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The COVID-19 spread in India and its dependence on temperature and relative humidity

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Abstract

The coronavirus disease 2019 (COVID-19), the pandemic, is an unprecedented health emergency never seen in humankind's recorded history due to its sheer scale, rapid spread, and subsequent shock to the global economy. The respiratory viral pandemics of the 21st century (SARS-CoV-2 in 2003, Influenza AH1N1 in 2009) have revealed seasonality in environmental factors to play a role in the dynamics of their spread. Here, we report the observed state-level relationship between environmental factors such as temperature (T), relative humidity (RH), specific humidity (SH), and solar radiation (SR) on the COVID-19 spread over the Indian region. The results show that T and RH have a significant impact on the disease growth rate and doubling time. Every degree rise in temperature corresponds to a 0.99 % decrease in the number of cases and an increase in doubling time by ~ 1.13 days, implying a slowing down of spread. A similar analysis for RH reveals that more moisture leads to a higher growth rate and reduced doubling time. Lower SH and higher surface-reaching SR are found to reduce the spread and increase the doubling time similar to that of temperature. The range of average state-level T (RH) encountered during this period was between 24 and 35^{o}C (30 and 87%), which implies that environmental impact is still active at all these T (RH) and is not limited to specific T (RH) ranges. The progression of the season towards monsoon, post-monsoon, and after that winter with a continuous reduction in temperature will prove a significant challenge for health workers and policymakers attempting to enforce mitigation and control measures.

Keywords: COVID-19, Coronavirus, Temperature, Environment, Relative Humidity, India

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Highlights

1. The increase (decrease) in temperature leads to a decrease (increase) in COVID-19 spread. A 1^{o}C rise in temperature leads to the decline in disease cases by 0.99% and increases the doubling time by ~ 1.13 days.

2. Similarly, an increase in relative humidity tends to increase the growth rate and decrease the doubling time ~ 1.18 days.

3. Increasing solar radiation decreases disease cases and increases their doubling time.

4. There is significant potential for spread due to unfavorable environmental conditions towards monsoon, post-monsoon, and winter.

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1. Introduction

The novel coronavirus disease 2019 (COVID-19) pandemic caused by SARS-CoV-2 has spread rapidly to hundreds of countries and territories of the world, with more than 10.7 million cases and half a million deaths (WHO dashboard (https://COVID-19.who.int/) as of July 03, 2020) despite a series of mitigation efforts. The high transmissibility of SARS-CoV-2 (e.g., the median R0 value of 5.7, 95% CI 3.8-8.9) and the ability of asymptomatic and pre-symptomatic individuals to transmit the disease (Khalili et al., 2020) pose a significant challenge in isolation and contact tracing activities. The higher percentages of asymptomatic, pre-symptomatic, and mildly symptomatic infections (~80%) is also in contrast to previous zoonotic coronavirus diseases SARS-CoV 1 and the Middle East Respiratory Syndrome Coronavirus (MERS CoV) (Petrosillo et al., 2020). SARS-CoV-2 principally spreads via respiratory droplets, direct and indirect contact transmission, and close-range aerosol transmission (Prather et al., 2020). Knowledge from previous respiratory viral pandemics of the 21st century (SARS-CoV-2 in 2003, H1N1 IN 2009) has revealed seasonal cyclicity to play a role in the dynamics of spread (Dowell et al., 2004, Fisman, 2007). Cold temperature and relatively low humidity favor viral transmission and severity in several proposed ways (Lowen et al., 2007). Low temperature and humidity compromise the innate mucosal immunity of the nasal mucosa. Secondly, the SARS-CoV-2 fomites' ability to further transmit the disease is less in high temperature and humidity conditions. Thirdly, in relatively low humidity conditions, respiratory droplets quickly change to droplet nuclei and remain suspended for a long time facilitating aerosol transmission (Zhao et al., 2020).

