to condensed and higher concentrations air pollutants such as PM$_{2.5}$, PM$_{10}$ and NO$_{2}$ increase the level of risk for COVID-19 infections. In addition, the meteorological factors such as diurnal temperature range and relative humidity effected the daily infected cases. There was positive association between diurnal temperature range and COVID-19 infected cases but negatively correlated with absolute humidity. On other hand, the study suggested that the exposure to high concentration of SO$_2$ may not be related to COVID-19 infected cases and its increased risk. However, laboratory studies and a comfortable environment are needed for the basic elementary exploration about the disease mechanisms and the patient’s responses toward the infection caused by SARS-CoV-2.

Author’s Contribution

Mrunmayee Manjari Sahoo: Sole Author, Data collection, analysis and paper writing.

Funding

No Funding involved.
Conflict of Interest

Not Applicable.

Ethical Approval

Not Applicable

Consent to Publish

Not Applicable

Availability of data and Materials

The details and the sources of the data are mentioned within the manuscripts.

Bibliography

Å, J.S.P., Kumar, R., Devotta, S., 2005. Health risks of NO2, SPM and SO2 in Delhi (India) 39, 6868–6874. https://doi.org/10.1016/j.atmosenv.2005.08.004

As, A., 2010. Revised National Ambient Air Quality Standards 826, 1–18.

Ashikin, N., Mabahwi, B., Ling, O., Leh, H., Omar, D., 2014. Human Health and Wellbeing: Human health effect of air pollution. Procedia - Soc. Behav. Sci. 153, 221–229. https://doi.org/10.1016/j.sbspro.2014.10.056

Auler, A.C., Cássaro, F.A.M., Silva, V.O., Pires, L.F., 2020. Journal of Sci. Total Environ. 139090. https://doi.org/10.1016/j.scitotenv.2020.139090

Baccini, M., Biggeri, A., Lagazio, C., 2007. Parametric and semi-parametric approaches in the analysis of short-term effects of air pollution on health 51, 4324–4336. https://doi.org/10.1016/j.csda.2006.05.026

Bachur, R.G., Michelson, K.A., Neuman, M.I., Monuteaux, M.C., 2019. Temperature-Adjusted Respiratory Rate for the Prediction of Childhood Pneumonia. Acad. Pediatr. 19, 542–548.
Bashir, M.F., Ma, B., Bilal, Komal, B., Bashir, M.A., Tan, D., Bashir, M., 2020. Correlation between climate indicators and COVID-19 pandemic in New York, USA. Sci. Total Environ. 728, 138835. https://doi.org/10.1016/j.scitotenv.2020.138835

Bates, M.N., Pokhrel, A.K., Chandyo, R.K., Valentiner-branth, P., Mathisen, M., Basnet, S., Strand, T.A., Burnett, R.T., Smith, K.R., 2018. Kitchen PM 2.5 concentrations and child acute lower respiratory infection in Bhaktapur, Nepal: The importance of fuel type. Environ. Res. 161, 546–553. https://doi.org/10.1016/j.envres.2017.11.056

Borge, R., Requia, W.J., Yagüe, C., Jhun, I., Koutrakis, P., 2019. Impact of weather changes on air quality and related mortality in Spain over a 25 year period [1993 – 2017]. Environ. Int. 133, 105272. https://doi.org/10.1016/j.envint.2019.105272

Brendish, N.J., Malachira, A.K., Beard, K.R., Armstrong, L., Lillie, P.J., Clark, T.W., Southampton, N., Nhs, S., Trust, F., 2019. Hospitalised adults with pneumonia are frequently misclassified as another diagnosis. Respir. Med. 150, 81–84. https://doi.org/10.1016/j.rmed.2019.02.013

Breslin, N., Baptiste, C., Mph, C.G., Miller, R., Martinez, R., Bernstein, K., Ring, L., Landau, R., Purisch, S., Mph, A.M.F., Fuchs, K., Xx, D.S., Andrikopoulou, M., Rupley, D., Sheen, J., Aubey, J., Zork, N., Moroz, L., Mourad, M., Wapner, R., Simpson, L.L., Alton, M.E.D., Goffman, D., 2020. Coronavirus disease 2019 infection among asymptomatic and symptomatic pregnant women: two weeks of confirmed presentations to an affiliated pair of New York City hospitals. Am. J. Obstet. Gynecol. MFM 100118. https://doi.org/10.1016/j.ajogmf.2020.100118

Briz-redón, Á., Serrano-aroca, Á., 2020. Science of the Total Environment A spatio-temporal analysis for exploring the effect of temperature on COVID-19 early evolution in Spain. Sci. Total Environ. 728, 138811. https://doi.org/10.1016/j.scitotenv.2020.138811

Cai, Y., Wang, D., Zhou, L., Ge, X., Guo, X., Han, J., Yang, H., 2019. Application of RNAscope
technology to studying the infection dynamics of a Chinese porcine epidemic diarrhea virus variant strain BJ2011C in neonatal piglets. Vet. Microbiol. 235, 220–228.

https://doi.org/10.1016/j.vetmic.2019.07.003

Çapraz, Ö., Deniz, A., Doğan, N., 2017. Effects of air pollution on respiratory hospital admissions in Istanbul, Turkey, 2013 to 2015. ECSN. https://doi.org/10.1016/j.chemosphere.2017.04.105

Cevik, M., Bamford, C., Ho, A., 2020. COVID-19 pandemic – A focused review for clinicians. Clin. Microbiol. Infect. https://doi.org/10.1016/j.cmi.2020.04.023

Chan, J.F.W., Kok, K.H., Zhu, Z., Chu, H., To, K.K.W., Yuan, S., Yuen, K.Y., 2020. Genomic characterization of the 2019 novel human-pathogenic coronavirus isolated from a patient with atypical pneumonia after visiting Wuhan. Emerg. Microbes Infect. 9, 221–236.

