Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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Projections for COVID-19 pandemic in India and effect of temperature and humidity

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ABSTRACT

Background and aims: As, the COVID-19 has been deemed a pandemic by World Health Organization (WHO), and since it spreads everywhere throughout the world, investigation in relation to this disease is very much essential. Investigation of pattern in the occurrence of COVID-19, to check the influence of different meteorological factors on the incidence of COVID-19 and prediction of incidence of COVID-19 are the objectives of this paper.

Methods: For trend analysis, Sen's Slope and Man-Kendall test have been used, Generalized Additive Model (GAM) of regression has been used to check the influence of different meteorological factors on the incidence and to predict the frequency of COVID-19, and Verhulst (Logistic) Population Model has been used.

Results: Statistically significant linear trend found for the daily-confirmed cases of COVID-19. The regression analysis indicates that there is some influence of the interaction of average temperature (AT) and average relative humidity (ARH) on the incidence of COVID-19. However, this result is not consistent throughout the study area. The projections have been made up to 21st May, 2020.

Conclusions: Trend and regression analysis give an idea of the incidence of COVID-19 in India while projection made by Verhulst (Logistic) Population Model for the confirmed cases of the study area are encouraging as the sample prediction is as same as the actual number of confirmed COVID-19 cases.

1. Introduction

The COVID-19 pandemic (Coronavirus disease 2019), caused by SARS-CoV-2 (severe acute respiratory coronavirus syndrome 2), has created chaos in human society. According to World Health Organization reports, the disease is spread by respiratory droplets and communication pathways. Fever, cough, shortness of breath to pneumonia, kidney failure, and even death are some of the symptoms of this disease, which can take 2–14 days to appear in human body [1]. The pandemic began in the city of Wuhan (Hubei District) in China and affected an overwhelming majority of the countries. Since then, it has been a persistent march of new cases and deaths. This infectious COVID-19 disease has reported thousands of deaths worldwide due to the rapid pandemic risk and the lack of antiviral drugs and vaccinations [2].

Now, the pandemic COVID-19 has become a major threat to India. Several nations, like India, have gone into a lockdown situation to keep this deadly virus from spreading. Throughout India, since January 30, 2020, COVID-19 cases have been gradually growing. As reported on May 10, 2020, the Ministry of Health and Family Welfare has confirmed 62,939 cases with 2,109 deaths [3] and accordingly, all districts of India are classified as red, orange and green zones on the basis of the incidence of COVID-19 cases. India is the world's second most populated nation after China. Uncontrolled pandemic in India has the potential to affect about 1/6th of the world's population. Study of this epidemic, allows the Government to take the requisite measures to reduce the effects of this global pandemic. A range of factors may influence the transmission of coronaviruses including climatic conditions (such as temperature and humidity), population density, and standard of the medical facility and so forth [4,5]. But realizing the relationship between environment and COVID-19 propagation is the secret to predicting this pandemic's severity and end-time [6]. Using data from reported cases of India, we examined the associations between meteorological causes and the frequent occurrences of COVID-19 and also the trend of the growth of the disease. The aim is