The behavior of the ongoing COVID-19 pandemic has been strikingly different across continents. Although several factors, including population density, testing capacities, public awareness, differing resilience to a health crisis, and early implementation of lockdown measures could have contributed to these differences, it is also speculated that meteorological/environmental factors could also contribute to these differences. In a statistical analysis of the mean COVID-19 cases per population ratio between countries based on the hemispheric locations, Northern Hemisphere countries had substantially higher cases than Southern Hemisphere countries. [0.0609 ± 0.146 vs 0.0085 ± 0.013, respectively, P < .01] (Ozdemir et al. 2020). In the month of March, when India was in the very early stage of the pandemic, various mathematical models projected the severity of COVID-19 pandemic in terms of cases and deaths, which led to the bold decision of early, extensive and prolonged lockdowns aimed at bringing down the basic reproductive number (R0) as well as blunting the effect of the pandemic. Despite the initial uniform national policy, the spread of COVID 19 has not been uniform across various states of India, which encounters significant Spatio-temporal variations in the prevailing weather conditions. Several studies have investigated the role of environmental factors such as temperature, humidity, solar radiation, winds, and air pollution on the spread of this disease (Saadat et al., 2020; Coocia, 2020; Mohammed et al., 2020; Notari, 2020). However, a systematic countrywide study has not been carried out over the Indian region except for a couple of studies that attempted such relationships for a few states and cities/towns (Bherwani et al., 2020, Vishnuradhan et al., 2020). This study thus attempts to understand the impact of environmental factors on the spread of COVID-19 over the whole Indian region based on state-level public domain information on both COVID-19 cases and satellite-based meteorological information.

2. Data and Methodology

The cumulative number of COVID-19 cases time series were obtained from the dashboard www.COVID19india.org. The dashboard aggregates information from all reliable government

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sources such as the Ministry of Home and Family Welfare (MoHFW), and health information reports from the state government sources and is then manually curated for quality.

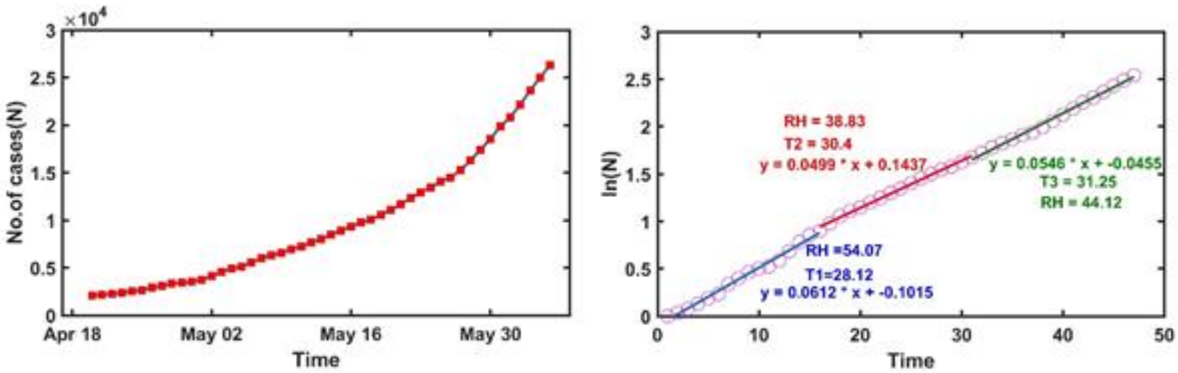

Fig. 1. a) Typical growth in number of COVID cases over the state of Delhi. b) Typical figure showing the rate of growth using the logarithmic scale for 15 days each, their slope and corresponding temperature and relative humidity.

Fig. 1a shows the typical time series obtained for the state of Delhi. One of the significant challenges in elucidating the relationship between the disease spread and environmental factors is substantial seasonality in most meteorological parameters over India. For example, increasing temperature from winter towards summer, coupled with an increase in COVID-19 cases, leads to false-positive correlations. Similar is the case for other meteorological parameters as well. Therefore, to avoid issues related to strong seasonality, the datasets were separated into different time slices to obtain the growth rate from the logarithm of cumulative COVID-19 (due to large range in numbers) cases during that particular period using simple linear regression. The growth rate is thus estimated for different periods and geographic regions and then accumulated and correlated with meteorological parameters averaged for the corresponding period. This procedure avoids issues related to strong seasonality and false correlations. It is widely accepted that two weeks is the maximum period in which the disease may become symptomatic in those infected