https://doi.org/10.1080/22221751.2020.1719902

Charles, M., Bernard, I., Villalba, A., Oden, E., Burioli, E.A. V, Allain, G., Trancart, S., Bouchart, V., Houssin, M., 2020. High mortality of mussels in northern Brittany – Evaluation of the involvement of pathogens , pathological conditions and pollutants. J. Invertebr. Pathol. 170, 107308. https://doi.org/10.1016/j.jip.2019.107308

Chauhan, A.J., Johnston, S.L., 2003. Air pollution and infection in respiratory illness 95–112.

https://doi.org/10.1093/bmb/ldg022

Chen, C., Liu, C., Chen, R., Wang, W., Li, W., Kan, H., Fu, C., 2018. Ambient air pollution and daily hospital admissions for mental disorders in Shanghai, China. Sci. Total Environ. 613, 324–330.

Chen, D., Xiao, Y., Tang, S., 2019. Air quality index induced nonsmooth system for respiratory infection. J. Theor. Biol. 460, 160–169. https://doi.org/10.1016/j.jtbi.2018.10.016

Chen, Z., Chen, D., Zhao, C., Kwan, M., Cai, J., Zhuang, Y., Zhao, B., Wang, X., Chen, B., Yang, J., Li, R., He, B., Gao, B., Wang, K., Xu, B., 2020. Influence of meteorological conditions on PM 2.5 concentrations across China : A review of methodology and mechanism. Environ. Int. 139,
Cheng, M., Wang, B., Yang, M., Ma, J., Ye, Z., Xie, L., Zhou, M., 2020. Journal Pre-proof. https://doi.org/10.1016/j.envint.2020.105558

Chew, S., Kolosowska, N., Saveleva, L., Malm, T., Kanninen, K.M., 2020. Impairment of mitochondrial function by particulate matter: Implications for the brain. Neurochem. Int. 104694. https://doi.org/10.1016/j.neuint.2020.104694

Chong, K., Kee, N., Mehta, P.R., Shukla, G., Mehta, A.R., 2020. COVID-19, SARS and MERS: A neurological perspective. J. Clin. Neurosci. https://doi.org/10.1016/j.jocn.2020.04.124

Chuang, Y.H., Mazumdar, S., Park, T., Tang, G., Arena, V.C., Nicolich, M.J., 2011. Atmospheric Pollution Research Generalized linear mixed models in time series studies of air pollution. Atmos. Pollut. Res. 2, 428–435. https://doi.org/10.5094/APR.2011.049

Cirera, L., García-marcos, L., Giménez, J., Moreno-grau, S., Tobias, A., 2012. Daily effects of air pollutants and pollen types on asthma and COPD hospital emergency visits in the industrial and Mediterranean Spanish city of Cartagena 40, 231–237. https://doi.org/10.1016/j.aller.2011.05.012

Civil, I., Morettini, M., 2020. COVID-19 in Italy: Dataset of the Italian Civil Protection Department. Data Br. 30, 105526. https://doi.org/10.1016/j.dib.2020.105526

Coccia, M., 2020. Journal Pre-proof. Sci. Total Environ. 138474. https://doi.org/10.1016/j.scitotenv.2020.138474

Cuesta-mosquera, A.P., Wahl, M., Acosta-lópez, J.G., García-reynoso, J.A., Aristizábal-zuluaga, B.H., 2020. Mixing layer height and slope wind oscillation: Factors that control ambient air SO2 in a tropical mountain city. Sustain. Cities Soc. 52, 101852. https://doi.org/10.1016/j.scs.2019.101852
Cuhadaroglu, B., Demirci, E., 1997. AI ID = JUlIr.r, li 15.

Dastoorpoor, M., Masoumi, K., Vahedian, M., 2019. Associations of short-term exposure to air pollution with respiratory hospital admissions in Ahvaz, Iran. Process Saf. Environ. Prot. 123, 150–160. https://doi.org/10.1016/j.psep.2019.01.012

Fattorini, D., Regoli, F., 2020. Role of the chronic air pollution levels in the Covid-19 outbreak risk in Italy. Environ. Pollut. 114732. https://doi.org/10.1016/j.envpol.2020.114732

Frontera, A., Martin, C., Vlachos, K., Sgubin, G., 2020. Regional air pollution persistence links to COVID-19 infection zoning. J. Infect. 2019–2020. https://doi.org/10.1016/j.jinf.2020.03.045

Galy-lacaux, C., Liouesse, C., Adon, M., Diop, B., Hadji, E., Doumbia, T., Gardrat, E., Ababacar, S., Jarnot, C., 2016. Measurements of NO2, SO2, NH3, HNO3 and O3 in West African urban environments ronique Yoboue 135. https://doi.org/10.1016/j.atmosenv.2016.03.050

Gao, Y., Wang, Z., Liu, C., Peng, Z., 2019. Assessing neighborhood air pollution exposure and its relationship with the urban form. Build. Environ. https://doi.org/10.1016/j.buildenv.2018.12.044

Ge, E., Lai, K., Xiao, X., Luo, M., Fang, Z., Zeng, Y., Ju, H., Zhong, N., 2018. AC SC. Environ. Pollut. https://doi.org/10.1016/j.envpol.2018.08.068

Ge, E., Ph, D., Fan, M., Qiu, H., Ph, D., Hu, H., Sc, D., Tian, L., Ph, D., Wang, X., Xu, G., Ph, D., Wei, X., Ph, D., 2017. Ambient sulfur dioxide levels associated with reduced risk of initial outpatient visits for tuberculosis: A population based time series. Environ. Pollut. 228, 408–415. https://doi.org/10.1016/j.envpol.2017.05.051

