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Research paper

# Coronavirus COVID-19 outbreak and control: Effect of temperature, relative humidity, and lockdown implementation

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A B S T R A C T

Meteorological parameters are important factors that have an influence on infectious diseases. The present study aimed to explore the correlation between the spread of COVID-19, temperature, and relative humidity. The effect of human-imposed control parameters in the form of lockdown on the dissipation of COVID-19 was also analysed. Data were collected on the three study variables – temperature, relative humidity, and lockdown period – from nine of the most infected cities worldwide as well as information on changes in the number of COVID-19 patients from the beginning to a specific point in the lockdown period. A generalised regression model was applied to explore the effect of temperature and relative humidity on the change in daily new cases of COVID-19. The regression analysis did not find any significant correlation between temperature, humidity, and change in number of COVID-19 cases. Analysis of the cities with wide-ranging temperature variations showed a negative correlation of COVID-19 transmission ($P = 0.079$) with temperature, but a relatively non-significant correlation with relative humidity ($P = 0.198$). The number of total deaths was also higher in low-temperature countries compared with high-temperature countries. The specific growth rate in COVID-19 cases was decreased by more than 66% after implementation of a lockdown. This growth rate was exponentially decreased over time through the proper implementation of lockdown. Analysis of the real-case scenario and application of predictive models showed that for New York, Lombardy, and Madrid more than 120 days of strict lockdown was required for complete control of the transmission of COVID-19.



## 1. Introduction

The outbreak of coronavirus has led to a global health emergency. In late December 2019, a new type of coronavirus was discovered in Wuhan, China, later named "SARS-CoV-2" [1] and the infectious disease caused by this virus was termed "COVID-19" [2]. The virus is transmitted through human touch and/or respiratory droplets usually produced by coughing, sneezing, or talking [3]. As a result, the outbreak has spread from Wuhan, China to the rest of the world affecting almost 205 countries. To date, more than 64 million (64,194,674 on December 2, 2020) people have been infected by COVID-19, of whom nearly 1,486,829 have died and 44,441,249 have recovered [4]. These numbers have been increasing exponentially daily, with the worst scenario seen in the United States, Brazil, Italy, Spain, France, Germany, the United Kingdom, and Iran.

Researchers are trying to understand the metabolic behaviour of the novel coronavirus as well as the characteristics of transmission. People with severe COVID-19 illness are treated in specialised and intensive care units. Maintaining social distance, practicing basic hygiene habits, and wearing masks can be used as a protective measure [5]. Besides preventing the spread of coronavirus infection, it is necessary to predict the future behaviour of COVID-19 disease; for example, how it will spread, which regions would be most at risk, and how long it takes for complete recovery. It is very important to predict the transmission scenario of the COVID-19 epidemic based on experimental or field data. This will help policymakers take the necessary actions to reduce the severity of this epidemic.

A few COVID-19 epidemiological studies have been conducted based on relevant environmental parameters, such as temperature, pressure, and relative humidity [6,7]. Most of this work was

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focused on the city of Wuhan. To date, and to the best of our knowledge, there has been no scenario analysis of coronavirus infection to predict the recovery period through the application of lockdowns. This study draws a relationship of the percentage change (% change) in daily new COVID-19 cases as a function of temperature and relative humidity in different cities and countries (New York City, USA; Lombardy, Italy; Madrid, Spain; Wuhan, China; Victoria, Australia; Chile; Guayas, Ecuador; Bangladesh; Kuala Lumpur, Malaysia; UAE; Delhi, India; Sao Paulo, Brazil; Lagos, Nigeria; and Khartoum, Sudan). A number of cities with wide-ranging temperature variations were used to assess the effect of temperature on COVID-19 transmission and mortality. The effect of lockdown, restricting the movement of people from place to place to avoid contact, on the rate of transmission of COVID-19, was also examined. Based on the analysis of real-time data from New York City, Lombardy, and Madrid, a model was proposed to predict the complete recovery period possible with a strict maintenance of lockdown.

## 2. Materials and methods

### 2.1. Data collection

Data on temperature were collected from the Time and Date AS website [8] and data on humidity were from the AccuWeather website [9]. The source of the data on coronavirus-related cases for New York were from the Department of Health [10]. Other data were collected from Johns Hopkins coronavirus resource centre [11] and Wikipedia [12].

