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The dark cloud with a silver lining: Assessing the impact of the SARS COVID-19 pandemic on the global environment

Preet Lal, Amit Kumar, Shubham Kumar, Sheetal Kumari, Purabi Saikia, Arun Dayanandan, Dibyendu Adhikari, M.L. Khan

HIGHLIGHTS

• COVID-19 cases in the tropical regions were relatively lower than the European & American regions.
• Observed a substantial reduction in NO2, low reduction in CO, and low to moderate reduction in AOD
• High COVID-19 hazard (AH: 4 to 9 g m−3) in major of the globe during April–July 2020
• Northern Hemisphere may be more susceptible compared to tropical regions in May–July 2020.
• Tropical regions may be comparatively more prone to outbreaks in October–November 2020.

GRAPHICAL ABSTRACT

ABSTRACT

The Severe Acute Respiratory Syndrome-Coronavirus Disease 2019 (COVID-19) pandemic caused by a novel coronavirus known as SARS-CoV-2 has caused tremendous suffering and huge economic losses. We hypothesized that extreme measures of partial-to-total shutdown might have influenced the quality of the global environment because of decreased emissions of atmospheric pollutants. We tested this hypothesis using satellite imagery, climatic datasets (temperature, and absolute humidity), and COVID-19 cases available in the public domain. While the majority of the cases were recorded from Western countries, where mortality rates were strongly positively correlated with age, the number of cases in tropical regions was relatively lower than European and North American regions, possibly attributed to faster human-to-human transmission. There was a substantial reduction in the level of nitrogen dioxide (NO2: 0.00002 mol m−2), a low reduction in CO (<0.03 mol m−2), and a low-to-moderate reduction in Aerosol Optical Depth (AOD: -0.1 to -0.2) in the major hotspots of COVID-19 outbreak during February–March 2020, which may be attributed to the mass lockdowns. Our study projects an increasing
coverage of high COVID-19 hazard at absolute humidity levels ranging from 4 to 9 g m\(^{-1}\) across a large part of the globe during April–July 2020 due to a high prospective meteorological suitability for COVID-19 spread. Our findings suggest that there is ample scope for restoring the global environment from the ill-effects of anthropogenic activities through temporary shutdown measures.

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1. Introduction

In 2020 a novel coronavirus known as SARS-CoV-2 struck the world through widespread human transmission (Bukhari and Jameel, 2020), creating fears of a new plague similar to the Spanish Flu in 1918, Mexican Smallpox in 1967, AIDS in the early 1980s, SARS in 2002/03, Bird Flu in 2005, Swine Flu in 2009/10, and Ebola in 2014 (Harari et al., 2007). First discovered by the Chinese Center for Disease Control and Prevention (Li et al., 2020), the first case of COVID-19 was reported in the region of Wuhan in the central Hubei Province of China on 31st December 2019 (Shi et al., 2020; TWC India, 2020). Rising global death tolls combined with the high infectivity of the virus, mild clinical symptoms, an uncertain incubation period, lack of pre-existing human immunity, and the possibility of asymptomatic healthy carriers (Bouey, 2020) led to the WHO declaring COVID-19 a “Public Health Emergency of International Concern (PHEIC)” on 30th January 2020 (World Health Organization, 2020a). COVID-19 is transmitted via droplets and fomites (contact with contaminated surfaces) (Bouey, 2020), with children less affected than adults and the elderly. A coronavirus patient can transmit the disease to three people on average without intervention (compared with one for the common influenza, two for Ebola, and 18 for measles) (Liu et al., 2020). Symptoms of COVID-19 range from mild symptoms similar to the common cold or flu (Guo et al., 2020; Peeri et al., 2020; Shi et al., 2020; Wang et al., 2020), with major symptoms appearing 2–14 days from infection and including trouble breathing, persistent pain or pressure in the chest, mental confusion or inability to arouse, and bluish lips or face (CDC, 2020a). Those with persistence symptoms often require specialized respiratory management at intensive care units (Chan et al., 2020; Rodriguez-Morales et al., 2020; Zhu et al., 2020). As there is no pre-existing immunity in humans for several undocumented viruses in the environment including SARS-CoV-2, every individual on the planet is assumed to be a susceptible host to COVID-19 (World Health Organization, 2020a). To date there is no known specific and effective pharmacological treatment for COVID-19 (Cortegiani et al., 2020). Despite China’s preventative measures to control the spread of COVID-19, several other countries are still struggling to contain the virus (Dong et al., 2020). Various pandemic risk reduction measures such as social distancing, cluster lockdowns, mass quarantines, extensive travel bans, and disruptions to transportation systems have had a direct impact on local and global socio-political relations and economic growth (Long and Feng, 2020).