Gerling, L., Löschau, G., Wiedensohler, A., Weber, S., 2020. Statistical modelling of roadside and urban background ultrafine and accumulation mode particle number concentrations using generalized additive models. Sci. Total Environ. 703, 134570.
Giacomelli, E., Dorigo, W., Fargion, A., Calugi, G., Cianchi, G., Pratesi, C., 2020. Acute thrombosis of an aortic prosthetic graft in a patient with severe COVID-19 related pneumonia. Ann. Vasc. Surg. https://doi.org/10.1016/j.avsg.2020.04.040

Glick, A.F., Tomopoulos, S., Fierman, A.H., Elixhauser, A., Trasande, L., M, A.G.E.D.H., 2019. Association Between Outdoor Air Pollution Levels and Inpatient Outcomes in Pediatric Pneumonia Hospitalizations, 2007 to 2008. Acad. Pediatr. 19, 414–420. https://doi.org/10.1016/j.acap.2018.12.001

Gralton, J., Tovey, E., McLaws, M.L., Rawlinson, W.D., 2011. The role of particle size in aerosolised pathogen transmission: A review. J. Infect. 62, 1–13. https://doi.org/10.1016/j.jinf.2010.11.010

Hachem, M., Saleh, N., Paunescu, A., Momas, I., Bensefa-colas, L., 2019. Science of the Total Environment Exposure to traffic air pollutants in taxicabs and acute adverse respiratory effects: A systematic review. Sci. Total Environ. 693, 133439. https://doi.org/10.1016/j.scitotenv.2019.07.245

Hao, J., Yang, Z., Huang, S., Yang, W., Zhu, Z., Tian, L., 2019. The association between short-term exposure to ambient air pollution and the incidence of mumps in Wuhan, China: A time-series study. Environ. Res. 177, 108660. https://doi.org/10.1016/j.envres.2019.108660

Hellewell, J., Abbott, S., Gimma, A., Bosse, N.I., Jarvis, C.I., Russell, T.W., Munday, J.D., Kucharski, A.J., 2020. Articles Feasibility of controlling COVID-19 outbreaks by isolation of cases and contacts 488–496. https://doi.org/10.1016/S2214-109X(20)30074-7

Hendryx, M., Luo, J., Chojenta, C., Byles, J.E., 2019. Air pollution exposures from multiple point sources and risk of incident chronic obstructive pulmonary disease (COPD) and asthma. Environ. Res. 179, 108783. https://doi.org/10.1016/j.envres.2019.108783

Her, M., 2020. Journal Proof. One Heal. 100137. https://doi.org/10.1016/j.onehlt.2020.100137

Herfst, S., Böhringer, M., Karo, B., Lawrence, P., Lewis, N.S., Mina, M.J., Russell, C.J., Steel, J., de
Swart, R.L., Menge, C., 2017. Drivers of airborne human-to-human pathogen transmission. Curr. Opin. Virol. 22, 22–29. https://doi.org/10.1016/j.coviro.2016.11.006

Hernandez, A.D., Boag, B., Neilson, R., Forrester, N.L., 2018. IJP: Parasites and Wildlife Variable changes in nematode infection prevalence and intensity after Rabbit Haemorrhagic Disease Virus emerged in wild rabbits in Scotland and New Zealand. IJP Parasites Wildl. 7, 187–195. https://doi.org/10.1016/j.ijppaw.2018.05.002

Hu, Yabin, Xu, Z., Jiang, F., Li, S., Liu, S., Wu, M., Yan, C., Tan, J., Yu, G., Hu, Yi, Yin, Y., Tong, S., 2020. Science of the Total Environment Relative impact of meteorological factors and air pollutants on childhood allergic diseases in Shanghai, China 706. https://doi.org/10.1016/j.scitotenv.2019.135975

Huang, C., Lin, H., Tsai, C., Huang, H., Lian, I., 2017. The Interaction Effects of Meteorological Factors and Air Pollution on the Development of Acute Coronary Syndrome 1-10. https://doi.org/10.1038/srep44004

Kersen, W. Van, Oldenwening, M., Aalders, B., Bloemsma, L.D., 2020. Acute respiratory effects of livestock-related air pollution in a panel of COPD patients. Environ. Int. 136, 105426. https://doi.org/10.1016/j.envint.2019.105426

Keshavarzian, E., Jin, R., Dong, K., Kwok, K.C.S., Zhang, Y., Zhao, M., 2020. Highlights: Appl. Math. Model. https://doi.org/10.1016/j.apm.2020.01.019

Khan, S., Siddique, R., Shereen, M.A., Ali, A., Liu, J., Bai, Q., Bashir, N., Xue, M., 2020. Emergence of a Novel Coronavirus, Severe Acute Respiratory Syndrome Coronavirus 2: Biology and Therapeutic Options. J. Clin. Microbiol. 58, 1–9. https://doi.org/10.1128/jcm.00187-20

Kim, D., Chen, Z., Zhou, L., Huang, S., 2018. ScienceDirect Air pollutants and early origins of respiratory diseases. Chronic Dis. Transl. Med. https://doi.org/10.1016/j.cdtm.2018.03.003

Kim, Hyomi, Kim, Honghyok, Lee, J., 2019. Effect of air pollutant emission reduction policies on
Kudo, E., Song, E., Yockey, L.J., Rakib, T., Wong, P.W., Homer, R.J., 2019. Low ambient humidity impairs barrier function and innate resistance against influenza infection 116, 10905–10910. https://doi.org/10.1073/pnas.1902840116

Lau, H., Khosrawipour, V., Kocbach, P., Mikolajczyk, A., Ichii, H., Schubert, J., Bania, J., Khosrawipour, T., 2020. ScienceDirect Internationally lost COVID-19 cases. J. Microbiol. Immunol. Infect. 1–5. https://doi.org/10.1016/j.jmii.2020.03.013

