Data Report

Plausible Role of Environmental Factors on COVID-19 Transmission in the Megacity Delhi, India

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ABSTRACT

The role of environmental factors in the transmission of COVID-19 still needs to be determined. The main objective of the present study is to explore the relationship between environmental factors (both meteorological and air pollution parameters) and the daily confirmed COVID-19 cases over Delhi, India. This study employed a secondary data analysis of COVID-19 (from 1 March to 30 June, 2020) from the Delhi State Health Bulletin and the environmental factors from the Indian Meteorological Department (IMD) and Central Pollution Control Board (CPCB) of India. Pearson’s correlation coefficients were assessed to show the correlation between environmental factors and daily confirmed COVID-19 cases. The temperature (maximum, minimum, average, and dew point) and wind speed exhibited a significant positive correlation with daily COVID-19 cases. However, diurnal temperature range, rainfall, and relative humidity showed non-significant correlations. Air pollutants were found to be weakly associated with daily COVID-19 cases. However, O3 exhibited a significant positive correlation with daily COVID-19 cases in Delhi. The probability distribution analysis reveals that approximately 80% of the total confirmed cases were registered when the average temperature was higher than 30°C. The present study finds a prominent relationship between different environmental factors and COVID-19 transmission in Delhi. However, further detailed analysis over different parts of entire India is required to get a complete picture and solid conclusion.

Keywords: COVID-19; Temperature; Humidity; AQI; Delhi.

INTRODUCTION

The world is presently going through a very distressing stage with the spread of Coronavirus disease 2019 (COVID-19). This is highly contagious and has been declared by the World Health Organization (WHO) as a pandemic after the reporting of 118319 confirmed cases and 4292 deaths worldwide (WHO, 2020a). Since the start of COVID-19, large worldwide efforts have been constantly dedicated to improving the understanding about the virus. Recently, COVID-19 aerosol drivers, impacts, and mitigation studies have received immense global attentions (e.g., Hadei et al., 2020; Hsiao et al., 2020; Jain and Sharma, 2020; Lednicky et al., 2020; Mohd Nadzir et al., 2020; Mutuka et al., 2020; Safarian et al., 2020; Suhaimi et al., 2020). Several studies confirmed that COVID-19 is generally transported, propagated, and transmitted by humans through respiratory droplets and close contacts (Chan et al., 2020; Hsiao et al., 2020; Lai et al., 2020; Li et al., 2020; Wang et al., 2020; WHO, 2020b). The survival and transmission of viruses by droplets are usually expedited in dry and cold weather conditions (Casanova et al., 2010). Moreover, the transmission of viruses can be affected by population density and the medical care quality (Casanova et al., 2010; Dalziel et al., 2018). Several studies claimed that weather conditions could influence the growth, viability, range of spread, and transmission of COVID-19 causing viruses (Hastie and Tibshirani, 1990; Chan et al., 2011; Van Doremalen et al., 2013; Chen et al., 2020). Recent studies have demonstrated significant correlations between meteorological parameters (i.e., temperature, humidity, wind speed) and the

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spread of COVID-19 pandemic (e.g., Bashir et al., 2020; Chen et al., 2020; Ma et al., 2020; Pani et al., 2020a; Sahin, 2020; Sajadi et al., 2020; Tosepu et al., 2020; Zhu et al., 2020). A positive correlation between mean temperature and COVID-19 cases was reported in China (Zhu et al., 2020). A study by Tosepu et al. (2020) found a significant association between average temperature and COVID-19 pandemic in Indonesia. Wang et al. (2020) investigated the impact of temperature on the spread of COVID-19 and suggested that the temperature significantly affects the spread of COVID-19. However, other studies have stated contradictory results that weather conditions may not be associated with COVID-19 pandemic (e.g., Shi et al., 2020; Jamil et al., 2020). For example, Shi et al. (2020) reported a negative correlation between temperature and COVID-19 transmission based on daily weather reports. However, the exact information about the impact of weather conditions on the COVID-19 pandemic is still limited (specifically in tropical countries) and controversial.