Such extreme measures to control the virus have potentially resulted in decreases of aerosols and atmospheric pollutants due to the disruption of anthropogenic-based emissions (https://www.theguardian.com/world/2020/mar/20/coronavirus-the-week-the-week-shut-down). Aerosols have direct and indirect contributions on climate change at regional and global scales (Huang et al., 2014; Menon et al., 2002; Qian and Giorgi, 1999) as increased levels of Aerosol Optical Depth (AOD) affects atmospheric stability and precipitation as aerosols disturb the scattering and absorption of solar radiation (Jiang et al., 2016), the hydrological cycle (Prasad et al., 2004) and vegetation cover and its growth (Lal et al., 2019; Sarkar and Kafatos, 2004). In addition to climatic effects, aerosols increase respiratory problems in humans and decrease visibility in urban areas (Prasad et al., 2005). A study on the 2002/03 Severe Acute Respiratory Syndrome (SARS) showed a positive relationship between long term exposure to air pollution (PM\(_{10}\), NO\(_2\), CO, O\(_3\), and SO\(_2\)) in China and a higher risk of dying (84%) in regions of moderate and high air pollution index (Cui et al., 2003). Similarly, higher concentrations of other atmospheric pollutants such as nitrogen dioxide (NO\(_2\)) have been linked with diseases such as bronchoconstriction, breathing or respiratory problems, lung infections, and reduced immunity, which lead to an increased susceptibility to colds and flu (Goings et al., 1989).

The COVID-19 pandemic outbreak had brought major economic disruption in the world (Khan et al., 2020; WTO, 2020), with disruptions in global supply chains, business and consumer confidence, the decline in commodity prices, international tourism and business travel, and less demand for imported goods and services (Boone et al., 2020). The long-term economic impacts include changes in health care expenditure as well as downstream impacts of COVID-19 on mortality and morbidity (Abiad et al., 2020), with a rapid increase in economic anxiety in the population at large (Fetzer et al., 2020).

Human coronaviruses have shown strong winter seasonality between December and April, becoming undetectable in the summer months in temperate regions of the world (Gaunt et al., 2010). Average temperature (5–11 °C), relative humidity (RH: 47–79%) and latitude profiles exhibited similarity in the timing of COVID-19 outbreak during January 2020 in Wuhan, China, and February 2020 in other affected regions (Sajadi et al., 2020). Similarly, 90% of COVID-19 cases have been reported in countries with a temperature range of 3° to 17 °C and between an absolute humidity (AH) of 4 to 9 g m\(^{-3}\) (Bukhari and Jameel, 2020). Laboratory conditions conducive to the survival of the members of the coronavirus family are low temperatures (4 °C), and moderate to high RH (20–80%) (Casanova et al., 2010). However, the SARS-CoV-2 may survive for several days on plastics and metals at moderate temperatures (between 21 and 23 °C) and a RH of 40% (van Doremalen et al., 2020). This suggests there may be a direct relationship between temperature, humidity, environmental pollutants, and the spread of SARS-CoV-2. Therefore, the objectives of the present study are to (i) assess the status of COVID-19 cases across the globe, (ii) study the meteorological correlates of COVID-19 occurrences, and (ii) assess the impact of COVID-19 pandemic on the quality of the global environment.

2. Data used and methodology

We used satellite data, COVID-19 reported case data, and meteorological data (Table 1) to assess the impacts of COVID-19 on the global environment. The country-wise cumulative cases of COVID-19 affected population and death tolls were acquired from WHO (https://www.who.int) and analyzed on a weekly basis until 10 April 2020 in a GIS environment. Temperature and relative humidity hourly datasets of 0.25° were taken from the Copernicus Climate Data Store (CDS), and European Center for Medium-Range Weather Forecast (ECMWF) (https://cds.climate.copernicus.eu) used to calculate Absolute Humidity. Data on the weekly concentration of Carbon Monoxide (CO), NO\(_2\), and AOD for the period of 01 January to 21 April 2020 were acquired and analyzed. The same datasets were acquired for the period of 01 January to 21 April 2019 to compare the variability of said parameters. Standardized anomalies (SA) of AOD and near-surface air temperature (2 m above the surface) for January to March was estimated using Eq. (1).