Lee, S.W., Yon, D.K., James, C.C., Lee, S., Koh, H.Y., Sheen, Y.H., Oh, J., Han, M.Y., Sugihara, G., 2019. Short-term effects of multiple outdoor environmental factors on risk of asthma exacerbations: age-stratified time-series analysis. J. Allergy Clin. Immunol. https://doi.org/10.1016/j.jaci.2019.08.037

Li, J., Hu, Y., Liu, L., Wang, Q., Zeng, J., Chen, C., 2020. l P of. Sci. Total Environ. 137432. https://doi.org/10.1016/j.scitotenv.2020.137432

Li, S., 2017. A Generalized Additive Model Combining Principal Component Analysis for PM 2.5 Concentration Estimation. https://doi.org/10.3390/ijgi6080248

Liang, W., Liu, W., Kuo, H., 2009. Diurnal temperature range and emergency room admissions for chronic obstructive pulmonary disease in Taiwan 17–23. https://doi.org/10.1007/s00484-008-0187-y

Liang, Zhen, Xu, C., Fan, Y., Liang, Zhi-qing, Kan, H., Chen, R., 2020a. Ecotoxicology and Environmental Safety Association between air pollution and menstrual disorder outpatient visits : A time-series analysis. Ecotoxicol. Environ. Saf. 192, 110283. https://doi.org/10.1016/j.ecoenv.2020.110283

Liang, Zhen, Xu, C., Ji, A., Liang, S., Kan, H., Chen, R., Lei, J., Li, Y., Liu, Zhi-qing, Cai, T., 2020b.
Chemosphere Effects of short-term ambient air pollution exposure on HPV infections: A five-year hospital-based study. Chemosphere 252, 126615.
https://doi.org/10.1016/j.chemosphere.2020.126615

Lim, E., Chung, J., Sandberg, M., Ito, K., 2020. Influence of chemical reactions and turbulent diffusion on the formation of local pollutant concentration distributions. Build. Environ. 168, 106487.
https://doi.org/10.1016/j.buildenv.2019.106487

Lin, M., Kor, C., Chang, C., Chai, W., Soon, M., 2018. Association of meteorological factors and air NO2 and O3 concentrations with acute exacerbation of elderly chronic obstructive pulmonary disease. Sci. Rep. 1–9. https://doi.org/10.1038/s41598-018-28532-5

Lin, X., Liao, Y., Hao, Y., 2018. Chemosphere The burden associated with ambient PM 2.5 and meteorological factors in Guangzhou, China, 2012 e 2016: A generalized additive modeling of temporal years of life lost. Chemosphere 212, 705–714.
https://doi.org/10.1016/j.chemosphere.2018.08.129

Lin, Y., Chang, C., Chang, S., Chen, P., Lin, C., Wang, Y., 2013. Temperature, nitrogen dioxide, circulating respiratory viruses and acute upper respiratory infections among children in Taipei, Taiwan: A population-based study. Environ. Res. 120, 109–118.
https://doi.org/10.1016/j.envres.2012.09.002

Liu, G., Yan, X., Sedykh, A., Pan, X., Zhao, X., Yan, B., 2020. Ecotoxicology and Environmental Safety Analysis of model PM 2.5-induced inflammation and cytotoxicity by the combination of a virtual carbon nanoparticle library and computational modeling. Ecotoxicol. Environ. Saf. 191, 110216. https://doi.org/10.1016/j.ecoenv.2020.110216

Liu, J., Zhou, J., Yao, J., Zhang, X., Li, L., Yan, J., Shi, Y., Ren, X., Niu, J., Zhu, W., 2020. ur l P re. Sci. Total Environ. 138513. https://doi.org/10.1016/j.scitotenv.2020.138513

Liu, W., Cai, J., Fu, Q., Zou, Z., Sun, C., Zhang, J., 2020. Chemosphere Associations of ambient air...
pollutants with airway and allergic symptoms in 13,335 preschoolers in Shanghai, China.

Liu, W., Huang, C., Hu, Y., Fu, Q., Zou, Z., Sun, C., Shen, L., Wang, X., Cai, J., Pan, J., Huang, Y., Chang, J., Sun, Y., Sundell, J., 2016. Associations of gestational and early life exposures to ambient air pollution with childhood respiratory diseases in Shanghai, China: A retrospective cohort study. Chemosphere 252, 126600. https://doi.org/10.1016/j.chemosphere.2020.126600

Liu, Xiaoping, Lv, X., Peng, Z., Shi, C., 2019. of. Sustain. Cities Soc. 101822. https://doi.org/10.1016/j.scs.2019.101822

Liu, Xiaoxiao, Wang, J., Zhang, Y., Yu, H., Xu, B., Zhang, C., 2019. Comparison between two GAMs in quantifying the spatial distribution of Hexagrammos otakii in Haizhou Bay, China. Fish. Res. 218, 209–217. https://doi.org/10.1016/j.fishres.2019.05.019

Liu, Y., Xie, S., Yu, Q., Huo, X., Ming, X., Wang, J., 2017. Short-term effects of ambient air pollution on pediatric outpatient visits for respiratory diseases in Yichang city, China *. Environ. Pollut. 227, 116–124. https://doi.org/10.1016/j.envpol.2017.04.029

Lodigiani, C., Iapichino, G., Carenzo, L., Cercconii, M., Ferrazzi, P., Sebastian, T., Kucher, N., Studt, J., Sacco, C., Alexia, B., Teresa, M., Barco, S., Task, H.C.-, 2020. Venous and arterial thromboembolic complications in COVID-19 patients admitted to an academic hospital in Milan, Italy. Thromb. Res. 191, 9–14. https://doi.org/10.1016/j.thromres.2020.04.024

Lowen, A.C., Steel, J., 2014. Roles of humidity and temperature in shaping influenza seasonality 1–13. https://doi.org/10.1128/JVI.03544-13

Lu, H., Stratton, C.W., Tang, Y., n.d. Outbreak of Pneumonia of Unknown Etiology in Wuhan China: the Mystery and the Miracle. J. Med. Virol.