### 2.2. Specific growth rate

The specific growth rate of COVID-19 cases ($\mu$) refers to the steepness of the growth of COVID-19 cases. It was defined as the increase in number of COVID-19 cases per unit of total COVID-19 cases per unit time:

$$\mu = \frac{1}{N}\frac{dN}{dt} \tag{1}$$

$$1\text{n}N = 1\text{n}N_0 + \mu t \tag{2}$$

where $N$ is the number of COVID-19 cases, $N_0$ is the initial number of COVID-19 cases, and $t$ is time (days). $\mu$ (COVID-19 cases/COVID-19 cases/day; simple noted by 1/day) was calculated from the slope of ln $N$ vs. $t$ curve.

### 2.3. Other calculations

The % change in COVID-19 cases can be calculated according to Eq. (3):

$$\frac{(total\ COVID\text{-}19\ cases)_t - (total\ COVID\text{-}19\ cases)_{t-1}}{(total\ COVID\text{-}19\ cases)_{t-1}} \times 100 \tag{3}$$

### 2.4. Predictive model

Most of the biological system follows an exponential relationship, either in terms of the COVID-19 transmission rate [6], or in the reduction of the rate. Implementation of lockdown decreased the value of $\mu$ exponentially. The decrease in $\mu$ over time can be

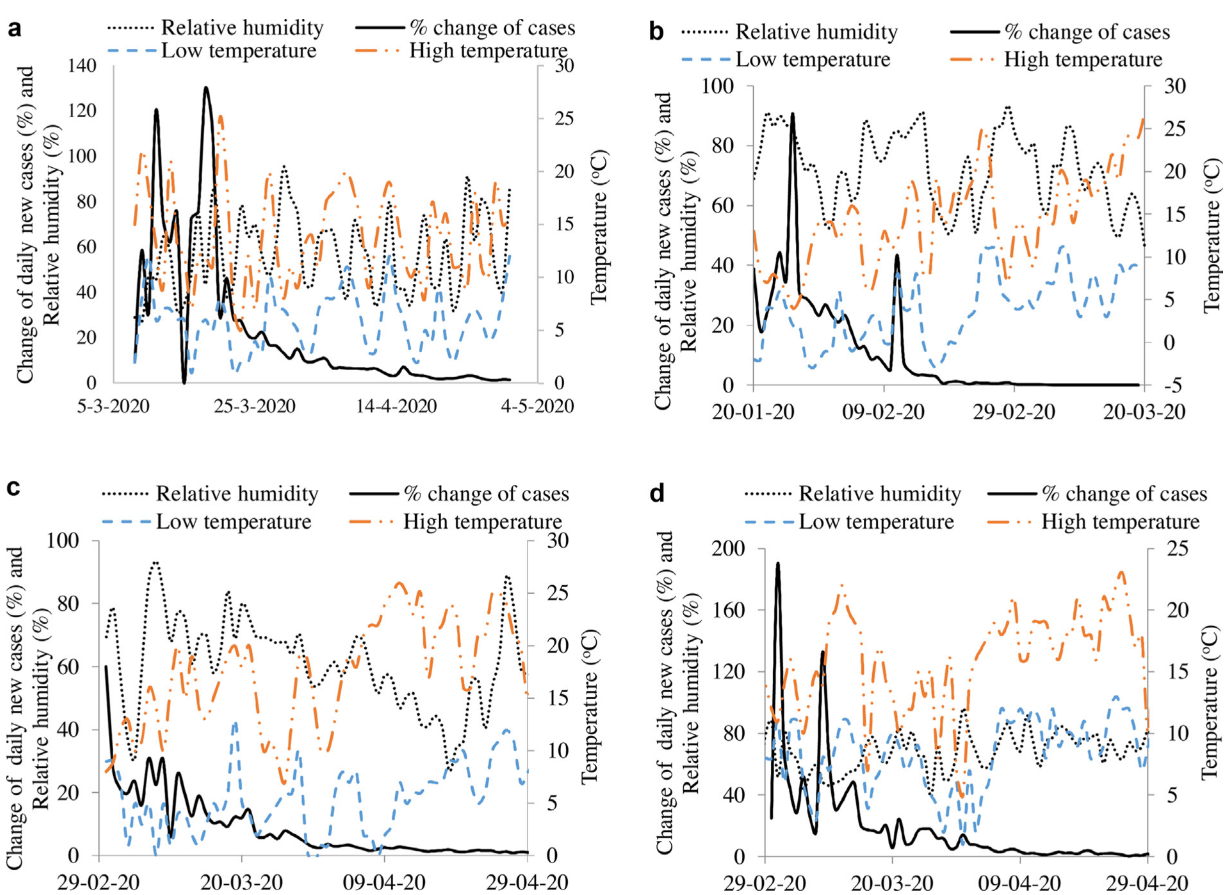


**Fig. 1.** COVID-19 outbreaks expressed as percentage change in daily COVID-19 cases and the relationship with temperature and relative humidity: (a) New York, USA, (b) Wuhan, China, (c) Lombardy, Italy, and (d) Madrid, Spain.

expressed as Eq. (4), which was also used as a predictive model to calculate the time needed for complete control of COVID-19 transmission.

$$\mu = \mu_0 \exp(-\eta t) \quad (4)$$

