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Are population size and diverse climatic conditions the driving factors for next COVID-19 pandemic epicenter in India?

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ABSTRACT

Although a nationwide lockdown was imposed in India amid COVID-19 outbreak since March 24, 2020, the COVID-19 infection is increasing day-by-day. Till June 10, 2021 India has recorded 29,182,072 COVID cases and 359,695 deaths. A number of factors help to influence COVID-19 transmission rate and prevalence. Accordingly, the present study intended to integrate the climatic parameters, namely ambient air temperature (AT) and relative humidity (H) with population mass (PM) to determine their influence for rapid transmission of COVID-19 in India. The sensibility of AT, H and PM parameters on COVID-19 transmission was investigated based on receiver operating characteristics (ROC) classification model. The results depicted that AT and H models have very low sensibility (i.e., lower area under curve value 0.26 and 0.37, respectively compared with AUC value 0.5) to induce virus transmission and discrimination between infected people and healthy ones. Contrarily, PM model is highly sensitive (AUC value is 0.912, greater than AUC value 0.5) towards COVID-19 transmission and discrimination between infected people and healthy ones and approximate population of 2.25 million must impose like social distancing, personal hygiene, etc. as strategic management policy. Therefore, it is predicted, India could be the next epicenter of COVID-19 outbreak because of its over population.

Introduction

The COVID-19 epidemic reported in Wuhan, China has been caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [19]. Higher transmissibility of this virus, mainly human-to-human, raised much concern globally. Since its outbreak from a wet market in Wuhan, it spread internationally and affected approximately 216 countries or territories [18]. Accordingly, this robust transmission internationally compelled WHO to substitute the epithet ‘epidemic’ with ‘pandemic’ [20]. World Health Organization (WHO) has recorded so far 173,674,509 confirmed cases and 3,744,408 deaths globally until June 10, 2021 [18]. Accordingly, the COVID-19 outbreaks have led to an adverse effect on the mental health in general population and healthcare staff professionals, which ultimately leading to a rise in anxiety, fear, depression, agony and associated mental illness due to implementation of emergencies and lockdowns, and healthcare regulation by governments [3]. In addition to this, the socio-economic and environmental aspects of Covid-19 outbreaks towards cleaner environments have also been documented by Bashir et al. [2].

Presently, the viral infection is spreading at high transmission rate in India, in comparison with neighboring countries including Bangladesh, Nepal, Bhutan, Sri Lanka, China, Afghanistan, and Pakistan [18]. However, the occurrence of first confirmed COVID-19 case was recorded on January 30, 2020 in Kerala state. From January 30, 2020 to June 10, 2021 India has acknowledged 29,182,072 confirmed COVID-19 cases encompassing 359,695 deaths and 27,645,225 recovery cases [18]. Southern states, namely Kerala and Karnataka and Maharashtra were initially the most affected states imposed curtaills on mass gatherings on March 10th, 2020. Consequently, mass gatherings in places like institutions, shopping malls and theatres were closed across the country from March 16 onwards [14]. Furthermore, the Government curtails the movement of migratory workers across the country.

Different factors could influence the survival and transmission of the virus such as climatic conditions (mainly temperature and relative humidity) [15], medical care quality [17], personal hygiene and social distance [21]. A number of studies demonstrated the role of ambient temperature (AT) and relative humidity in COVID-19 virus transmission based on epidemiological researches [5,8,22]. They reported either increase or decrease in virus transmissibility and survivability in the environment. Apart from this, population mass (PM) could play a crucial
role in disease transmission, in particular, in India and could aid to become a next epicenter of COVID-19, because demographically India is the second most populous country after China in the world. Likely, Lombardy region of northern Italy, which is one of the richest and densely populated regions in Europe, is now the most severely affected region by COVID-19 outbreak [10]. Tosepu et al. [16] demonstrated that COVID-19 outbreak in Jakarta is positively correlated with weather parameters namely ambient temperature and rainfall. Further, Pani et al. [11] and Auler et al. [1] reported the influence of meteorological parameters namely temperature, wind speed, relative humidity, dew point, pressure and water vapor for COVID-19 outbreak in Singapore and Brazil, respectively. India is experiencing diverse climatic conditions, resulting differences in ambient air temperature (AT) and relative humidity (H). More recently, Gupta et al. [6] used a prediction model to know which Indian regions could be more vulnerable to COVID-19 spreading. Therefore, establishment of an integration between climatic conditions and population size with COVID-19 transmission becomes very crucial to control and prevent this pandemic for the survival of mankind in India. The receiver operating characteristics (ROC) in this regard will help to measure the sensitivity analyses of these parameters based on classification models using the confusion matrix. Therefore, the present study was aimed to 1) determine the sensibility of climatic parameters, namely ambient air temperature and relative humidity and population mass on COVID-19 transmission in different states/territories of India and 2) identify their role in policy implementation by governmental policy makers as management strategy.