Standardized anomalies

\[ \text{SA} = \frac{\text{Observed} - \text{longtermmean (2001–2020)}}{\text{standard deviations}} \tag{1} \]

Climate Data Operator (CDO) tool was used to estimate standard deviations and climatological mean. Projected near-surface air temperature,
and relative humidity (RH) datasets acquired from CIMIP-5 model at RCP 8.5 scenario until November 2020 and were used to estimate the possible impacts of COVID-19 on different countries under future meteorological conditions. Absolute Humidity was calculated using Clausius Clapeyron (Iribarne and Godson, 1973) Eq. (2).

\[
AH = \frac{6.112 \times e^T + 243.5 \times RH}{273.15 + T}
\]

whereas, \(T\) = Temperature in °C, \(RH\) = Relative humidity.

AH might play an important role in determining the spread of SARS-CoV-2 as the majority of COVID-19 cases (320,000) have been observed in regions of AH: 4 to 9 g m\(^{-3}\) (Bukhari and Jameel, 2020). Therefore, global COVID-19 hazard assessment was estimated based on AH on future projected data for the period of April to November 2020. The AH-based hazard map was classified into 4 different classes considering their possible habitat suitability viz., high hazard (AH: 4 to 9 g m\(^{-3}\)), moderate hazard (AH: 2 to 4 g m\(^{-3}\) and 9 to 12 g m\(^{-3}\)), low hazard (AH: <2 and 12 to 15 g m\(^{-3}\)) and very low hazard (AH: >15 g m\(^{-3}\)).

### 3. Results and discussion

#### 3.1. Impact on human beings

The cases related to COVID-19 affected population and death tolls were mapped and analyzed (Fig. 1). A total of 1,240,239 persons with confirmed cases and 81,661 deaths occurred due to COVID-19 around the world till 10th April 2020 (World Health Organization, 2020b).

| Datasets | Spatial resolution | Temporal resolution | Source | Citation |
|----------|-------------------|---------------------|--------|---------|
| Nitrogen Dioxide | 0.01° | Daily | Sentinel 5P | (Veefkind et al., 2012) |
| Carbon Monoxide | 0.01° | Daily | Sentinel 5P | (Veefkind et al., 2012) |
| Temperature | 0.25° | Hourly | ERA-5 | Copernicus Climate Change Service (C3S), (2017) |
| Aerosol Optical Depth | 1° × 2.5° | Monthly | CIMIP-5 (IPSL-CM5A-MR) | (Institut Pierre-Simon Laplace, 2017) |
| Relative Humidity | 1° × 2.5° | Daily | MODIS_D3 | (Platnick et al., 2015) |
| Aerosol Optical Depth | 0.25° | Hourly | ERA-5 | Copernicus Climate Change Service (C3S), (2017) |
| COVID-19 Report | – | – | WHO/John Hopkins | (World Health Organization, 2020b; Dong et al., 2020) |

week-1: 01 Jan to 07 Jan, week-2: 08 Jan to 14 Jan, week-3: 15 Jan to 21 Jan, week-4: 22 Jan to 29 Jan, week-5: 30 Jan to 05 Feb, week-6: 06 Feb to 12 Feb, week-7: 13 Feb to 19 Feb, week-8: 20 Feb to 26 Feb, week-9: 27 Feb to 04 Mar, week-10: 05 Mar to 11 Mar, week-11: 12 Mar to 18 Mar, week-12: 19 Mar to 25 Mar 2020, week-13: 26 Mar to 01 Apr, week 14: 02 Apr to 08 Apr, Week 15: 09 Apr to 15 Apr and week 16: 16 Apr to 21 Apr.

\[ a \] https://sentinel.esa.int/web/sentinel/user-guides/sentinel-5p-tropomi.  
\[ b \] https://cds.climate.copernicus.eu/cdsapp#!/search?type=dataset.  
\[ c \] https://giovanni.gsfc.nasa.gov/giovanni/.  
\[ d \] https://www.who.int/emergencies/diseases/novel-coronavirus-2019.  
\[ e \] https://coronavirus.jhu.edu/map.html.
of confirmed cases was highest in the European region (8.3%), followed by the Eastern Mediterranean region (5.2%), South-East Asian region (4.4%), and African region (4.3%) with the lowest deaths as compared to confirmed cases reported from the region of Americas (3.5%) and Western Pacific region (3.4%) (Table 2).