Here, $\eta$ (1/days) is the specific decreasing rate of $\mu$ and $\mu_0$ is $\mu$ at the beginning of lockdown. $\eta$ (1/days) was estimated from the slope of ln ($\mu$) vs. $t$ (days) curve and $\mu_0$ from the intercept.

The regression coefficient ($R^2$) was used to evaluate the fitting ability of the predictive model. The closer the fitting coefficient is to 1, the more accurate the prediction.

### 2.5. Statistical analysis

Temperature and relative humidity were selected as independent variables for the daily new cases of COVID-19. Each dataset was divided based on the different cities, such as New York, Lombardy, Madrid, and Wuhan, to eliminate the chance of any error. The following polynomial equation Eq. (5) was employed to examine the data:

$$X = A_0 + A_1 T + A_2 H + A_3 TH \quad (5)$$

where $X$ is the % change in daily new cases, $A_0$ is the constant coefficient, $A_1$, $A_2$, and $A_3$ are regression coefficients, and $T$ and $H$ are independent variables for temperature and humidity, respectively. Regression analysis with ANOVA was conducted to evaluate the significance of the independent variables temperature and relative humidity on the % change in daily new cases of COVID-19.

Moreover, the significance of the effect of temperature, considering the average temperature of April 2020, on the total number of COVID-19 cases in different cities and countries was also evaluated using Eq. (5). The cities and countries used in this study were: New York, USA; Lombardy, Italy; Madrid, Spain; Wuhan, China; Victoria, Australia; Chile; Guayas, Ecuador; Bangladesh; Kuala Lumpur, Malaysia; UAE; Delhi, India; Sao Paulo, Brazil; Lagos, Nigeria; and Khartoum, Sudan.