Materials and methods

Study area

India, officially the Republic of India, is a country in South Asia. It is the second-most populous country with approximately 1.37 billion inhabitants, the seventh-largest country by area approximately 3,287,263 km², and the most populous democracy in the world (https://en.wikipedia.org/wiki/India). India is a federal union and has 37 cumulative entities comprising 29 states and 8 union territories. India possesses a diverse climate and community. The contour map of different climatic zones and population density of India is presented in Figs. 1 and 2, respectively (https://censusindia.gov.in/2011-prov-results/data_files/india/Final_PPT_2011chapter7.pdf).

Data collection

The number of daily confirmed official cases were collected from the official websites of India (https://www.mygov.in/covid-19). Daily as well as cumulative data were collected from this site until May 25, 2020 for this study (7,175,880 COVID-19 patients including 110,118 deaths...
and 6,227,295 recovery cases (https://www.mygov.in/covid-19). Climatic data namely temperature and relative humidity was collected from India Meteorological Department (IMD) (https://mausam.imd.gov.in) and online (https://www.timeanddate.com) on monthly basis from January to May 2020 and average value was calculated. Similarly, population density was collected from ADHAR India (https://www.uidai.gov.in) (Fig. 2). Statistical data of states or union territories of India including mean annual AT, H, PM, CC (coronavirus cases), and RCI (rate of coronavirus infection) from January 30 to 31 May 31, 2020 have been tabulated in Table 1. The maximum values of AT, H, PM and CC belong to Maharashtra, Tamil Nadu, Gujrat, Delhi, Rajasthan, Madhya Pradesh and Uttar Pradesh (Table 1), and the minimum values were recorded at Sikkim, Arunachal Pradesh, Mizoram and Meghalaya.

Analysis of receiver operating characteristics (ROC)

The receiver operating characteristics (ROC) is a probability curve, demonstrating the sensitivity or true positive rate (TPR) versus specificity or false positive rate (FPR). Basically, it is showing the performance of a classification model at different thresholds using the confusion matrix [7]. Jahangiri et al. [7] demonstrated the importance of receiver operating characteristics (ROC) to analyze the sensitivity and specificity of meteorological parameters on COVID-19 transmission rate in Iran. Generally, in classification model four different combinations of actual and predicted values (Fig. 3a) have been depicted following the methodology described by Powers [12] and Jahangiri et al. [7]. Accordingly, TP and FP represent the true positive and false positive, respectively while TN and FN represent true negative and false negative, respectively. Consequently, these indices are explained more explicitly as follows:

TP: Model predicted that person has infection and it is true.
FP: Model predicted that person has infection and it is false.
TN: Model predicted that person has no infection and it is true.
FN: Model predicted that person has no infection and it is false.

The actual values have been categorized (as true or false) while predicted values have been classified as positive or negative. Sensitivity is defined as ratio of true positives to all positives while specificity is defined as ratio of true negatives to all negatives. The sensitivity (synonym as True Positive Rate, TPR) and specificity (synonym as False Positive Rate, FPR) have been defined theoretically by using the following equations (Eqs. (1) and (2), respectively) [4]:

\[
TPR / Sensitivity = \frac{TP}{TP + FN} \tag{1}
\]

\[
FPR / Specificity = \frac{TN}{TN + FP} \tag{2}
\]