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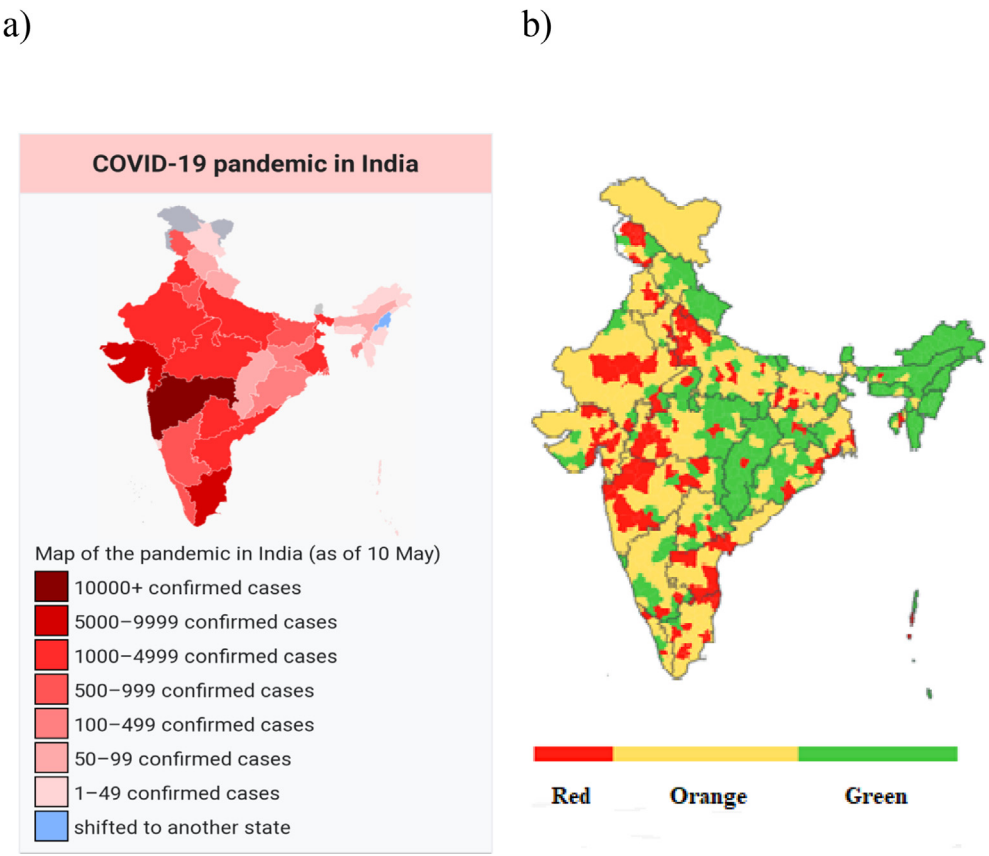

Fig. 1. a) Confirmed cases of COVID-19 (Map not for scale) and b) Classified zones on the basis of COVID-19 cases in India as of 10th of May, 2020 [©Wikipedia].

to give statistical evidence on the potential evolution of COVID-19 under changing climate conditions. The current situation of India can be witnessed from Fig. 1.

2. Materials and methods

2.1. Study area and data

The Government of India is offering a number of websites and applications to track COVID-19 events. Daily counts of those states and union territories in India having more than 1000 laboratory-confirmed cases were obtained from https://www.covid19india.org/, the official reports of the Ministry of Health and Family Welfare of India from 1st of April, 2020 to 10th of May, 2020. Accordingly, 10 states and 1 union territory have been selected namely Maharashtra, Gujarat, Tamil Nadu, Delhi, Rajasthan, Madhya Pradesh, Uttar Pradesh, Andhra Pradesh, West Bengal, Punjab and Telengana [3]. The period of analysis was selected taking into account the lockdown declared by Govt. of India and also the total daily counts of other states are less than 1000.

The meteorological data, daily minimum temperature (MinT) and maximum temperature (MaxT), daily average temperature (AT) and daily average relative humidity (ARH) of each state and union territory have been retrieved from https://en.tutiempo.net/that provides a web base platform for the researcher to examine the climate data. The website provides a generous amount of the world weather data.

Table 1
Total count of confirmed cases.

State	Total Count of Confirmed Cases
Andhra Pradesh	1936
Delhi	6803
Gujrat	8121
Madhya Pradesh	3548
Maharashtra	21869
Punjab	1781
Rajasthan	3721
Tamil Nadu	7080
Telangana	1099
Uttar Pradesh	3363
West Bengal	1902

Table 2
Sen's Slope estimates for trend detection.