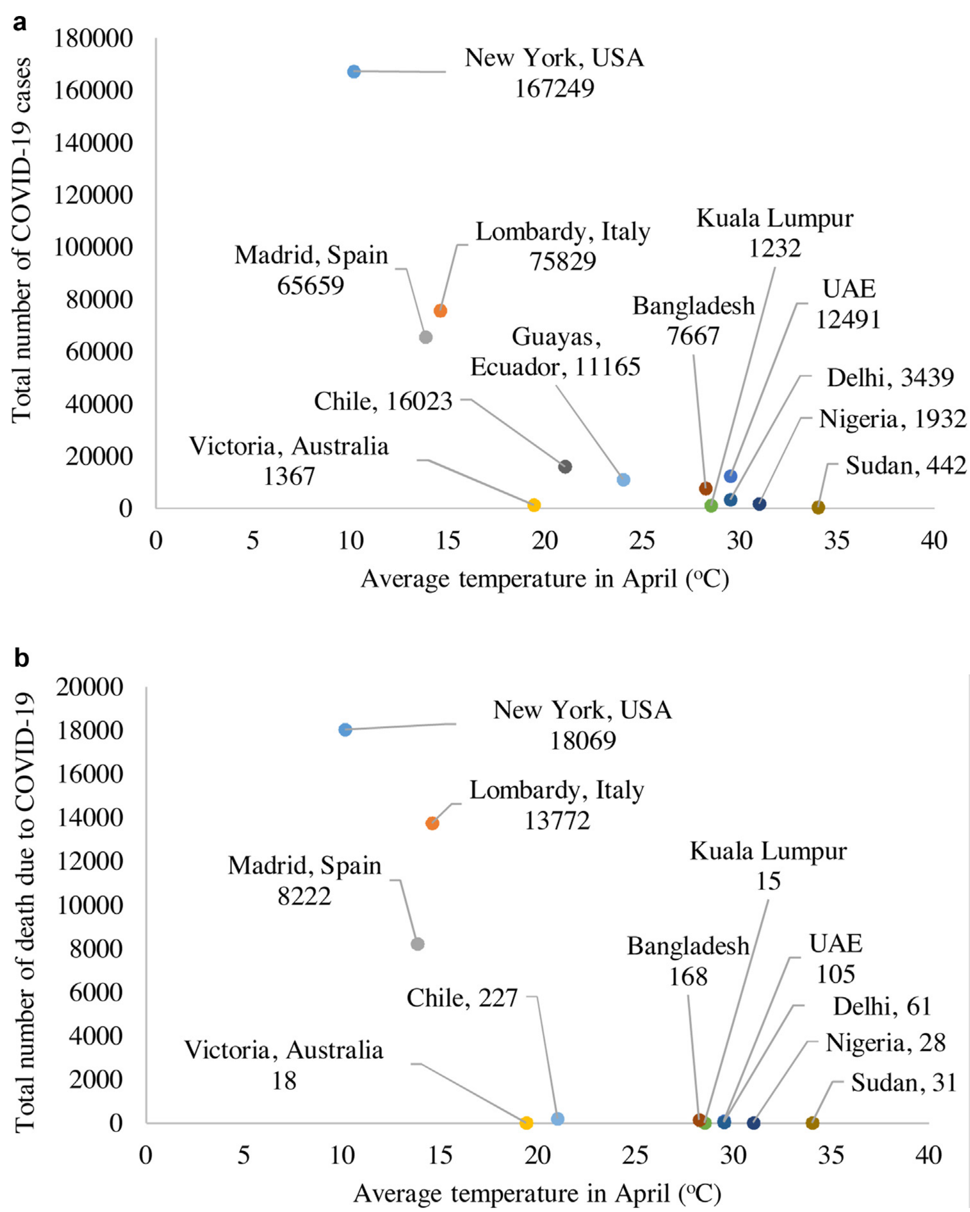


**Fig. 2.** COVID-19 outbreaks in different cities and countries expressed as (a) total number of cases and (b) total number of death and the relationship with temperature.

## 3. Results and discussion

### 3.1. COVID-19 cases as a function of temperature and relative humidity

In New York City, the outbreak of COVID-19 started in the first week of March 2020. The number of coronavirus cases was only 11 on March 7 but increased to 43,139 on March 31, and was 167,249 on April 30, 2020. The % change in daily new number of COVID-19 cases with temperature and relative humidity throughout March 8 to April 30, 2020 is shown in Fig. 1a. The figure shows that there was some relationship between the % change in daily new cases with temperature and relative humidity. The % change in daily new cases increased with increasing temperature and relative humidity. The days with increased temperature and relative humidity led an increase in the % change in cases within the next 2–3 days. This happened while the highest temperature was below 25 °C; it is not clear what the behaviour of COVID-19 is above this temperature. However, the change in daily new cases was reduced after March 20 due to the implementation of a statewide "stay at home" order and a warning to New York State's 19 million residents that those who defied this edict could face civil fines, implemented from March 22. The implementation of the "stay at home" order led to a dramatic decrease in the % change in daily new cases. This indicates the effectiveness of this law in controlling the transmission of COVID-19, since the major transmission route is human-to-human transmission [3]. However, since the % change in daily new cases was still positive it indicated that the scenario was still getting worse. From the experience in Wuhan, China, it was observed that it took approximately 40 days to control the overall situation after implementation of a citywide shutdown (Fig. 1b). Therefore, we could assume that the COVID-19 situation would be under control in New York City after April 20, 2020, which in reality was not true.