The global country-wise assessment indicated the majority of affected populations were from the United States of America (34.34% of the global cases), followed by Spain (12.29%), Italy (11.58%), Germany (9.15%), France (6.88%), China (6.72%), Iran (5.34%) and UK (5.25%). While COVID-19 initially came to attention in the Hubei province of China and subsequently spread to many other regions of the world through global travel (Huang et al., 2020) due to its highly transmissible nature (Bogoch et al., 2020), a consistent pattern of COVID-19 cases was observed from east to west along the 30° to 50° N latitude including South Korea, Japan, Iran, and Northern Italy. Notably, COVID-19 failed to significantly spread to countries immediately south of China as the number of patients and reported deaths in Southeast Asia was much lower compared to temperate regions (Dong et al., 2020). High temperatures (>40 °C) and extremely low temperatures (<−4 °C) restrict the spread of the members of the coronavirus family (Casanova et al., 2010) and is expected to diminish COVID-19 considerably in affected areas above 30°N in the coming months (Sajadi et al., 2020).

The continent level assessment showed that Europe (799,696) was severely affected, with the country of Spain (152,446) being the most affected country followed by Italy (143,626), Germany (113,525), France (85,531), and UK (65,081) (Fig. 2 and Table 1). North America became the 2nd most-affected continent, with the worldwide highest number of cases observed in the USA (425,889), Canada (197,593), Mexico (31,811), Panama (25,258) and Dominican Republic (23,491). Notably, COVID-19 failed to significantly spread to countries immediately south of China as the number of patients and reported deaths in Southeast Asia was much lower compared to temperate regions (Dong et al., 2020). High temperatures (>40 °C) and extremely low temperatures (<−4 °C) restrict the spread of the members of the coronavirus family (Casanova et al., 2010) and is expected to diminish COVID-19 considerably in affected areas above 30°N in the coming months (Sajadi et al., 2020).

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Weekly analysis of AH (water vapour/moisture in the air regardless of temperature) exhibited higher concentrations (i.e., 16 to 24 g m\(^{-3}\)) at 30°S to 30°N latitudes. Major outbreaks of COVID-19 occurred in the region between 30°N and 50°N latitudes, with AH: 4 to 14 g m\(^{-3}\). Virus transmission was much lower in regions of high humidity (>13 g m\(^{-3}\)) as well as moderate temperature (around 17 °C) (Fig. 4). It may be one major reason for the lower number of cases in the tropics. Similarly, cases are very low in regions located in the extreme Northern and the Southern Hemisphere due to low temperatures (<2 °C) as well as low absolute humidity (<2 g m\(^{-3}\)).

SARS-Cov may not have had the ability to survive in higher temperature due to lipid layer breakdown (Chan et al., 2020) and SARS-CoV-2 may have similar behavior (El Zowalaty and Järhult, 2020). While AH started increasing in major parts of Europe after 8th week and 9th week, the value stayed under 10 g m\(^{-3}\), which is within the reported favourable range of coronavirus transmission (4 to 9 g m\(^{-3}\)) (Bukhari and Jameel, 2020). The Indian subcontinent had an AH range of 12 to 18 g m\(^{-3}\) in recent weeks but, during 1st week to 8th week, the majority of regions had some extent of favourable AH range for virus transmission (i.e., 8 to 12 g m\(^{-3}\)). Despite this, the number of reported cases was lower than expected, possibly due to early preventive measures and complete lockdown in most tropical countries.

While in the upper part of the Northern Hemisphere with a temperature <0 °C recorded very few cases, increasing COVID-19 cases during mid-March in regions of moderately high mean monthly temperatures (~20 °C) may be attributed to coronavirus transmission by international travellers. Although detection of the number of cases varies due to multiple factors such as the number of tests, global connectivity, medical facilities, time, and the extent of implementation of government policies, several South Asian and African countries have announced lockdowns after the 2nd week of March as a preventive measure to curb the virus spread at stages 1 and 2.