Similarly, the knowledge about the impact of atmospheric pollution levels on the COVID-19 pandemic is still limited. Generally, better air quality enhances the quality of life and mainly relieves those who are suffering from respiratory problems. Exposure to air pollutants like carbon monoxide (CO), nitrogen oxides (NOx), ozone (O3), particulate matters including finer PM2.5 (particulate matter ≤ 2.5 µm in aerodynamic diameter) and coarser PM10 (particulate matter ≤ 10 µm in aerodynamic diameter), polycyclic aromatic hydrocarbons (PAHs), and volatile organic compounds (VOCs) normally can induce several harmful health impacts including respiratory diseases in humans (Kelly and Fussell, 2011; Carugno et al., 2016; Pani et al., 2019a, b, 2020b; Sopian et al., 2020; Zoran et al., 2020). Moreover, exposure to air pollution induces oxidative stress, damages the immune system, and also lowers the host's ability and resistance to viral infections (Yin and Wunderink, 2018; Martelletti and Martelletti, 2020; Suhaimi et al., 2020). Hence, people with certain medical issues would probably face challenges to fight against the COVID-19 (Suhaimi et al., 2020).

India, the second most populated country in the world (with a population of 1.38 billion as of March, 2020; Ministry of Statistics and Programme Implementation, 2020), reported the first case of COVID-19 on 30 January, 2020. India currently has the largest number of confirmed cases in Asia with the number of total confirmed cases breaking the 100,000 and 200,000 marks on 19 May and 3 June, 2020, respectively. However, the fatality rate in India is relatively low (2.8%) as compared to the global value (6.13%) as of 3 June, 2020 (https://en.wikipedia.org/wiki/CV19_pandemic_in_India). Delhi, India is considered as one of the most polluted megacities in the world based on the environmental performance index (WHO, 2016). Moreover, Delhi is the second most populated city in the world (World Population Review, 2020). Although many factors have been shown to influence the COVID-19 incidence rate, this study primarily aims to investigate the role of Indian tropical weather in the transmission and spread of COVID-19 by exploring the correlations between environmental factors (both meteorological parameters and air pollutants) and COVID-19 cases in the megacity Delhi, India. This kind of information is essential to show whether tropical climates, along with poor air quality are less or more favorable to the spread of the virus.

MEASUREMENTS, DATA, AND METHODOLOGY

Study Area

The present study domain includes the megacity Delhi in India. It is the second leading megacity in the world (The World’s Cities in 2018, Data Booklet, United Nations, 2018) with 16.8 million of inhabitants and about the population density of 11297 persons per sq. km (https://www.niti.gov.in/niti/content/population-density-sq-km). Delhi normally experiences four major distinct seasons, i.e., winter (December–February), summer (Mar–May), monsoon (June–September), and post-monsoon (October–November). Delhi experiences a semi-arid climate with an extremely hot summer, average rainfall, and a very cold winter (Kumar and Goyal, 2011). In general over Delhi, the temperature changes between 42°C and 48°C during summer and 4°C and 10°C in winter (Mahato et al., 2020). It was well reported that about 80% of the total annual precipitation over Delhi occurs during the monsoon (Perrino et al., 2011). Over Delhi, the weather during the winter period was significantly influenced by the western disturbances. Dust from the Sahara, Arabian deserts, Gulf, and the Thar Desert, mainly influence in pre-monsoon and post-monsoon seasons (Singh and Naseema, 2013; Tiwari et al., 2014).

Datasets

The data of daily confirmed COVID-19 cases and related deaths over Delhi were collected from the Delhi State Health Bulletin reports (http://health.delhigovt.nic.in). The daily data of basic meteorological parameters such as maximum temperature (MAX_T), minimum temperature (MIN_T), average temperature (Ave_T), diurnal temperature range (DTR), dew point, relative humidity (RH), wind speed (WS), and rainfall, from 1 March to 30 June, 2020 for the station New Delhi (Palam), was obtained from the India Meteorological Department (IMD; www.imd.gov.in). Simultaneous, daily concentrations of air pollutants such as PM2.5, PM10, CO, O3, and NO2 were obtained over the same station from the Central Pollution Control Board (CPCB) of Indian online portal for air quality data dissemination (https://app.cpcbccr.com/ccr/#/caaqm-dashboard-all/caaqm-landing).