A very similar type of response in the relationship between % change in COVID-19 cases, temperature, and relative humidity was observed for the cities of Lombardy, Italy (Fig. 1c) and Madrid, Spain (Fig. 1d). The % change in COVID-19 cases dramatically decreased after implementation of lockdown. A similar behaviour was observed in Victoria, Australia (Fig. A1a in supplementary material) were lockdown was properly implemented. However, in the cities/countries of, e.g., Delhi, Sao Paulo, Lagos, and Sudan where the implementation of lockdown was less respected there was no significant reduction in % change in COVID-19 cases (Figure A1(b–e) in supplementary material). Regression analysis and ANOVA of the polynomial equation Eq. (6) were conducted to evaluate the significance of the effect of temperature and relative humidity on the daily new cases of COVID-19. The results of these analyses are presented in the supplementary material S1 (A1–A9), and revealed that temperature ($0.007 < P > 0.92$) and humidity ($0.003 < P > 0.87$) do not have a significant effect on the transmission of COVID-19, independent of strict lockdown implementation. Ma et al. (2020) found a positive impact of temperature and humidity on COVID-19-related mortality. The average temperature of the four cities considered in this study were around 10 °C, with an average high and low temperature

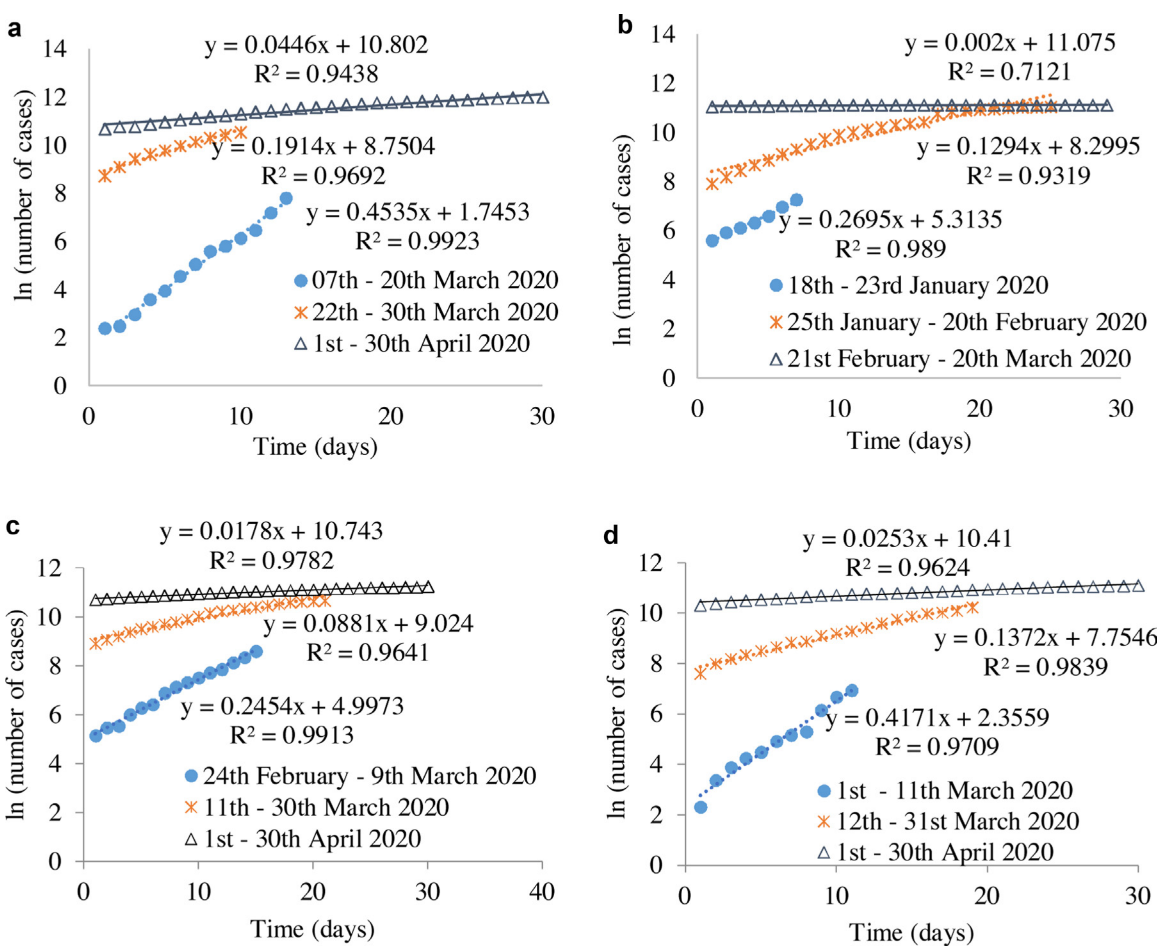


**Fig. 3.** Effect of "stay at home" or lockdown on the specific growth rate of COVID-19 cases in (a) New York, USA, (b) Wuhan, China, (c) Lombardy, Italy, and (d) Madrid, Spain.

**Table 1**
Estimated $\mu_0$ and $\eta$ values for different cities.

| City | $\mu_0$ (1/day) | η (1/day) |
|---|---|---|
| New York, USA | 0.341 | 0.0696 |
| Lombardy, Italy | 0.1496 | 0.0592 |
| Madrid, Spain | 0.2886 | 0.0662 |

range of 4.5–14.1 °C in March and 6.1–18.1 °C in April. However, this narrow temperature range may not be sufficient to prove the effect of temperature on COVID-19 transmission.

Including areas with wide-ranging temperature variations may be more suitable in evaluating the effect of temperature on COVID-19. In April the average temperatures of Victoria (Australia), Chile, Guayas (Ecuador), Bangladesh, Kuala Lumpur (Malaysia), UAE, Delhi (India), Nigeria, and Sudan were 19.4, 21, 24, 28.25, 28.5, 29.5, 29.5, 31, and 34 °C, respectively. The number of COVID-19 cases in these cities decreased significantly with increasing temperature (Fig. 2a). This clearly indicated that the areas with an average temperature over 25 °C had significantly reduced transmission rates of COVID-19. The results of regression analysis and ANOVA (supplementary material S1; A5) showed a negative