Firstly, step by step movement of threshold values at each level [both sensitivity (TPR) and specificity (FPR)] were performed following the methodology described by Jahangiri et al. [7] to generate the ROC curve, generally assigned from 0 to 1 (Fig. 3b). The computed sets demonstrate the sensitivity and specificity analysis of each point [4]. Values lower and higher than threshold value are classified as predicted negative and positive values, respectively. Generally, output ROC curve (Fig. 3c) has two main areas (A1 and A2) and three critical points (P1 through P3). A1 and A2 indicates high and low sensitive regions, respectively and total areas is called ‘area under the curve’ (AUC), i.e., AUC = A1 + A2. AUC value 1 indicates an ideal model, meaning it can
distinguish separability in the best preferable way. On the other hand, the AUC value 0 indicates an imperfect model, which means it distinguishes separability very badly. At P1, the threshold value is more than 1 and, in this case, only FN and TN are activated. Contrarily, the threshold value is less than 0 at P2 and this condition indicates only TP and FP are activated. However, the most important part of ROC curve is P3 point. It is also called optimum or cut-off point, which indicates minimum distance from the point (0, 1). Furthermore, this point is considered as a buffer or boundary region of A1 and A2 sensitive regions [4,7].

Results and discussion

Here, sensitivity and specificity responses were determined in the SPSS statistical package based on the ROC curve indicated true positive rate and true negative rate, respectively. Horizontal axis (x-axis) denoted specificity responses, while vertical (y-axis) denoted sensitivity responses. The diagonal line in the ROC curve indicated a weak model and, in this case, only TP and FP are activated. However, the most important part of ROC curve is P3 point. It is also called optimum or cut-off point, which indicates minimum distance from the point (0, 1). Furthermore, this point is considered as a buffer or boundary region of A1 and A2 sensitive regions [4,7].

Table 1
COVID-19 state-wise status in India (as on May 20, 2020; Ministry of Home Affairs, GoI).

| S. No. | Name of State / UT          | AT  | H   | Population     | CC   | Deaths** | RCI  |
|-------|-----------------------------|-----|-----|----------------|------|----------|------|
| 1     | Andaman and Nicobar Islands | 28  | 76.4| 417,036        | 1668 | 0        | 0.399|
| 2     | Andhra Pradesh              | 28.4| 79.6| 53,903,393     | 377  | 56       | 0.001|
| 3     | Arunachal Pradesh           | 22.4| 74  | 1,570,458      | 2182 | 0        | 0.139|
| 4     | Assam                       | 22.8| 72.4| 35,607,039     | 896  | 4        | 0.003|
| 5     | Bihar                       | 22.8| 70  | 124,799,926    | 52   | 13       | 0.004|
| 6     | Chandigarh                  | 19  | 70.4| 1,158,479      | 6859 | 3        | 0.025|
| 7     | Chhattisgarh                | 26.6| 58  | 29,436,231     | 52,667| 0        | 0.179|
| 8     | Dadar Nagar Haveli          | 27.6| 60.2| 350,724        | 39   | 0        | 0.011|
| 9     | Delhi                       | 22.8| 46.4| 18,710,922     | 14   | 276      | 0.007|
| 10    | Goa                         | 28.6| 72.4| 1,586,250      | 1    | 0        | 0.005|
| 11    | Gujarat                     | 27.2| 41.8| 63,872,394     | 3    | 888      | 0.004|
| 12    | Haryana                     | 22.4| 59.4| 28,204,692     | 1438 | 16       | 0.005|
| 13    | Himachal Pradesh            | 20.2| 72.4| 7,451,955      | 41   | 5        | 0.001|
| 14    | Jammu and Kashmir           | 10  | 68.4| 13,606,320     | 2060 | 23       | 0.015|
| 15    | Jharkhand                   | 22  | 63  | 38,593,948     | 1668 | 4        | 0.004|
| 16    | Karnataka                   | 27.6| 53.8| 67,562,686     | 377  | 44       | 0.001|
| 17    | Kerala                      | 29.2| 75.2| 35,699,443     | 2182 | 5        | 0.006|
| 18    | Ladakh                      | 10  | 68.4| 289,023        | 896  | 0        | 0.310|
| 19    | Madhya Pradesh              | 24.8| 49.8| 85,358,965     | 52   | 300      | 0.006|
| 20    | Maharastra                  | 27.2| 76.8| 123,144,223    | 6859 | 1695     | 0.006|
| 21    | Manipur                     | 19.6| 73.8| 3,091,545      | 52,667| 0        | 1.70 |
| 22    | Meghalaya                   | 22.8| 72.4| 3,366,710      | 39   | 1        | 0.001|
| 23    | Mizoram                     | 19.6| 81   | 1,239,244      | 1438 | 7        | 0.003|
| 24    | Odisha                      | 26.8| 74.8| 46,356,334     | 473  | 0        | 0.002|
| 25    | Puducherry                  | 28.4| 76.4| 1,413,542      | 41   | 0        | 0.003|
| 26    | Punjab                      | 20.2| 72.4| 30,141,373     | 2060 | 40       | 0.007|
| 27    | Rajasthan                   | 24.4| 42   | 81,032,689     | 7300 | 167      | 0.009|
| 28    | Tamil Nadu                  | 29  | 71   | 77,841,267     | 17,082| 5882     | 0.022|
| 29    | Telengana                   | 30.6| 54.2| 39,362,732     | 1920 | 1015     | 0.005|
| 30    | Tripura                     | 24.2| 75.2| 4,158,794      | 194  | 133      | 0.005|
| 31    | Uttar Pradesh               | 19.2| 71.6| 11,250,858     | 349  | 53       | 0.003|
| 32    | Uttar Pradesh               | 22.4| 67.6| 237,882,725    | 6532 | 3066     | 0.003|
| 33    | West Bengal                 | 24.6| 58.96| 99,609,303    | 3816 | 1136     | 0.044|
| 34    | Lakshadweep                 | 30.2| 76.6| 73,183         | 0    | 0        | 0    |
| 35    | Sikkim                      | 21.8| 68   | 690,283        | 1    | 0        | 0.0001|
| 36    | Nagaland                    | 23  | 73   | 2,249,695      | 0    | 0        | 0    |
| 37    | Daman and Diu               | 27.6| 60.2| 265,000        | 0    | 0        | 0    |