State	Sen's Slope	Mann-Kendall
Andhra Pradesh	1.000000	<0.001
Delhi	6.600000	<0.001
Gujrat	11.28571	<0.001
Madhya Pradesh	2.175192	<0.001
Maharashtra	29.07500	<0.001
Punjab	1.444444	<0.001
Rajasthan	2.266667	<0.001
Tamil Nadu	6.098462	<0.001
Telangana	−0.79285	<0.001
Uttar Pradesh	2.826050	<0.001
West Bengal	2.361413	<0.001

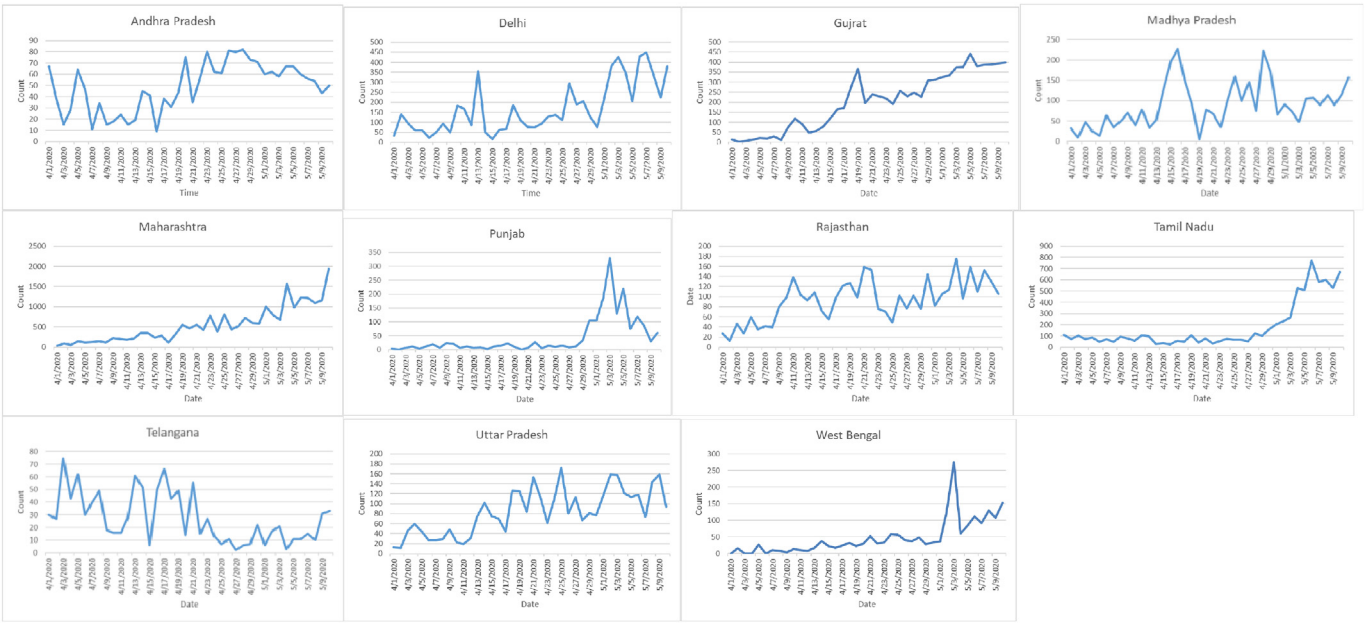

Fig. 2. Day wise Confirmed cases of COVID-19 upto 10th of May, 2020.

2.2. Statistical analysis

The Sen's Slope [7] and Mann-Kendall [8,9] method were used to verify the existence or absence of linear trend in daily laboratory-confirmed cases of COVID-19. Significant + ve value of Sen's Slope indicates a significant linear increase in daily confirmed cases where, as on the other hand, Sen's Slope's significant -ve value implies a significant linear decrease in daily confirmed cases.