correlation of temperature with COVID-19 transmission ($P = 0.079$) but there was relatively insignificant correlation of relative humidity with COVID-19 transmission ($P = 0.198$). It can be concluded that high temperatures reduced the rate of COVID-19 transmission. A number of studies also support the finding of reduced COVID-19 transmission with temperature [13,14]. Fig. 2b shows the number of deaths due to COVID-19 in the aforementioned cities and countries with their temperatures. The number of deaths due to COVID-19 was significantly low while the average temperature was higher than 25 °C; the number of deaths was low in cities and countries at high temperatures.

However, the transmission of COVID-19 significantly increased in a number of countries with relatively high average temperatures (21–29 °C) like Brazil, Mexico, India, and Bangladesh. This was mainly due to the improper implementation of lockdown. The social and economic situation of low-income population groups in these countries was the main barrier to proper implementation of lockdown and one of the main causes of the relatively high COVID-19 transmission rate.

The average temperature during winter (November, December, and January) in most of the south and west areas of Asia such as India and Bangladesh is around 10 °C. These countries are at a high risk of COVID-19 outbreaks next winter if they do not take the necessary protective measures. Wang et al. [3] found that, to a certain extent, temperature could significantly change the transmission of COVID-19. They found the average temperature of Wuhan (around 2.4–12.5 °C) to be the optimal temperature for viral transmission, and suggested adopting the strictest control measures to prevent future outbreaks in countries and regions with a lower temperature. Sajadi et al. (2020) [15] also reported that average temperatures of 5–11 °C with low specific humidity were favourable for COVID-19 transmission.

### *3.2. Effect of lockdown or stay-at-home on specific COVID-19 cases*

As preventive measures for the control of COVID-19 transmission, almost all affected countries have implemented lockdown of the entire country or of cities. This practice has significantly reduced the transmission of COVID-19 expressed here as the specific growth rate of COVID-19 cases. In this study we also examined the decreasing pattern of the specific growth rate of COVID-19 cases, comparing it before and after the implementation of lockdown (Fig. 3). For example, implementation of the "stay at home" order on March 22, 2020 in New York City led to a reduction in the specific growth rate from 0.4535 (1/day) to 0.1914 (1/day) in March, and in April it decreased to 0.0446 (per day) (Fig. 3a).