| Cases being reassigned to states | 1403 |
| Total#                           | 145,380 |

Indicates that COVID-19 spread level in states and union territories with a temperature less than 27.8 °C is comparatively higher than other states and union territories. Additionally, the linear relationship with COVID-19 state-wise status in India (as on May 20, 2020; Ministry of Home Affairs, GoI). The 'area under curve' (AUC) value for the AT model is around 0.26, indicating an imperfect model. This indicates that ambient temperature has no influence on India's COVID-19 spreading, i.e., AT has no capability to distinguish the infected people and healthy people and has very low performance. Because the AUC value 0.5 indicates no discrimination. Additionally, the AT model is linear in nature. The cutoff or optimum point of AT model is P3 (0.333, 0.206) (Fig. 4). The cut-off point indicates that COVID-19 spread level in states and union territories with a temperature less than 27.8 °C is comparatively higher than other states and union territories. Additionally, the linear relationship with COVID-19 infected peoples depicted that COVID-19 transmission rate has very low sensibility against recorded ambient air temperature in different states and union territories of India. Similar findings have been reported in Iran by Jahangiri et al. [7]. Therefore, it can be concluded that COVID-19 infection in higher temperature climates is less than lower or moderate temperature conditions. Likely, the influence of climatic parameter namely ambient temperature in spreading of COVID-19 infection have been demonstrated in different countries by several authors [1,13,15,16].