The air quality index (AQI) was computed in order to understand the overall improvement in air quality in Delhi. Details of AQI can be found elsewhere (CPCB, 2014; Sahu and Kota, 2017), and only a brief about it compiled here. AQI needs PM2.5, PM10, CO, SO2, NO2, O3, NH3, and lead (Pb); out of these minimum concentrations of at least three air pollutants must be available including either PM2.5 or PM10 (Sharma et al., 2020). The sub-index AQI for each pollutant can be estimated as follows (e.g., Sharma et al., 2020),

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AQI = \frac{(IN_{hi} - IN_{lo})}{(B_{hi} - B_{lo})} \times (C_{i} - B_{lo}) + IN_{lo}
\]
where, $C$ represents the concentration of pollutant “$i$”. $IN_{LO}$ and $IN_{HI}$ are the corresponding AQI values. $BL_{LO}$ and $BL_{HI}$ are the breakpoint concentrations smaller and greater to $C$. The overall AQI is the maximum $AQI_i$ and corresponding air pollutant is the dominating one. AQI generally follows a scale of 0–500. AQI between 0–50, 51–100, 101–200, 201–300, 301–400, and 401–500 represents good, satisfactory, moderate, poor, very poor, and severe, respectively.

In this study, we used the Pearson’s correlation method to obtain the relationship between environmental factors (both meteorological parameters and air pollutants) and the confirmed daily COVID-19 cases. The Pearson’s correlation method measures the linear correlation between two variables. It has a value between +1 and –1, where 1 is a total positive linear correlation, 0 is no linear correlation, and –1 is a total negative linear correlation. This method is widely used in scientific analyses.

RESULTS AND DISCUSSION

**Temporal Evolution of the COVID-19 Cases**

Fig. 1 presents the temporal pattern of the daily total confirmed COVID-19 cases and the related mortality over Delhi during the study period (1 March–30 June, 2020). Over Delhi, the first confirmed COVID-19 case was reported on 2 March, 2020 and first death due to the COVID-19 was reported on 14 March, 2020. As of 16 July, 2020, the reported total confirmed COVID-19 cases and the related deaths were 116993 and 3487, respectively (http://health.delhigovt.nic.in). However, after 30 March, the confirmed daily COVID-19 cases were sharply increased in Delhi. Surprisingly, a total of 437 deaths was reported on 17 June, 2020 (https://www.hindustantimes.com/india-news/why-was-there-a-sudden-spike-in-coronavirus-deaths-in-delhi/story-HsIU8CutiTRpEM869oz1VL.html); however, the data for this particular day is removed from the database as an outlier while doing the correlation analyses. Furthermore, we distributed the daily confirmed COVID-19 cases and deaths with respect to each week during the entire study period (Figs. 1(b) and 1(d)). We considered 1–7 March, 2020 as a first week and so on up to 30 June, 2020. A total of ~17 weeks of data for the entire study period was included in this study. The observed COVID-19 confirmed cases (deaths) for each week (1–11) are as follows, 4 (0), 5 (1), 18 (0), 12 (0), 406 (5), 458 (8), 804 (28), 807 (11), 1224 (8), 2580 (7), 2577 (55), 3424 (85), 5067 (190), 8948 (310), 10490 (506), 16292 (821), and 24124 (457). COVID-19 cases sharply increased after the 5th week and reached the peak in the 17th week. In the case of mortality, we noticed two significant peaks during the 15th and 16th weeks, respectively.

The day to day variations in different meteorological parameters over Delhi are shown in Fig. 2. The temperature shows significant variations during the study period (Fig. 2(a)). MAX_T was found as high as 47.6°C on 27 May, 2020. The observed mean Ave_T was 28.8 ± 5.4°C during the entire study period. Similarly, the dew point over Delhi shows a significant day to day variations varying from 10.7°C to 26.8°C with the mean value of 18.9 ± 3.9°C. Interestingly, a gradual increase in the dew point is evident particularly during the month of June, 2020 (Fig. 2(b)). As well-known
Fig. 2. Day-to-day variations in meteorological parameters over Delhi during March 1–June 30, 2020.