The central government of China imposed a lockdown in Wuhan on January 23, 2020, and the specific growth rate of COVID-19 cases decreased from 0.2695 to 0.1294 (1/day). After 1 month of lockdown, it decreased to 0.002 (1/day) (Fig. 3b). A similar response was found for Lombardy, Italy, and Madrid, Spain: The specific growth rate of COVID-19 cases decreased from 0.2454 to 0.0881 (1/day) in March and to 0.0178 (1/day) in April (Fig. 3c) and from 0.4171 to 0.1372 (1/day) in March and to 0.0253 (1/day) in April (Fig. 3d), respectively. As a result of lockdown, the specific growth rate of COVID-19 cases was significantly reduced.

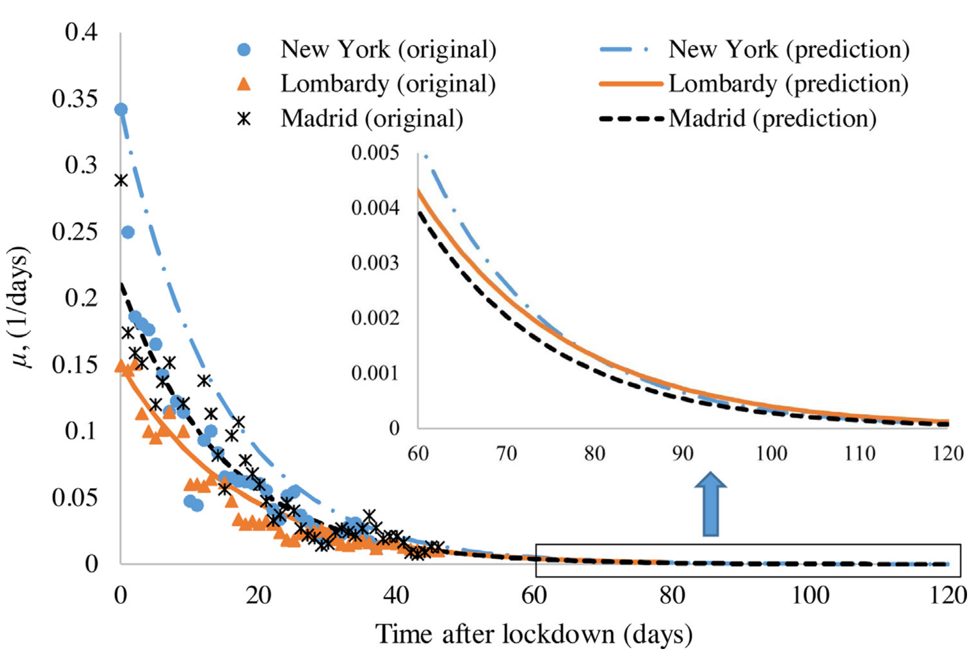


**Fig. 4.** Scenario analysis and prediction for complete recovery through the proper implementation of lockdown using predictive model.

### 3.3. Real-time data analysis to calculate the time required for complete control of COVID-19 transmission using predictive model

The predictive model used in this study is described in Eq. (4). The model parameters–initial specific growth rate of COVID-19 cases ($\mu_0$) and specific decreasing rate of $\mu$ ($\eta$)–were estimated from the data available after lockdown and are listed in Table 1. At the beginning of the lockdown, the number of COVID cases was higher in New York City (12,305; March 23, 2020) compared with Lombardy (7,280; March 11, 2020) and Madrid (1,990; March 11, 2020). At that time the transmission of COVID-19 rate was very high ($\mu_0$ = 0.341/day) in New York City compared with the other cities. The specific growth rate of COVID-19 cases ($\mu$) decreased exponentially through the implementation of lockdown. Thanks to the proper implementation of lockdown and the extended testing ability, a significantly decreased ($\eta$ = 0.0696/day) growth rate was observed for New York City compared with Lombardy ($\eta$ = 0.0552/day) and Madrid ($\eta$ = 0.0662/day) (Table 1). Using these initial data listed in Table 1 and the proposed predictive model (Eq. (4)), it was possible to estimate the time required for recovery (Fig. 4) of cities or countries. The model validation was confirmed by the regression coefficient ($R^2$), which was 0.8915 for New York City 0.9389 for Lombardy, and 0.8896 was for Madrid, and also by a visual comparison of the data in Fig. 4.