Luong, L.M.T., Phung, D., Sly, P.D., Morawska, L., Thai, P.K., 2016. Science of the Total Environment The association between particulate air pollution and respiratory admissions among young
children in Hanoi, Vietnam. Sci. Total Environ. https://doi.org/10.1016/j.scitotenv.2016.08.012

Ma, Y., Zhao, Y., Liu, J., He, X., Wang, B., Fu, S., Yan, J., Niu, J., Zhou, J., Luo, B., 2020. Jo ur na of. Sci. Total Environ. 138226. https://doi.org/10.1016/j.scitotenv.2020.138226

Mäkelä, K., Ollila, H., Sutinen, E., Vuorinen, V., Peltola, E., Kaarteenaho, R., 2019. Annals of Diagnostic Pathology Inorganic particulate matter in the lung tissue of idiopathic pulmonary fibrosis patients reflects population density and fine particle levels. Ann. Diagn. Pathol. 40, 136–142. https://doi.org/10.1016/j.anndiagpath.2019.04.011

Mallik, C., Sarathi, P., Kumar, P., Panda, S., Boopathy, R., Das, T., Lal, S., 2019. Influence of regional emissions on SO2 concentrations over Bhubaneswar, a capital city in eastern India downwind of the Indian SO2 hotspots. Atmos. Environ. 209, 220–232. https://doi.org/10.1016/j.atmosenv.2019.04.006

Marr, L.C., Tang, J.W., Mullekom, J. Van, Lakdawala, S.S., 2019. Mechanistic insights into the effect of humidity on airborne influenza virus survival, transmission and incidence.

Martins, N.R., Carrilho, G., 2020. A simulation study of decreased life expectancy from exposure to ambient particulate air pollution (PM2.5) in naturally ventilated workspaces. J. Build. Eng. 30, 101268. https://doi.org/10.1016/j.jobe.2020.101268

Mason, T.G., Schooling, C.M., Chan, K.P., Tian, L., 2019. An evaluation of the air quality health index program on respiratory diseases in Hong Kong: An interrupted time series analysis. Atmos. Environ. 211, 151–158. https://doi.org/10.1016/j.atmosenv.2019.05.013

Miao, Y., Shen, Y., Lu, C., Zeng, J., Deng, Q., 2017. Maternal exposure to ambient air temperature during pregnancy and early childhood pneumonia. J. Therm. Biol. 69, 288–293. https://doi.org/10.1016/j.jtherbio.2017.09.001

Moghanibashi-mansourieh, A., 2020. Assessing the anxiety level of Iranian general population during COVID-19 outbreak. Asian J. Psychiatr. 51, 102076. https://doi.org/10.1016/j.ajp.2020.102076
Muhammad, S., Long, X., Salman, M., 2020. Science of the Total Environment COVID-19 pandemic and environmental pollution: A blessing in disguise? Sci. Total Environ. 728, 138820. https://doi.org/10.1016/j.scitotenv.2020.138820

Naclerio, R., Ansotegui, I.J., Bousquet, J., Canonica, G.W., 2020. International expert consensus on the management of allergic rhinitis (AR) aggravated by air pollutants Impact of air pollution on patients with AR: Current knowledge and future strategies. World Allergy Organ. J. 13, 100106. https://doi.org/10.1016/j.waojou.2020.100106

Nephew, B.C., Nemeth, A., Hudda, N., Beamer, G., Mann, P., Petitto, J., Cali, R., Febo, M., Kulkarni, P., Poirier, G., King, J., Durant, J.L., Brugge, D., 2020. Traffic-related particulate matter affects behavior, inflammation, and neural integrity in a developmental rodent model. https://doi.org/10.1016/j.envres.2020.109242

Niu, S., Tian, S., Lou, J., Kang, X., Zhang, L., Lian, H., Zhang, J., 2020. Clinical characteristics of older patients infected with COVID-19: A descriptive study. Arch. Gerontol. Geriatr. 89, 104058. https://doi.org/10.1016/j.archger.2020.104058

Ogen, Y., 2020. Science of the Total Environment Assessing nitrogen dioxide (NO2) levels as a contributing factor to coronavirus (COVID-19) fatality. Sci. Total Environ. 726, 138605. https://doi.org/10.1016/j.scitotenv.2020.138605

Oh, H., Ho, C., Koo, Y., Baek, K., Yun, H., Hur, S., Choi, D., Jhun, J., Shim, J., 2020. Impact of Chinese air pollutants on a record-breaking PMs episode in South Korea for 11–15 January 2019. Atmos. Environ. 117262. https://doi.org/10.1016/j.atmosenv.2020.117262

Onozuka, D., 2020. The influence of diurnal temperature range on the incidence of respiratory syncytial virus in Japan 813–820. https://doi.org/10.1017/S0950268814001575

Pan, G., Zhang, S., Feng, Y., Takahashi, K., 2010. Air pollution and children’s respiratory symptoms in six cities of Northern China. Respir. Med. 104, 1903–1911.
Pearce, J.L., Beringer, J., Nicholls, N., Hyndman, R.J., Tapper, N.J., 2011. Quantifying the influence of local meteorology on air quality using generalized additive models. Atmos. Environ. 45, 1328–1336. https://doi.org/10.1016/j.atmosenv.2010.11.051