that the dew point is the temperature to which air must be cooled to become saturated without changing the pressure and this is greatly associated with the human comfort. It was also reported that high values of dew point (> 23°C) would be uncomfortable for humans and can induce heat stress (e.g., Pani et al., 2020a). The RH also shows a large daily variations (Fig. 2c; range: 27–100%) with a mean value of 66.5 ± 16.7%. The minimum RH during the study period was noticed in May, 2020. WS have also exhibited a large variability, ranging from 0 to 20 m s\(^{-1}\) with the mean value of 4.7 ± 2.9 m s\(^{-1}\) (Fig. 2d). In the study period, highest rainfall about 37 mm was recorded over Delhi (Fig. 2c).

Similarly, the daily variations in air-pollution related parameters are shown in Fig. 3. The observed mean values for the different air pollutants during the study period are as follows, CO = 0.8 ± 0.5 mg m\(^{-3}\), \(O_3\) = 26 ± 10 µg m\(^{-3}\), NO\(_x\) = 37 ± 39 ppbv, PM\(_{10}\) = 113 ± 50 µg m\(^{-3}\), PM\(_{2.5}\) = 44 ± 17 µg m\(^{-3}\), and AQI = 107 ± 44. The Indian government had implemented four phases (24 March–14 April 14; 15 April–3 May; 4–7 May, and 18–31 May in 2020) of lockdown (total or partial) in India to control the spread of COVID-19 (https://www.mygov.in/corona-data/covid19-statewise-status). All the air pollutants (except \(O_3\)) exhibited a sharp decrease in their concentrations due to the reductions of anthropogenic activities including traffic movements and industrial operations owing to the enforcement of national lockdown in India. AQI over Delhi was mostly moderate (within 100–200 for 57 days) during the study period.

Correlation between Environmental Factors and COVID-19 Cases

Fig. 4 shows the results of correlation analysis between the number of confirmed COVID-19 cases and different environmental factors (both meteorological parameters and air pollutants) in Delhi. Significant positive correlations of temperature (MAX\(_T\), MIN\(_T\), and Ave\(_T\)) and dew point with confirmed daily COVID-19 cases were evident (Fig. 4) in Delhi. Interestingly, Min\(_T\) and dew point temperature exhibited better correlations with COVID-19 cases as compared to MAX\(_T\), Ave\(_T\), and DTR. Similarly, temperature (MAX\(_T\), MIN\(_T\), and Ave\(_T\)) and dew point also showed significant positive correlations with mortality (deaths). However, RH exhibited a weak negative correlation (r = −0.16) with COVID-19 cases over Delhi. A significant positive correlation (r = 0.46) was evident between WS and COVID-19 cases. DTR and rainfall were not significantly correlated with COVID-19 daily cases. Deaths showed a significant positive correlation (r = 0.6) with Ave\(_T\), but a negative correlation (r = −0.19) with RH. From the results based on correlation analysis, it can be concluded that the daily Ave\(_T\), MIN\(_T\), dew point and WS were strongly associated with the daily confirmed COVID-19 cases in Delhi, India. In the case of air pollution parameters, only \(O_3\) exhibited a significant positive correlation with COVID-19 cases while others showed weak negative correlations.

Overall, the observed correlations of daily COVID-19 cases with Ave\(_T\) and RH in Delhi were well-matched with the previous reports of Bashir et al. (2020), Tosepu et al. (2020) and Ma et al. (2020). Bashir et al. (2020) also reported the positive correlation of COVID-19 cases with temperature and negative association with humidity in New York, USA. A significant association (r = 0.39) of COVID-19 with average temperature was observed in Jakarta, Indonesia (Tosepu et al., 2020). Ma et al. (2020) reported a negative
correlation of COVID-19 daily death counts with RH ($r = -0.32$), in Wuhan, China. However, we noticed a higher correlation ($r = 0.6$) between Ave_T and COVID-19 daily cases in Delhi, India as compared to the study over Jakarta, Indonesia.