Generalized additive models (GAM) have been applied during the study periods to quantify the states-specific associations between meteorological factors and daily cases of COVID-19 events, accounting for short-term temporal patterns [10]. GAM is a generalized regression model in which the linear predictor is linearly dependent on undefined smooth functions of certain predictor variables, and the subject of concern is on inferences regarding such smooth functions. The model relates a univariate response variable *Y*, to some predictor variables x_i and an exponential family of distribution is specified for *Y* such as normal, binomial, poisson distributions and so on.

As the variances of the daily counts were larger than their means, and hence the distribution of COVID-19 cases was assumed to be a negative binomial. According to WHO, coronavirus carriers are infectious 2 days before the onset of the symptoms. And hence, three-day average temperature and relative humidity have been considered for the model [6]. The model is given by:

$$Y_t = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + e_t$$

where Y_t is the daily cases of confirmed COVID-19 count, β_0 is the intercept term, β_1 denotes the effect of moving average of AT, β_2 denotes the effect of moving average of ARH, β_3 denotes the effect of MaxT, β_4 denotes the effect of MinT, β_5 denotes the effect of the interaction of AT and ARH and e_t is the disturbance term.

For prediction of the COVID-19 cases we have used Verhulst (Logistic) Population Model. To incorporate exponential growth time series we use this prediction model for forecasting [11].

3. Results

The total counts of confirmed cases from 1st of April, 2020 to 10th of May, 2020 have been presented in Table 1. Table 2 shows that all the states other than Telangana exhibit a significant upward liner trend for the confirmed cases. In case of Telangana, the trend is negative. These results are statistically significant as the p-value of Mann-Kendall is less than 0.05. These results of increase and decrease are also witnessed in Fig. 2.

The estimates of regression coefficients of the GAM for the states are listed in Table 3. Statistically significant effect of AT were found for Madhya Pradesh (1.42575), Maharashtra (2.75604), Punjab (1.48788) and Tamil Nadu (−15.89823), effect of ARH were found for Madhya Pradesh (1.21126), Punjab (0.58497) and Tamil Nadu (−6.79347), effect of MaxT were found for Maharashtra (−0.31561) and Tamil Nadu (0.43246), effect of MinT were found for Gujrat (0.20924) and Uttar Pradesh (0.189119) and effect of interaction between AT and ARH were found for Madhya Pradesh (0.03761), Punjab (0.02753) and Tamil Nadu (0.22832). However, these effects of meteorological variables vary from state to state [Table 4].

Results of Verhulst (Logistic) Population Model are listed in Table 5. Unlike the trend analysis and GEM analysis, here we have accounted the confirmed cases from 2nd May to 13th of May, 2020 as the incidence of confirmed COVID-19 cases rises significantly after April, 2020. Prediction of for three group up to May 5, 2020, up to May 9, 2020 and May 13, 2020 are same as that of actual figure. Two group of prediction have been listed up to May 17, 2020 and up to May 21, 2020.

4. Discussion

The linear upward (increasing) trend that has been found in the study area except Telangana is a worrisome sign for India. Additionally, from the beginning of May the incidence of COVID-19 rises in more recurrent way. The study argued that both daily temperature and relative humidity had an effect on the incidence of COVID-19 in most of the study region. Nevertheless, the relationship between COVID-19 and AT and ARH has not been consistent

Table 3
Results of GAM regression.