Peng, L., Xiao, S., Gao, W., Zhou, Y., Zhou, J., Yang, D., Ye, X., 2019. Short-term associations between size-fractionated particulate air pollution and COPD mortality in Shanghai, China*. Environ. Pollut. 113483. https://doi.org/10.1016/j.envpol.2019.113483

Pettersson, J.H., Piorkowski, G., Mayxay, M., Rattanavong, S., Vongsouvath, M., Davong, V., Alfsnes, K., Eldholm, V., Lamballerie, X. De, Holmes, E.C., Newton, P.N., Dubot-pérès, A., 2019. Meta-transcriptomic identification of hepatitis B virus in cerebrospinal fluid in patients with central nervous system disease. Diagnostic Microbiol. Infect. Dis. 95, 114878. https://doi.org/10.1016/j.diagmicrobio.2019.114878

Phosri, A., Ueda, K., Phung, V.L.H., Tawatsupa, B., Honda, A., Takano, H., 2019. Effects of ambient air pollution on daily hospital admissions for respiratory and cardiovascular diseases in Bangkok, Thailand. Sci. Total Environ. 651, 1144–1153.

Prata, D.N., Rodrigues, W., Bermejo, P.H., 2020. Science of the Total Environment Temperature significantly changes COVID-19 transmission in ( sub ) tropical cities of Brazil. Sci. Total Environ. 729, 138862. https://doi.org/10.1016/j.scitotenv.2020.138862

Pun, V.C., Tian, L., Ho, K., 2017. Particulate matter from re-suspended mineral dust and emergency cause-specific respiratory hospitalizations in Hong Kong. Atmos. Environ. https://doi.org/10.1016/j.atmosenv.2017.06.038

Qi, L., Gao, Yuan, Yang, Jun, Ding, X., Xiong, Y., Su, K., Liu, T., Li, Q., Tang, W., Liu, Q., Gao, Y, Yang, J., 2020. Journal Pre 2012–2018. https://doi.org/10.1016/j.scitotenv.2020.136682

Qi, X., Mei, G., Cuomo, S., Liu, C., Xu, N., 2019. Data analysis and mining of the correlations between

714 https://doi.org/10.1016/j.rmed.2010.07.018

715

716

717

718

719

720

721

722

723

724

725

726

727

728

729

730

731

732

733

734

735

736

737
meteorological conditions and air quality: A case study in. Internet of Things 100127.

Qiu, X., Wei, Y., Wang, Y., Di, Q., Sofer, T., Abu, Y., Schwartz, J., 2020. Inverse probability weighted distributed lag effects of short-term exposure to PM 2.5 and ozone on CVD hospitalizations in New England Medicare participants - Exploring the causal effects. Environ. Res. 182, 109095.

Ravindra, K., Rattan, P., Mor, S., Nath, A., 2019. Generalized additive models: Building evidence of air pollution, climate change and human health. Environ. Int. 132, 104987.

Remuzzi, A., Remuzzi, G., 2020. Health Policy COVID-19 and Italy: what next? Lancet 2, 10–13.

Rojas-roa, Y., Rodriguez-villamizar, L.A., 2019. Short-term joint effects of ambient air pollutants on emergency department visits for respiratory and circulatory diseases in Colombia, 248, 380–387. https://doi.org/10.1016/j.envpol.2019.02.028

Rooij, M.M.T. De, Smit, L.A.M., Erbrink, H.J., Hagenaars, T.J., Hoek, G., Ogink, N.W.M., Winkel, A., Heederik, D.J.J., Wouters, I.M., 2019. Endotoxin and particulate matter emitted by livestock farms and respiratory health effects in neighboring residents. Environ. Int. 132, 105009.

Saha, P.K., Khlystov, A., Snyder, M.G., Grieshop, A.P., 2018. SC. Atmos. Environ. https://doi.org/10.1016/j.atmosenv.2018.01.019

Sahoo, M.M., Patra, K.C., Swain, J.B., Khatua, K.K., 2017. Evaluation of water quality with application of Bayes’ rule and entropy weight method. Eur. J. Environ. Civ. Eng. 21, 730–752.
Sangeetha, S.K., Sivakumar, V., 2019. Journal of Atmospheric and Solar-Terrestrial Physics Long-term temporal and spatial analysis of SO\textsubscript{2} over Gauteng and Mpumalanga monitoring sites of South Africa. J. Atmos. Solar-Terrestrial Phys. 191, 105044. https://doi.org/10.1016/j.jastp.2019.05.008

Sangkharat, K., Fisher, P., Thomas, G.N., Thorns, J., Pope, F.D., 2019. The impact of air pollutants on ambulance dispatches: A systematic review and meta-analysis of acute effects *. Environ. Pollut. 254, 112769. https://doi.org/10.1016/j.envpol.2019.06.065

Segars, J., Katler, Q., Mcqueen, D.B., Glenn, T., Knight, Z., Feinberg, E.C., Hugh, S., Toner, J.P., Kawwass, J.F., 2020. Prior and Novel Coronaviruses, COVID-19, and Human Reproduction: What Is Known? Fertil. Steril. https://doi.org/10.1016/j.fertnstert.2020.04.025

Shahzad, F., Shahzad, U., Fareed, Z., Iqbal, N., 2020. of. Sci. Total Environ. 139115. https://doi.org/10.1016/j.scitotenv.2020.139115

Shereen, M.A., Khan, S., Kazmi, A., Bashir, N., Siddique, R., 2020. COVID-19 infection: origin, transmission, and characteristics of human coronaviruses. J. Adv. Res. https://doi.org/10.1016/j.jare.2020.03.005

Steel, J., Palese, P., Lowen, A.C., 2011. Transmission of a 2009 pandemic influenza virus shows a sensitivity to temperature and humidity similar to that of an H3N2 seasonal strain. J. Virol. 85, 1400–1402.