The validated model was applied for the scenario analysis; i.e., to predict the time require to achieve almost complete recovery after applying the lockdown. If the lockdown procedure continues in the same way, together with other supporting measure, as in the beginning of the lockdown period, a period of more than 120 days is required for New York City, Lombardy, and Madrid, to establish almost complete control of COVID-19 transmission (Fig. 4). Although Lombardy had the lowest specific growth rate at the beginning of lockdown, it took almost the same time as New York and Madrid to establish control due to the lowest decreasing rate of specific growth rate ($\eta$) for Lombardy. The predictive model developed here can also be applied in scenario analysis for other cities where lockdown was potentially applied.

## 4. Conclusion

The cities and countries with an average temperature higher than 25 °C had a significantly reduced rate of COVID-19 transmission and number of deaths due to COVID-19. Countries like India, Bangladesh, and others where the average daily temperature in winter is around 10 °C are at a high risk of severe effects of COVID-19 during the winter season (November, December, and January). Proper implementation of lockdown led to a two- to threefold reduction in the specific growth rate of COVID-19 cases. The specific growth rate of COVID-19 cases decreased exponentially after applying lockdown. A predictive model was proposed to predict the time for recovery through the proper implementation of lockdown. According to this model, New York city, USA, Lombardy, Italy, and Madrid, Spain need more than 120 days for complete control of COVID-19 transmission after applying potential lockdown.

**Disclosure of interest**

The authors declare that they have no competing interest.

## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.arcped.2020.12.006.

## References

[1] Gorbalenya AE, Baker SC, Baric RS, et al. The species severe acute respiratory syndrome-related coronavirus: classifying 2019-nCoV and naming it SARS-CoV-2. Nat Microbiol 2020;5:536–44.
[2] WHO.. Naming the coronavirus disease (COVID-19) and the virus that causes it. Geneva: WHO; 2020.
[3] Wang M, Jiang A, Gong L, et al. Temperature significant change COVID-19 transmission in 429 cities. medRxiv 2020. http://dx.doi.org/10.1101/2020.02.22.20025791 [2020.02.22.20025791].
[4] Worldometer. COVID-19 coronavirus pandemic; 2020 [https://www.worldometers.info/coronavirus/#countries].
[5] WHO. Coronavirus disease (COVID-19) advice for the public. Geneva: WHO; 2020.
[6] Oliveiros B, Caramelo L, Ferreira NC, et al. Role of temperature and humidity in the modulation of the doubling time of COVID-19 cases. medRxiv 2020. http://dx.doi.org/10.1101/2020.03.05.20031872 [2020.03.05.20031872].
[7] Ma Y, Zhao Y, Liu J, et al. Effects of temperature variation and humidity on the mortality of COVID-19 in Wuhan. medRxiv 2020. http://dx.doi.org/10.1101/2020.03.15.20036426 [2020.03.15.20036426].
[8] AS TaD.. World temperatures – weather around the world; 2020 [https://www.timeanddate.com/weather].
[9] AccuWeather. Local, national & global daily weather forecast; 2020 [https://www.accuweather.com].
[10] Health Do.. Information on Novel Coronavirus; 2020 [https://www.health.ny.gov/diseases/communicable/coronavirus/].
[11] University JH. Johns Hopkins Coronavirus Resource Centre; 2020 [https://coronavirus.jhu.edu/].
[12] Wikipedia. 2019–2020 coronavirus pandemic; 2020 [https://en.wikipedia.org/wiki/2019%E2%80%9320_coronavirus_pandemic].
[13] Wang J, Tang K, Feng K, et al. High temperature and high humidity reduce the transmission of COVID-19. medRxiv 2020. http://dx.doi.org/10.1101/2020.03.05.20031872.
[14] Chan KH, Peiris JSM, Lam SY, et al. The effects of temperature and relative humidity on the viability of the SARS coronavirus. Adv Virol 2011;2011: 734690–700.
[15] Sajadi MM, Habibzadeh P, Vintzileos A, et al. Temperature, humidity and latitude analysis to predict potential spread and seasonality for COVID-19 2020. JAMA Netw Open 2020;3:e2011834. http://dx.doi.org/10.1001/jamanetworkopen.2020.11834.