States	Parameter	Estimates	p-value
Andhra Pradesh	Intercept, β_0	−28.10783	0.2132
	AT, β_1	0.88819	0.1817
	ARH, β_2	0.49752	0.2597
	MaxT, β_3	−0.05697	0.5006
	MinT, β_4	0.13458	0.0712
	ATxARH, β_5	0.01415	0.2932
Delhi	Intercept, β_0	9.999257	0.216
	AT, β_1	−0.036883	0.902
	ARH, β_2	−0.207407	0.237
	MaxT, β_3	−0.103124	0.126
	MinT, β_4	−0.084796	0.313
	ATxARH, β_5	0.008437	0.148
Gujrat	Intercept, β_0	−3.37997	0.8149
	AT, β_1	−0.01978	0.9621
	ARH, β_2	−0.38041	0.3559
	MaxT, β_3	0.0485	0.6484
	MinT, β_4	0.20924	0.0209[a]
	ATxARH, β_5	0.01318	0.2785
Madhya Pradesh	Intercept, β_0	−43.84455	0.0161[a]
	AT, β_1	1.42575	0.0171[a]
	ARH, β_2	1.21126	0.0341[a]
	MaxT, β_3	0.05988	0.6292
	MinT, β_4	0.01476	0.8649
	ATxARH, β_5	0.03761	0.0336[a]
Maharashtra	Intercept, β_0	−73.01116	0.08333
	AT, β_1	2.75604	0.04875[a]
	ARH, β_2	0.85921	0.14815
	MaxT, β_3	−0.31561	0.00205[a]
	MinT, β_4	0.10324	0.32944
	ATxARH, β_5	0.02675	0.16511
Punjab	Intercept, β_0	−32.17071	0.01551[a]
	AT, β_1	1.48788	0.00664[a]
	ARH, β_2	0.58497	0.00540[a]
	MaxT, β_3	0.01837	0.86233
	MinT, β_4	0.16984	0.18284
	ATxARH, β_5	0.02753	0.00058[a]
Rajasthan	Intercept, β_0	−2.751481	0.587
	AT, β_1	0.255311	0.23
	ARH, β_2	0.149194	0.394
	MaxT, β_3	−0.071146	0.413
	MinT, β_4	0.053367	0.366
	ATxARH, β_5	−0.004053	0.462
Tamil Nadu	Intercept, β_0	464.62175	0.0167[a]
	AT, β_1	−15.89823	0.0127[a]
	ARH, β_2	−6.79347	0.0115[a]
	MaxT, β_3	0.43246	0.0158[a]
	MinT, β_4	−0.09937	0.4576
	ATxARH, β_5	0.22832	0.0102[a]
Telangana	Intercept, β_0	1.562944	0.965
	AT, β_1	−0.100075	0.925
	ARH, β_2	0.217862	0.756
	MaxT, β_3	0.142809	0.292
	MinT, β_4	0.117128	0.322
	ATxARH, β_5	−0.009049	0.673
Uttar Pradesh	Intercept, β_0	4.354975	0.586
	AT, β_1	−0.066434	0.851
	ARH, β_2	0.020638	0.899
	MaxT, β_3	−0.064778	0.606
	MinT, β_4	0.189119	0.040[a]
	ATxARH, β_5	−0.00067	0.908
West Bengal	Intercept, β_0	18.65133	0.4096
	AT, β_1	−0.666464	0.3498
	ARH, β_2	−0.06807	0.7822
	MaxT, β_3	−0.008686	0.9179
	MinT, β_4	0.159345	0.0991
	ATxARH, β_5	0.002448	0.7522

[a] Significant with 95% confidence.

Table 4
Effect of at, ARH, MaxT and MinT on COVID-19 incidence.

State	Effect on COVID-19 incidence			
	AT[a]	ARH[b]	MaxT[c]	MinT[d]
Andhra Pradesh	+ ve	+ ve	-ve	+ ve
Delhi	-ve	-ve	-ve	-ve
Gujrat	-ve	-ve	+ ve	+ ve
Madhya Pradesh	+ ve	+ ve	+ ve	+ ve
Maharashtra	+ ve	+ ve	-ve	+ ve
Punjab	+ ve	+ ve	+ ve	+ ve
Rajasthan	+ ve	+ ve	-ve	+ ve
Tamil Nadu	-ve	-ve	+ ve	-ve
Telangana	-ve	+ ve	+ ve	+ ve
Uttar Pradesh	-ve	+ ve	-ve	+ ve
West Bengal	-ve	-ve	-ve	+ ve

[a] Average Temperature,
[b] Average Relative Humidity,
[c] Maximum Temperature,
[d] Minimum Temperature.