Su, W., Wu, X., Geng, X., Zhao, X., Liu, Q., Liu, T., 2019. The short-term effects of air pollutants on influenza-like illness in Jinan, China 1–12.

Sun, W., Palazoglu, A., Singh, A., Zhang, H., Wang, Q., Zhao, Z., Cao, D., 2015. Atmospheric Pollution. Atmos. Pollut. Res. 6, 245–253. https://doi.org/10.5094/APR.2015.029

Tan, W., Zhu, H., Zhang, N., Dong, D., Wang, S., 2019. Characterization of the PM\textsubscript{2.5} concentration in surgical smoke in different tissues during hemihepatectomy and protective measures 72.
Particulate air pollution in Ho Chi Minh city and risk of hospital admission for acute lower respiratory infection (ALRI) among young children. Environ. Pollut. 113424.

https://doi.org/10.1016/j.etap.2019.103248

Association of ambient air pollution with lengths of hospital stay for hanoi children with acute lower-respiratory infection, 2007 e 2016. Environ. Pollut. 247, 752–762. https://doi.org/10.1016/j.envpol.2019.01.115

Acute effects of ambient air pollution on lower respiratory infections in Hanoi children: An eight-year time series study. Environ. Int. 110, 139–148. https://doi.org/10.1016/j.envint.2017.10.024

Characteristics of COVID-19 infection in Beijing. J. Infect. 80, 401–406. https://doi.org/10.1016/j.jinf.2020.02.018

Science of the Total Environment Integrated dispersion-deposition modelling for air pollutant reduction via green infrastructure at an urban scale. Sci. Total Environ. 723, 138078. https://doi.org/10.1016/j.scitotenv.2020.138078

Association between multi-pollutant mixtures pollution and daily cardiovascular mortality: An exploration of exposure-response relationship. Atmos. Environ. 186, 136–143. https://doi.org/10.1016/j.atmosenv.2018.05.034

Coronaviruses, in: Medical Microbiology. 4th Edition. University of Texas Medical Branch at Galveston.

Short-term air pollution exposure and cardiovascular events: A 10-year study in the urban area of
Wang, G., Hernandez, R., Weninger, K., Brown, D.T., 2007. Infection of cells by Sindbis virus at low temperature 362, 461–467. https://doi.org/10.1016/j.virol.2006.12.036

Wang, Q., Su, M., 2020. Jo u nr Pr oo. Sci. Total Environ. 138915. https://doi.org/10.1016/j.scitotenv.2020.138915

Wang, R., Pan, M., Zhang, X., Fan, X., Han, M., 2020. I P re of. Int. J. Infect. Dis. https://doi.org/10.1016/j.ijid.2020.03.070

Wei, F., Wu, M., Qian, S., Li, D., Jin, M., Wang, J., Shui, L., Lin, H., Tang, M., Chen, K., 2020. Science of the Total Environment Association between short-term exposure to ambient air pollution and hospital visits for depression in China. Sci. Total Environ. 724, 138207. https://doi.org/10.1016/j.scitotenv.2020.138207

Wu, Y., Jing, W., Liu, J., Ma, Q., Yuan, J., Wang, Y., Du, M., Liu, M., 2020. Science of the Total Environment Effects of temperature and humidity on the daily new cases and new deaths of COVID-19 in 166 countries 729, 1–7. https://doi.org/10.1016/j.scitotenv.2020.139051

Wu, Z., 2019. Study on the spatial – temporal change characteristics and influence factors of fog and haze pollution based on GAM. Neural Comput. Appl. 31, 1619–1631. https://doi.org/10.1007/s00521-018-3532-z

Xiao, T., Yang, Y., Zhang, Y., Cheng, P., Yu, H., 2019. Jo Pr f. Res. Vet. Sci. https://doi.org/10.1016/j.rvsc.2019.11.006

Xie, J., Zhu, Y., 2020. Science of the Total Environment 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

Xie, M., Ni, H., Zhao, D., Cheng, J., Wen, L., Li, K., Yang, H., Wang, S., Zhang, H., Wang, X., Su, H.,
Effect of diurnal temperature range on the outpatient visits for acute bronchitis in children: a time-series study in Hefei, China. 2016. https://doi.org/10.1016/j.puhe.2016.12.016

Xu, H., Fu, X., Kim, L., Lee, H., Ma, S., Goh, K.T., Wong, J., Habibullah, S., Kee, G., Lee, K., Lim, T.K., Tambyah, P.A., Lim, L., Ng, L.C., 2014. Statistical Modeling Reveals the Effect of Absolute Humidity on Dengue in Singapore. https://doi.org/10.1371/journal.pntd.0002805

Xu, Z., Hu, W., Williams, G., Clements, A.C.A., Kan, H., Tong, S., 2013. Air pollution, temperature and pediatric influenza in Brisbane, Australia. Environ. Int. 59, 384–388. https://doi.org/10.1016/j.envint.2013.06.022

Xu, Z., Liu, Y., Ma, Z., Li, S., Hu, W., Tong, S., 2014. Impact of temperature on childhood pneumonia estimated from satellite remote sensing. Environ. Res. 132, 334–341. https://doi.org/10.1016/j.envres.2014.04.021

Xu, Z., Shi, L., Wang, Y., n.d. Pathological findings of COVID-19 associated with acute respiratory distress syndrome [published online ahead of print February 18, 2020]. Lancet Respir Med.