(WHO). Therefore, we define the time slices to be 15 days to estimate the growth rate of COVID-19 cases and corresponding averages of surface air temperature (T), relative humidity (RH), specific humidity (SH), and surface-reaching solar radiation (SR). The meteorological parameters are taken from reanalysis products (e.g., ERA5 at 25km resolution for surface T, RH (850 hPa), and SH (850 hPa) and NCEP at 2ox2o degree resolution for SR) were averaged spatially for the entire state. The analysis was carried out during the period (April 20 to June 05 2020). Only states with a population density of more than 200 km-2 are used in our analysis. The time series of these variables for each state were generated using appropriate shapefiles corresponding to each state. This exercise provided the opportunity to obtain the full range and distribution of T, RH, SH, and SR (irradiance), both temporally and spatially, representing the vast climatic conditions prevailing over the Indian region. In addition to exploring the growth rate as mentioned, the doubling time for the cumulative number of first day cases of each 15-day bins was also estimated using their estimated growth rate. These were also then analyzed for their relationship to averaged environmental factors corresponding to the respective time for doubling. The simple Pearson correlation coefficient is used to estimate the strength of the relationship of COVID-19 growth rate and doubling time, and results are tested for statistical significance.

3. Result and Discussion

3.1. Growth rate

Fig. 2 shows the logarithmic growth rate of the cumulative number of cases per day with respect to temperature. The slope is negative, implying that a higher temperature is associated with slower growth and vice versa. The correlation between growth rate and temperature was -0.43 and statistically significant at the 99% level. From the slope, it can be calculated that every degree rise in temperature leads to a slowing down of the number of cases by ~ 0.99%. This appears to be a

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slightly weaker dependence than other studies reported elsewhere that show new cases decline by 3 to 4.8% per °C (Wu et al., 2020; Prata et al., 2020). However, these values are quite high for the Indian scenario as the average growth rate of the COVID in the country itself is relatively lower than global growth rates.

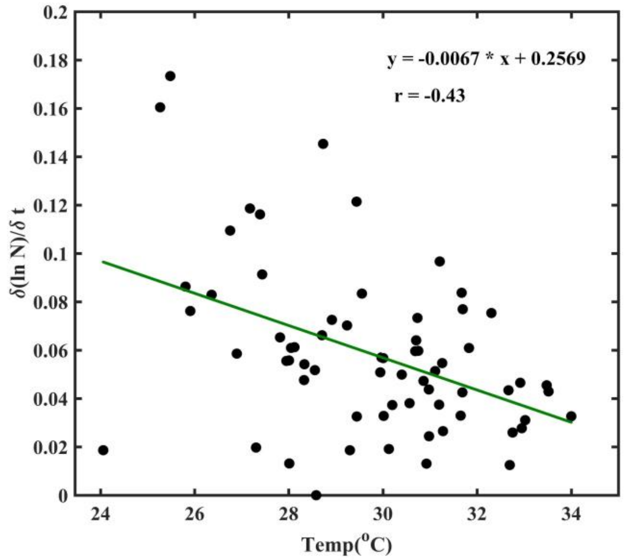

Fig. 2. The relationship between the growth rate of COVID-19 cases and surface air temperature. Each point represents the growth rate observed in different states at different times.

A similar analysis with RH shows a correlation of +0.39 with increased RH leading to increased cases by 1% for every 10% rise in RH. Past studies have shown that lower humidity conditions enhance coronaviruses' virus transmission (Chan et al., 2011). Therefore, this relationship is a bit surprising. This may simply be a consequence of the inherent connection between temperature and relative humidity. A similar analysis with SH, which represents the actual amount of moisture content in the atmosphere, is carried out, and this also reveals a positive relationship (r=+0.22) as the growth rate. Even though this correlation was not statistically significant, the similarity in the sign of the association implies that the COVID-19-RH relationship may be a robust feature.

Surface reaching SR has been shown to reduce transmission of viral infections (Sagripandu and Lytle, 2020), mostly radiation in wavelength region UV-C (McDevitt et al., 2012). However, since surface-reaching broadband total SR does not contain a significant amount of UV-C due to its absorption by the Ozone layer in the upper atmosphere, it is argued that solar radiation may not necessarily affect COVID-19 transmission (Seyer and Sanlidag, 2020). Our analysis does show that increasing SR reduces the growth rate (r=-0.31). It is not clear what causes such correlations, but it may be a reflection of the relationship between SR and temperature. It may be noted that this relationship is not statistically significant (see Table 1 for more details on different parameters used and their statistical measures).