across the nations. Incidence of meteorological variables varies due to vast geographical heterogeneity across India. The cumulative incidence of COVID-19 cases was higher in North and South India, as more business, agricultural, industrial and other associated activities are happening in this region of India than in the rest of the country. In addition, owing to the lockout declared by the Government on March 2020, the staffs from other areas of India are compelled to stay there. WHO finds coronavirus carriers to be contagious 2 days before the start of symptoms [12]. We, therefore, used three-day moving average of daily AT and ARH for the analysis of GAM. As India announced its lockdown at a stage when total, confirmed cases were less than 600, so in this research data are used after 7 days of lockdown. Another significant finding of this study is the significant interaction between ARH and AT, and COVID-19 incidence. Such results are compatible with the findings of China [10]. According to them, improved AT (ARH) culminated in a decreased influence of ARH (AT) on the incidence of COVID-19 in Hubei Province. The precise method of contact, however, is uncertain. They suggest one probable reason might be that a combination of low AT and humidity make the nasal mucosa prone to small ruptures, creating opportunities for virus invasion [10]. In addition, it is recommended that associations between different meteorological variables be included in the estimation process of the environment effect on the likelihood of COVID-19 transmission. Research findings of meteorological variables will be incorporated into the anticipation and regulation of COVID-19. With the help of Verhulst (Logistic) Population Model, projection of confirmed cases have been given up to 21st May. The predicted findings are quite promising as the predicting behaviour of the model as same as the already confirmed cases from 2nd May 2020 to 13th of May, 2020. In addition, due to this predicting nature, it is found quite useful than the time series forecasting methods like exponential smoothing, ARIMA for forecasting purposes in terms of COVID-19 pandemic. Because, ARIMA need a stationary time series and exponential smoothing cannot corporate with a dynamic change in time series.

5. Conclusion

In accordance to this analysis, the incidence of COVID-19 has a significant linear trend. Moreover, meteorological factors influence COVID-19 particularly the interactive effect between daily temperature and relative humidity on COVID-19 incidence. However, due to the inconsistency of results between various states, further studies are needed which include other meteorological variables as well. Keeping in mind the forecasting behaviour of Verhulst Population Model, it can be said that this research will definitely help the researchers as well as the policy makers in this field.

Table 5
Predicting results of Verhulst Population Model.

States	Total Confirmed Cases (from 02/05/2020)			Predicted Confirmed Cases (from 02/05/2020)				
	Upto 5/5/20	Upto 9/5/20	Upto 13/5/20	Upto 5/5/20	Upto 9/5/20	Upto 13/5/20	Upto 17/5/20	Upto 21/5/20
Andhra Pradesh	254	467	674	254	467	674	804.62	866.09
Delhi	1366	2804	4260	1366	2804	4260	5123.81	5484.91
Gujrat	1524	3076	4547	1524	3076	4547	5361.51	5685.01
Madhya Pradesh	334	742	1458	334	742	1458	2382.07	3196.53
Maharashtra	4019	8722	14416	4019	8722	14416	18490.40	20440.34
Punjab	866	1177	1339	866	1177	1339	1404.11	1427.49
Rajasthan	492	1042	1662	492	1042	1662	2073.76	2260.66
Tamil Nadu	1532	4009	6701	1532	4009	6701	8042.90	8464.04
Telangana	52	119	323	52	119	323	2022.67	2280.67
Uttar Pradesh	552	1045	1430	552	1045	1430	1608.66	1671.62
West Bengal	549	991	1495	549	991	1495	1899.52	2142.24

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Author's contribution

J. Hazarika supervised the work. K. Goswami and S. Bharali conceived the idea presented, discussed the methodology, S. Bharali organized the theoretical discussion and K. Goswami collected, analyzed the data and describe the results. All authors discussed the results and contributed to the final version of the manuscript.

Declaration of competing interest

The authors declare that there is no known competing interest, which could have influence in this paper.

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