Yáñez, M.A., Baettig, R., Cornejo, J., Zamudio, F., Fica, R., 2017. Urban airborne matter in central and southern Chile: Effects of meteorological conditions on fine and coarse particulate matter. Atmos. Environ. https://doi.org/10.1016/j.atmosenv.2017.05.007

Yang, Junhua, Kang, S., Ji, Z., Yin, X., Tripathee, L., 2020. Investigating air pollutant concentrations, impact factors, and emission control strategies in western China by using a regional climate-chemistry model. ECSN 125767. https://doi.org/10.1016/j.chemosphere.2019.125767

Yang, Jiandong, Zhang, M., Chen, Y., Ma, L., 2020. Pre of. https://doi.org/10.1016/j.ijid.2020.03.032

Yang, Y., Cao, Y., Li, W., Li, R., Wang, M., Wu, Z., Xu, Q., 2015. Science of the Total Environment Multi-site time series analysis of acute effects of multiple air pollutants on respiratory mortality: A population-based study in Beijing, China. Sci. Total Environ. 508, 178–187.
Yang, Z., Hao, J., Huang, S., Yang, W., Zhu, Z., 2020. Acute effects of air pollution on the incidence of hand, foot, and mouth disease in Wuhan, China. Atmos. Environ. 225, 117358.

Yao, M., Wu, G., Zhao, X., Zhang, J., 2020. Estimating health burden and economic loss attributable to short-term exposure to multiple air pollutants in China. Environ. Res. 109, 184.

Yin, G., Liu, C., Hao, L., Chen, Y., Wang, W., Huo, J., Zhao, Q., Zhang, Y., Duan, Y., Fu, Q., Chen, R., Kan, H., 2019. Associations between size-fractionated particle number concentrations and COPD mortality in Shanghai, China. Atmos. Environ. 214, 116875.

Yoon, H., 2019. Effects of particulate matter (PM 10) on tourism sales revenue: A generalized additive modeling approach. Tour. Manag. 74, 358–369.

Zhang, J., Wei, X., Jiang, L., Li, Y., Li, M., Zhu, H., Yu, X., Tang, J., Chen, G., Zhang, X., 2019. Bacterial community diversity in particulate matter (PM 2.5 and PM 10) within broiler houses in different broiler growth stages under intensive rearing conditions in summer.

Zhang, K., Batterman, S., 2010. Near-road air pollutant concentrations of CO and PM 2.5: A comparison of MOBILE6.2/CALINE4 and generalized additive models. Atmos. Environ. 44, 1740–1748. https://doi.org/10.1016/j.atmosenv.2010.02.008

Zhang, Y., Xiang, Q., Yu, C., Yang, Z., 2020. Asthma mortality is triggered by short-term exposures to ambient air pollutants: Evidence from a Chinese urban population. Atmos. Environ. 117, 271.

https://doi.org/10.1016/j.scitotenv.2014.11.070
https://doi.org/10.1016/j.atmosenv.2020.117358
https://doi.org/10.1016/j.envres.2020.109184
https://doi.org/10.1016/j.atmosenv.2019.116875
https://doi.org/10.1016/j.tourman.2019.04.008
https://doi.org/10.3382/japr/pfz006
https://doi.org/10.1016/j.atmosenv.2020.117271
https://doi.org/10.1016/j.atmosenv.2020.117271
Zhang, Y., Ye, C., Yu, J., Zhu, W., Wang, Y., Li, Z., Xu, Z., Cheng, J., Wang, N., Hao, L., Hu, W., 2019. Seasonal influenza A and B virus transmission in subtropical Shanghai, China Authors Wenbiao Hu, School of Public Health and Social Work; Institute of Health and. Sci. Total Environ. 134607. https://doi.org/10.1016/j.scitotenv.2019.134607

Zhao, R., Chen, S., Wang, W., Huang, J., Wang, K., Liu, L., Wei, S., 2017. The impact of short-term exposure to air pollutants on the onset of out-of-hospital cardiac arrest: A systematic review and meta-analysis. Int. J. Cardiol. 226, 110–117. https://doi.org/10.1016/j.ijcard.2016.10.053

Zhao, Y., Aarnink, A.J.A., Dijkman, R., Fabri, T., Jong, M.C.M. De, Koerkamp, P.W.G.G., 2012. Effects of Temperature, Relative Humidity, Absolute Humidity, and Evaporation Potential on Survival of Airborne Gumboro 1048–1054. https://doi.org/10.1128/AEM.06477-11

Zhen, Q., Deng, Y., Wang, Y., Wang, X., Zhang, H., Sun, X., Ouyang, Z., 2017. Science of the Total Environment Meteorological factors had more impact on airborne bacterial communities than air pollutants. Sci. Total Environ. 601–602, 703–712. https://doi.org/10.1016/j.scitotenv.2017.05.049

Zhu, S., Xia, L., Wu, J., Chen, S., Chen, F., Zeng, F., Chen, X., Chen, C., Xia, Y., Zhao, X., Zhang, J., 2018. Science of the Total Environment Ambient air pollutants are associated with newly diagnosed tuberculosis: A time-series study in Chengdu, China. Sci. Total Environ. 631–632, 47–55. https://doi.org/10.1016/j.scitotenv.2018.03.017

Zhu, Y., Wang, Y., Xu, H., Luo, B., Zhang, W., Guo, B., Chen, S., Zhao, X., Li, W., 2019. Joint effect of multiple air pollutants on daily emergency department visits in Chengdu, China. Environ. Pollut. 113548. https://doi.org/10.1016/j.envpol.2019.113548
Highlights

- Significant correlation ship was found between air pollutants and COVID-19 infections after control measures.
- Association of meteorological factors with increased risk of COVI-19 cases are clear.
- Positive correlations of PM$_{2.5}$, PM$_{10}$, NO$_2$ and DTR with COVID-19 infected cases were found.
- SO$_2$ showed a significant negative correlation with daily reported COVID-19 infected cases.
Graphical Abstract