The Probability Distribution of COVID-19 Cases

The total COVID-19 cases were further distributed with respect to different thresholds of Ave_T and RH. During the entire study period, the observed minimum Ave_T was 16.2°C and the maximum Ave_T was 38.2°C in Delhi. Likely, the minimum RH was 27% and the maximum RH was 100%. We made nine and eight thresholds for the distribution of total COVID-19 cases based on Ave_T and RH, respectively. Thresholds for Ave_T were < 20°C, 20–22°C, 22–24°C, 24–26°C, 26–28°C, 28–30°C, 30–32°C, 32–34°C and > 34°C. Similarly, thresholds for the RH were < 30%, 30–40%, 40–50%, 50–60%, 60–70%, 70–80%, 80–90% and >90%. The observed total COVID-19 cases and deaths for each Ave_T and RH thresholds are shown in Fig. 5 and the detailed statistics are presented in Table 1.

Results showed that 50.3% of the COVID-19 cases and 60.2% of deaths were associated with the Ave_T higher than 34°C. It was also noticed that 23.4% of the COVID-19 cases and 16.9% of deaths were associated with the Ave_T ranges between 32°C and 34°C (Fig. 5). Interestingly, only one and ten COVID-19 cases (zero deaths) were noticed when the Ave_T was < 20°C and between 20°C and 22°C, respectively. The observed mean RH for these two Ave_T thresholds was 88.2 ± 7.4% and 91.25 ± 7.7%. Similarly, out of a total of 122 days, 24 days were associated with Ave_T higher than 34°C and 35 days were associated with Ave_T ranges between 30°C and 34°C.

Similar statistics were seen with respect to RH. About 33.8% of COVID-19 cases and 45.4% of deaths were found when the RH was between 60% and 70%. Out of a total of 122 days of data period, 21 days were associated with the same criteria (60–70% of RH). During this period, the mean Ave_T was observed as 30.4 ± 4.3°C. Overall, ~66% of COVID-19 cases and ~76% of deaths were associated with RH between 27% and 70%. These results showed that high RH and normal Ave_T (~20–25°C) were strongly associated with lower numbers of daily COVID-19 cases in Delhi.

CONCLUSIONS

In the present study, we investigated the plausible relationship between environmental factors (both meteorological parameters and air pollutants from 1 March to 30 June, 2020) and the COVID-19 daily cases in the megacity Delhi, India. For this study, we utilized meteorological parameters from the India Meteorological Department and air pollution parameters from the Central Pollution Control Board (CPCB). COVID-19 showed a statistically significant positive correlation with temperature, whereas a weak negative correlation with RH. This finding
over Delhi was found corroborated with recently reported data over other locations (e.g., Bashir et al., 2020; Ma et al., 2020; Tosepu et al., 2020). Dew point temperature was found to be closely related to the number of daily COVID-19 cases and the related mortality. It was observed that the WS exhibited a significant positive correlation with daily COVID-19 cases over Delhi, indicating that the virus might be able to transmigrate with high wind. We also observed a prominent positive correlation of O$_3$ with daily COVID-19 cases in Delhi. The observed probability analysis revealed that the count of daily confirmed COVID-19 cases was significantly associated with a certain range of weather conditions. For example, the results showed that a higher number of COVID-19 cases were associated with the combination of RH between 50–80% and the higher Ave_T (> 30°C). However, only nine confirmed COVID-19 cases and zero deaths were evident when the weather was associated with high RH (> 90%) and low Ave_T (~20°C) conditions.
Similarly, the relatively less number of COVID-19 cases (12%) and deaths (10%) were associated with minimum RH (<50%). Overall, the present analysis shows that there was a clear relationship between COVID-19 cases and environmental factors such as temperature, RH, WS, and O₃. However, this study also includes several limitations since the meteorological and air pollutant data were taken from one single station which may affect correlations. However, this preliminary
study provides needful information for the general public to understand the environmental factors influencing on COVID-19 transmission over Delhi. A more detailed analysis over different parts of the country is required to conclude the plausible role of the environmental factors in the spread of COVID-19 in India.

FUNDING

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ACKNOWLEDGMENT

The authors acknowledge the India Meteorological Department and Central Pollution Control Board, New Delhi for the necessary meteorology and air pollution datasets used in this study.

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Received for review, June 14, 2020
Revised, August 5, 2020
Accepted, August 7, 2020