### 3.3. Release of atmospheric pollutants before and during COVID-19 outbreak

Nearly half of the world is under partial or complete lockdown due to the COVID-19 outbreak, leading to the shutdown of industries and motor vehicles and an associated reduction in the concentration of atmospheric pollutants. In the present study, the direct and indirect
impact of the COVID-19 outbreak on environmental pollution has been studied using spatio-temporal satellite-based products related to NO₂, CO, and AOD.

The Sentinel 5-P TROPOMI satellite-based weekly monitoring of global tropospheric NO₂ column number density exhibited its major coverage in subtropical to temperate regions of the Northern Hemisphere, where its concentration ranged from $0.00003 - 0.00007$ mol m$^{-2}$ (Fig. 5a–b). Although the highest concentration ($0.00007$ mol m$^{-2}$) was observed in eastern China, the southeast Asian region (including the Indo-Gangetic plain), western and southern Europe, and eastern North America during January–March 2019, a significant reduction in NO₂ concentration was recorded in 2020 primarily after 10th week and onwards. Major changes were observed in South Asia and South-East Asian countries including major parts of Indian regions like the IGP, where NO₂ concentration was drastically reduced during the 12th to 16th week as compared to previous weeks due to the shutdown of various industries and a travel ban issued.
on 24th March 2020. In Western Africa, major changes were observed from 7th and 8th week and had been continuously decreasing, whereas major changes in Europe were observed 12th week onwards. Besides, the variation in global NO2 concentration is influenced by global wind circulations (Arya, 1999; Grundstrom et al., 2015; Santurtún et al., 2017). A sharp reduction in NO2 concentration occurred across the globe, primarily in the Southern Hemisphere and tropical regions during January to March 2020. As compared to 2019, other highly populated regions of the world (Europe, North America, and IGP) had also observed low (<0.00003 mol m\(^{-2}\)) to moderate (<0.00005 mol m\(^{-2}\)) reductions in NO2 during 2020. These trends may be attributed to regional variations in the timing of the COVID-19 outbreak, as well as the implementation of preventive measures.

The incomplete burning of carbon-based fuels leads to the generation of CO which is spread by wind circulation patterns throughout the lower atmosphere (Novelli et al., 1998). The weekly monitoring of global CO column number density based on daily observation of Sentinel 5-P TROPOMI exhibited higher concentration (<0.04 mol m\(^{-2}\)) in the Southern Hemisphere (Europe and North American countries), and low concentration (<0.03 mol m\(^{-2}\)) in the Southern Hemisphere (Fig. 6a–b). Although changes observed worldwide were quite low (<0.03 mol m\(^{-2}\)) and near constant, a slight increase (0.04 to 0.05 mol m\(^{-2}\)) was observed in the Northern Hemisphere in 2020. In contrast, the Indian subcontinent recorded moderate to high concentrations of CO with slight decreases during the 11th and 16th week in 2020. The northern part of India (Delhi) observed a significant reduction in CO concentration during the 10th to 16th week due to effective implementation of the shutdown of major industries in response to the COVID-19 pandemic. The high concentration of CO during the 1st and 2nd week of January 2020 over the Australian continent and in tropical/subtropical regions during January to March 2020 may be attributed to the combined impact of Australian bushfire and Amazon forest fire incidents that took place during late 2019 to mid-February 2020 (Henriques-Gomes, 2020; Williamson et al., 2020).