3.2. **Doubling Time**

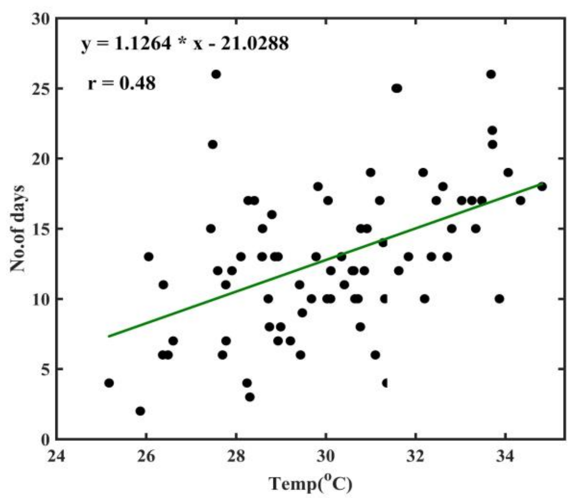

Fig. 3. The relationship between doubling time of COVID-19 cases and surface air temperature. Each point represents the growth rate observed in different states and different times.

Another measure of the COVID-19 spread is the doubling time of the number of disease cases. It may be mentioned that, depending on the doubling time for different states, the environmental factors were also averaged within the doubling time. Therefore, the averaging period of T, RH, SH, and SR considered in this is slightly different compared to the growth rate analysis, which was 15 days. It is found that the doubling time varied widely from a few days up to 26 days. The relationship between doubling time with T is shown in Fig. 3. It is clear that an increase in temperature increases doubling time (r=0.48), which means that the disease spread or growth is slowing consistent with the growth rate analysis. Quantifying this shows that for every degree rise (fall) in temperature, doubling time increases (decreases) by ~ 1.13 days. A similar study for RH shows the opposite result with respect to T (r=-0.37), as was also observed in the growth rate. An increase in RH leads to a decrease in doubling time by ~1.18 days for every 10% absolute change in RH. Overall, our analysis reveals that cold and humid conditions will lead to higher growth, whereas warm and dry conditions may lead to lower growth in COVID-19 cases. In both the analysis, the relationships were better for T and RH than SH and SR (Table 1).

Overall, our study shows that there is a clear dependence of COVID-19 spread or number of cases on environmental factors such as T, RH/SH, and SR. Our analysis also reveals that higher T reduces spread consistent with other studies carried out globally (Bukhari et al., 2020; Lowen et al., 2007; Mohammed et al., 2020; Notari et al., 2020; Prata et al., 2020; Saadat et al., 2020; Wu et al., 2020). However, our results on the effect of RH/SH contradict the previous studies, which states that higher humidity reduces spread. One of the possibilities for such assertion is that initial spread and analysis (winter to early summer period) was mostly restricted to the cold and dry countries in the higher latitudes when there were hardly any infections in the warm and humid tropics (Bukhari et al., 2020; Wu et al., 2020) leading to suggestions of latitudinal dependence

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(Mohammed et al., 2020). But other studies have shown that viral infections spread efficiently under drier conditions due to longer residence times of infective droplets (Zhao et al., 2020). Therefore, more systematic and detailed analysis is required using additional datasets from a wide range of spatially and temporally separated environmental conditions to conclude the effect of humidity on the spread dynamics.

Table 1. Statistical details of the analysis carried out between daily state-wise cumulative COVID cases and environmental/meteorological parameters. Bold numbers denote statistical significance at the 99% level.