Likely, the relative humidity (H) model has no influence on India's need for resources like food, shelter, etc. Moreover, overpopulation leads to unhygienic and dense living conditions, which helps to spread the disease very fast [9]. Likely, China’s Wuhan city is densely populated and many experts considered this for rapid spreading of COVID-19 virus like wildfire [9]. Furthermore, diverse climatic conditions of India aggravate the condition very badly.
COVID-19 spreading, i.e., H model has no capability to distinguish the infected and healthy people and the model has very low sensitivity, since it has AUC value 0.37 which is much lower than AUC 0.5. The model is similar to the linear AT model and resembles all features of AT model. However, the cutoff or optimum point of H model is P3 (0.333, 0.294) (Fig. 5), which indicates that COVID-19 spread level in states and union territories with a relative humidity less than 73.4% is comparatively higher than other states and union territories. Likely, the influence of relative humidity in spreading of COVID-19 infection have been demonstrated in different countries by several authors [1,11,15,16]. The expression of the PM model was totally different with regard to...
climatic variables (AT and H). Fig. 6 demonstrates the ROC curve of COVID-19 transmission rate based on PM variations in different states and union territories of India. The AUC value for the PM model is around 0.912, indicating a perfect model. This indicated that population mass has direct influence on India’s COVID-19 spreading, i.e., the PM model has very high performance (excellent) to distinguish infected and healthy people. Contrary to AT and H models, the PM model has nonlinear behavior with COVID-19 infected people in different states and union territories which indicates that it has higher sensitivity than AT and H models. Likely, Jahangiri et al. [7] recorded similar AUC value about 0.8 i.e., higher sensitivity of population size towards COVID-19 spreading in different provinces of Iran and have the capacity to distinguish between COVID-19 infected people and healthy people. Accordingly, the COVID-19 infection in India is now spreading very rapidly, since its first outbreak in Kerala on January 30, 2020. Fig. 7 demonstrates cumulative COVID-19 infection in India as well as different Indian states. Therefore, India could be the next COVID-19 pandemic epicenter in course of time. It is predicted that India may overtake China in next few years as per its population record [13,9]. Furthermore, the cutoff or optimum point of PM model is P3 (0.333, 0.735) (Fig. 6), which indicates that COVID-19 spread level in states and union territories with a population over 2.25 million is higher than other states and union territories. Similar to our findings Jahangiri et al. [7] recommended that provinces/cities with a population over 1.7 million should introduce stringent policy as management policy by government decision makers to curb the spreading of COVID-19 infection in Iran. Accordingly, the results of the present findings demonstrate that states and union territories with a population over 2.25 million must impose strict regulation and control measurement for strategic management through policy implementation to prevent the COVID spreading.

Conclusions

The following results demonstrate that climatic parameters (ambient air temperature and relative humidity) have a linear relationship with COVID-19 infected people in different states and union territories of India. The AUC value for the PM model is around 0.912, indicating a perfect model. This indicated that population mass has direct influence on India’s COVID-19 spreading, i.e., the PM model has very high performance (excellent) to distinguish infected and healthy people. Contrary to AT and H models, the PM model has nonlinear behavior with COVID-19 infected people in different states and union territories which indicates that it has higher sensitivity than AT and H models. Likely, Jahangiri et al. [7] recorded similar AUC value about 0.8 i.e., higher sensitivity of population size towards COVID-19 spreading in different provinces of Iran and have the capacity to distinguish between COVID-19 infected people and healthy people. Accordingly, the COVID-19 infection in India is now spreading very rapidly, since its first outbreak in Kerala on January 30, 2020. Fig. 7 demonstrates cumulative COVID-19 infection in India as well as different Indian states. Therefore, India could be the next COVID-19 pandemic epicenter in course of time. It is predicted that India may overtake China in next few years as per its population record [13,9]. Furthermore, the cutoff or optimum point of PM model is P3 (0.333, 0.735) (Fig. 6), which indicates that COVID-19 spread level in states and union territories with a population over 2.25 million is higher than other states and union territories. Similar to our findings Jahangiri et al. [7] recommended that provinces/cities with a population over 1.7 million should introduce stringent policy as management policy by government decision makers to curb the spreading of COVID-19 infection in Iran. Accordingly, the results of the present findings demonstrate that states and union territories with a population over 2.25 million must impose strict regulation and control measurement for strategic management through policy implementation to prevent the COVID spreading.
India. Climatic parameters (AT and H) have very low sensitivity towards COVID-19 discrimination (healthy vs infected) as it has comparatively lower AUC (0.26 and 0.37, respectively) than AUC value 0.5. The PM model has a nonlinear relationship and it has higher sensitivity towards COVID-19 transmission as well as discrimination (healthy vs infected) as PM model recorded AUC value around 0.912, which is much higher than AUC value 0.05. Additionally, the findings clearly demonstrate that states and union territories with a population over 2.25 million have to impose strict regulation and control measures as management strategy. Overall, the findings of the present study demonstrated that policy makers must bring stringent health care policies and implement preventive measures (social distancing, personal hygiene, etc.,) to reduce the COVID-19 transmission rate. Otherwise, it can be inferred that India could be the next epicenter of COVID-19 pandemic outbreak because of its overpopulation.

CRediT authorship contribution statement

Palas Samanta: Conceptualization, Software, Writing - original draft. Sukhendu Dey: Software, Formal analysis, Writing - original draft. Apurba Ratan Ghosh: Conceptualization, Software, Formal analysis, Writing - original draft.

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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