The MODIS Terra-Aqua sensors based global weekly AOD during January–March 2020 was analyzed and compared with January–March 2019 to deduce the impacts of the global COVID-19 outbreak followed by the complete/partial shutdown of major industrial, commercial, and transportation activities. The study exhibited episodic
variability of AOD with overall decreases (primarily in low-moderate AOD) during January–March 2020 in major hotspots than 2019. Western Africa, IGP, eastern China, and southern regions of South America were the locations with high AOD during January–March 2020, where the low-moderate reduction in AOD was observed as compared to January–March 2019 (Fig. 7a–b). Weekly assessment of AOD in China exhibited reductions of AOD during 1st to 7th Week 2020, representing a clear implication of suspension of human activities after the COVID-19 outbreak. After that, the increase of AOD was evident in China due to the resumption of industrial as well as commercial activities. Similarly, high variability of AOD with overall decreases (primarily in low-moderate AOD) during January–March 2020 in major hotspots than 2019. Western Africa, IGP, eastern China, and southern regions of South America were the locations with high AOD during January–March 2020, where the low-moderate reduction in AOD was observed as compared to January–March 2019 (Fig. 7a–b). Weekly assessment of AOD in China exhibited reductions of AOD during 1st to 7th Week 2020, representing a clear implication of suspension of human activities after the COVID-19 outbreak. After that, the increase of AOD was evident in China due to the resumption of industrial as well as commercial activities. Similarly, high variability of AOD with overall decreases (primarily in low-moderate AOD) during January–March 2020 in major hotspots than 2019. Western Africa, IGP, eastern China, and southern regions of South America were the locations with high AOD during January–March 2020, where the low-moderate reduction in AOD was observed as compared to January–March 2019 (Fig. 7a–b). Weekly assessment of AOD in China exhibited reductions of AOD during 1st to 7th Week 2020, representing a clear implication of suspension of human activities after the COVID-19 outbreak. After that, the increase of AOD was evident in China due to the resumption of industrial as well as commercial activities. Similarly, high variability of AOD with overall decreases (primarily in low-moderate AOD) during January–March 2020 in major hotspots than 2019. Western Africa, IGP, eastern China, and southern regions of South America were the locations with high AOD during January–March 2020, where the low-moderate reduction in AOD was observed as compared to January–March 2019 (Fig. 7a–b). Weekly assessment of AOD in China exhibited reductions of AOD during 1st to 7th Week 2020, representing a clear implication of suspension of human activities after the COVID-19 outbreak. After that, the increase of AOD was evident in China due to the resumption of industrial as well as commercial activities. Similarly, high
AOD was observed in the Indian region until the 10th week, and thereafter a significant reduction was evident due to the COVID-19 outbreak in India in the form of local transmissions (stage 2). Central and western Africa observed high AOD until the 9th week followed by a significant reduction during the 10th week. Again, AOD was observed to be high during the 11th Week in the African region. In major parts of the world, there is a continuous reduction of AOD till the 16th week and exceptionally some parts (central part of India, North-east India,
Fig. 7. Global weekly mean AOD concentration during (a) January–April 2019, (b) January–April 2020, and (c) standardized anomaly of AOD (Jan to March 2020) with respect to long-term monthly mean (2001–2020).
Bangladesh and Canada) showing an increase with reference to the previous weeks, which may be attributed by the coverage of desert or proximity to the sea. The standard anomaly of AOD with reference to the long term monthly means (2000–2019) was also evaluated. The study exhibited an increase in area under negative anomaly (≤0.06) of AOD primarily in parts of Africa, east China, and South America during January 2020 and in major parts of Central and North Africa and east Asia during February 2020 (Fig. 7c). In contrast, a positive anomaly of AOD was observed in the temperate region of the Southern Hemisphere followed...
by the Indian subcontinent and central China during January 2020 and in west Africa, and the Indian subcontinent during February–March 2020. The study exhibited an overall reduction in aerosol concentrations during January–March 2020 in large parts of the globe.

3.4. Future projections of absolute humidity and COVID-19 hazards assessment

The future projections of absolute humidity based on the CMIP-5 model at RCP 8.5 scenario until November 2020 were used to deduce the possible contribution of meteorological conditions to COVID-19 spread following January–March 2020 variations in AH and Bukhari and Jameel (2020) concepts of virus transmission at the different threshold of AH. AH plays a significant role in the transmission of SARS-CoV-2 (Carleton and Meng, 2020; Ficetola and Rubolini, 2020; Luo et al., 2020; Oliveira et al., 2020). A peak rate of spread of COVID-19 in temperate regions of the Northern Hemisphere having a mean temperature of ~5 °C, and AH of 4 to 9 g m⁻³ during the outbreak period was observed, while it was lower both in warmer/wetter and colder/drier regions (Ficetola and Rubolini, 2020). Nevertheless, changes in weather alone (i.e., increases or decreases of temperature and humidity) will not necessarily lead to declines in case counts without the implementation of extensive public health interventions (Luo et al., 2020).