Meteorological Parameters		N	R	p-value	Slope	Mean ± Standard deviation	Range
Temperature (°C)	**Growth Rate**	66	**-0.43**	0.0002	0.99 % $^{o}C^{-1}$	29.8 ± 2.3	24.1 to 34.0
Relative Humidity (%)		66	**+0.39**	0.001	+0.0009 day $^{-1}$	56.2 ± 14.4	30.4 to 86.8
Solar Radiation (W m^{-2}) (2°x2°, NCEP)		54	-0.31	0.02	-0.0003 (day^-1/(W/m^2))	290.7 ± 36.4	214.4 to 351.6
Specific humidity (g Kg^{-1})		66	+0.22	0.07	+0.004(day^-1/(g/kg))	10.4 ± 2	6.8 to 14.2
Temperature(°C)	**Doubling Time**	79	**+0.48**	7.8*10^-6	+1.13 (day/°C)	30.1 ± 2.3	25.2 to 34.8
Relative Humidity (%)		79	**-0.37**	8.4*10^-4	-1.18(day/10% RH)	56.7 ± 16.7	27.9 to 86.4
Solar Radiation (W m^{-2}) (2°x2°, NCEP)		64	+0.27	0.02	+0.039(day/(W/m^2))	295.0 ± 37.9	212.9 to 356.3
Specific humidity (g Kg^{-1})		79	-0.28	0.01	-0.67(day/(g/kg))	10.7 ± 2.2	6.4 to 14.2

4. **Implication**

The month of May is the hottest month of the year with dry conditions over several parts of India and temperatures on average fall from June/July with the arrival of monsoon rainfall, increasing the RH reaching a peak during August (see Fig. 4). The period during and after monsoon exhibits higher rainfall, RH, and surface cooling compared to pre-monsoon. This implies the possibility for increased spread (both in terms of growth rate and doubling time) of COVID-19 cases during monsoon and possibly winter if the current situation continues. The winter with its lower temperature is also unfavorable for the slowing down of the disease and its spread. The mean difference (country average) of as high as 7o C between summer and winter points to a possibility for greater potential spread of COVID-19 from an environmental perspective. Thus the policymakers must take targeted decisions that may also include environmental information to slow the spread. However, it must be stressed that the actual spread will eventually depend on human intervention such as strict enforcement of universal masking, physical distancing, and improved hand hygiene and possible commencement of herd immunity.

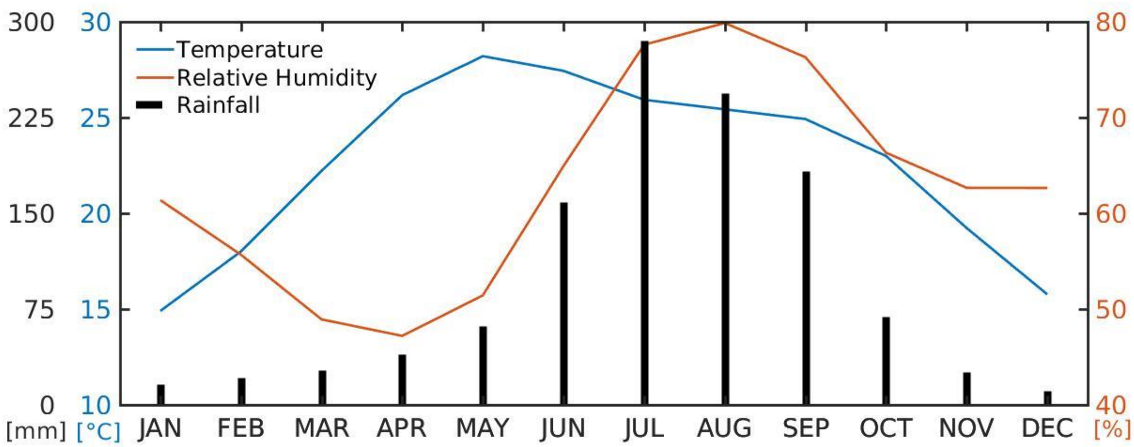

Fig. 4. The climatological seasonal variation of T, RH and rainfall over the Indian region.

5. Summary

Our analysis on the impact of environmental factors on COVID-19 cases and their growth over the Indian region shows the following,

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1. Surface air temperature is closely related to COVID-19 and its spread. Low temperature and high humidity appear to favor the spread of the disease.

2. An increase in T by one degree leads to a 0.99% decrease in the number of COVID-19 cases.

3. In terms of doubling time, a one-degree rise in temperature leads to slowing ~ 1.13 days. Similarly, an increase in 10% RH leads to an increase in doubling time by ~ 1.18 days.

4. The monsoon related rainfall and subsequent cooling of the country coupled with seasonal progression toward winter will environmentally favor COVID-19 transmission over India.

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