Therefore, a prospective global COVID-19 hazard based on AH from April to November 2020 was mapped and analyzed (Fig. 8). The study projected an increasing coverage of high COVID-19 hazard in a large part of the globe during April to July 2020 due to high prospective meteorological suitability (AH: 4 to 9 g m⁻³). The study illustrated a severe and high probability of COVID outbreak in major parts of the Northern Hemisphere as compared to the Southern Hemisphere during May–July 2020 barring primarily tropical regions. Thereafter, a reduction in COVID-19 hazard may be evident in the tropical and subtropical regions during August–September 2020 due to variations in regional meteorological conditions. Later, in October–November 2020, COVID-19 hazard will be resurgent in the tropical and subtropical regions (primarily in the Northern Hemisphere) and reduced in temperate and sub-tropical regions of the globe. In the Asian continent, virus transmission has a low possibility except in China as the majority of countries will have moderate AH (2 to 4 g m⁻³ and >10 g m⁻³) until September 2020 (Fig. 8). The study indicated severe COVID-19 pandemic hazard in the coming months due to meteorological suitability apart from local transmissions.

An important caveat of our study is that the environmental suitability analysis and predictions are based on the data available till 10th April 2020. Hence, future predictions on the potential areas as well as the meteorological suitability for COVID-19 transmission may vary with availability of new data. It is important to mention that the trend of infection may be potentially influenced by diverse factors comprising of the immunity level of individuals, degree of social interactions, quality of healthcare facilities, meteorological conditions, as well as the promptness of the government and society in responding to emergency situations. Thus, there are uncertainties associated with our model predictions. Hence, we advise the end users to practise caution while using the predictions.

4. Conclusions

Based on the above discussion, we conclude that the intensity of transmission of COVID-19 is not uniform in spite of its global spread. Mortality is positively correlated with age-group as well as severe pre-existing medical conditions. There has been a substantial reduction in the emission of atmospheric pollutants viz., NO₂ and AOD because of forced shutdowns reflecting high fossil fuel consumption based human lifestyles in the developed countries. In general, meteorological factors may not be directly related to the number of outbreaks. However, countries with temperatures between 4 °C ± 2 °C to -19 °C ± 2 °C and AH: 4 to 9 g m⁻³ are at a higher risk of COVID-19 outbreak despite preventive measures. Therefore, in the upcoming months, i.e., May–July 2020, the Northern Hemisphere may be more susceptible to outbreaks compared to tropical regions. However, tropical regions may be prone to outbreaks during the onset of winter in October, and November 2020 and appropriate actions and policy interventions should be implemented at local as well as international levels to contain COVID-19 outbreaks and minimize the consequent damages. International consensus is required for such extreme measures to take place and to ensure the long-term survival of mankind. However, the populations of vulnerable hosts as well as the infective agents and its virulence and ability to survive outside the host for prolonged time are some of the important factors responsible to create problems to human society. In the present scenario of high degree of mutations occurring in the strains of SARS-CoV-2, further studies may be conducted to identify the strains that have the important characteristics of virulence and ability to survive longer outside the hosts.

CRediT authorship contribution statement

Preet Lal: Conceptualization, Methodology, Software, Validation, Writing - original draft. Amit Kumar: Conceptualization, Methodology, Validation, Writing - original draft, Writing - review & editing. Shubh Kamal: Methodology, Software. Sheetal Kumari: Software. Purabi Saikia: Conceptualization, Validation, Writing - original draft, Writing - review & editing. Arun Dayanandan: Writing - original draft, Writing - review & editing. Dibyendu Adhikari: Writing - review & editing. M.L. Khan: Conceptualization, Writing - review & editing.

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.

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Abbreviations

| Abbreviation | Meaning                      |
|--------------|------------------------------|
| AH           | Absolute Humidity            |
| AOD          | Aerosol Optical Depth        |
| CDO          | Climate Data Operator        |
| CDS          | Climate Data Store           |
| CMIP         | Coupled Model Intercomparison Project |
| CO           | Carbon Monoxide              |
| CoV-2        | Coronavirus-2                |
| COVID-19     | Coronavirus Disease 2019     |
| IGP          | Indo Gangetic Plain          |
| IPSL CMSA-MR | Institute Pierre Simon Laplace Model Climate Model 5A-Medium Resolution |
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