World Journal of Advanced Research and Reviews, 2020, 06(03), 245–256

World Journal of Advanced Research and Reviews

e-ISSN: 2581-9615, Cross Ref DOI: 10.30574/wjarr

Journal homepage: https://www.wjarr.com

(RESEARCH ARTICLE)

An algebraic interpretation of the spread of COVID-19 in India and an assessment of the impact of social distancing

Roy Sudipto*

Department of Physics, St. Xavier's College, Kolkata, 30 Mother Teresa Sarani, Pin Code – 700016, West Bengal, India.

Publication history: Received on 15 June 2020; revised on 23 June 2020; accepted on 25 June 2020

Article DOI: https://doi.org/10.30574/wjarr.2020.6.3.0215

Abstract

An enormously infectious disease, called COVID-19, has been ravaging the world since January 2020. It has been declared a pandemic by the World Health Organization (WHO) in March 2020. The number of COVID-19 infections began to rise in India very rapidly since March 2020. A countrywide lockdown was in effect from 25 March 2020 to 31 May 2020. The objective of the present study is to provide a simple algebraic analysis of the trend that is evident in the spread of the disease in India. The standard mathematical models, regarding the spread of epidemics, are never easy for the policymakers to understand. Our algebraic approach is aimed at simplifying the calculation sufficiently to make it comprehensible to those involved in the prevention and control of the pandemic. The predictions, derived from this algebraic model, are found to be in reasonable agreement with the actual data of COVID-19 cases. The number of asymptomatic carriers, who are known to play a significant role in spreading the disease, has been determined in the present study. The effect of social distancing in slowing down the rate of transmission of the disease has been analyzed. Predictions have been made regarding the spread of the pandemic following the withdrawal of lockdown. All our calculations are based on extremely simple mathematical expressions, which can be easily understood and employed by those who have a rudimentary knowledge of algebra. This model can be used for making predictions regarding the spread of COVID-19 in any part of the world by a suitable tuning of the associated parameters.

Keywords: COVID-19; SARS-CoV-2; Pandemic; Social Distancing; Epidemiology; Mathematical Model

1. Introduction

In December 2019, a cluster of cases of pneumonia had been reported in Wuhan in Hubei province of China. It was later declared by the health administration of China that this disease was connected to a newly discovered coronavirus (SARS-CoV-2) and the highly infectious pneumonia caused by it was named coronavirus disease 2019 (COVID-19) by the World Health Organization (WHO) [1, 2]. This outbreak of novel coronavirus pneumonia was declared "a public health emergency of international concern" and later characterized as a pandemic by WHO [3]. As of 11 June 2020, there were 7,273,958 confirmed cases of COVID-19, including 413,372 deaths, in 216 countries, as reported to WHO globally [3]. According to WHO, no medicine has yet been found to have the ability to cure COVID-19. Some recent studies have manifested that chloroquine, an immune-modulant drug, which has generally been used for the treatment of malaria, is effective, to a certain extent, in reducing viral replication in infectious diseases like SARS (severe acute respiratory syndrome) and MARS (Middle East respiratory syndrome) [4, 5]. It has been revealed by the current studies that respiratory symptoms of COVID-19 such as fever, dry cough and dyspnea are the most common manifestations, quite similar to SARS in 2003 and MERS in 2012, indicating firmly the droplet transmission and contact transmission of the virus. In addition to the most common respiratory disorders, there are symptoms like diarrhea, nausea, vomiting, and abdominal discomfort which have widely been found in different degrees among different groups of people studied so far [6]. It has been revealed by recent evidences that the transmission of COVID-19 virus takes place through respiratory droplets and contact routes [7-11]. Transmission through droplets takes place when a person is within a distance of one metre from someone who has developed respiratory symptoms (coughing or sneezing) due to COVID-19 infection, and

* Corresponding author: Roy Sudipto; Email: roy.sudipto@sxccal.edu

is thereby running the risk of exposing his or her mucosae (mouth and nose) or conjunctiva (eyes) to immensely infective respiratory droplets which are usually found to be greater than 5-10 μm in diameter. Droplet transmission can also occur through fomites in the immediate vicinity around the infected person [12]. Thus, the transmission of the virus that causes COVID-19 can occur by direct contact with an infected person and indirect contact with surfaces in his or her immediate environment or with the objects that have been used on a patient, for example, a stethoscope or thermometer. The mode of airborne transmission is not the same as droplet transmission of the virus. It is caused by the microbes within droplet nuclei, which are generally like particles less than 5μm in diameter and released by the evaporation of larger droplets or exist within dust particles. These particles may remain in the air for long periods of time and they can be transmitted to persons over distances greater than one metre [13].

COVID-19 infection was first detected in India on 30 January 2020. As of 11 June 2020, a total of 286,579 cumulative cases of infection including 137,448 active cases, 141,028 recoveries and 8,102 deaths in the country were confirmed by the Ministry of Health and Family Welfare [14]. So far, the government has issued necessary guidelines and taken several measures to spread awareness regarding COVID-19 and to enforce social distancing of its citizens to break the chain of transmission of the disease. A nationwide lockdown was in effect from 25 March 2020 to 31 May 2020. A phase, called Unlock-1, which may be regarded as a partial lockdown, began on 01 June 2020.

In the present context, let us mention some recent studies concerning COVID-19 infections in India. Chatterjee *et al*. have conducted an extensive research to gather evidence that can direct the research activities towards the prevention and control of such a pandemic spreading so alarmingly in India [15]. A detailed study, carried out by Agarwal *et al*, has clearly manifested the need for a proper medical infrastructure to be set up in the country to tackle the huge flow of patients and to ensure the safety of the persons involved in healthcare services [16]. An elaborate mathematical study, conducted by Mandal *et al*, has emphasized on the policies to be undertaken to prevent the spread of COVID-19 by community transmission [17]. Some other mathematical models, based on standard conventional theories, have been constructed to predict the number of infections of COVID-19 in India with sufficient accuracy [18-25]. These models are expected to serve as efficient tools which would certainly help the policymakers of the country, at different levels, to make proper plans to prevent the spread of this disease.

Through a mathematical model, which we published previously, the effect of imposition of lockdown, in reducing the rate of transmission, was clearly demonstrated [26]. It was based on a differential equation which had to be solved to find the time evolution of the number of asymptomatic cases, from which, the number of symptomatic cases was estimated. In the present study, we have constructed the entire mathematical structure upon a simple algebraic equation. The purpose of choosing this method is to make the article comprehensible to the policymakers of the country who come from various educational backgrounds. The models, which are based on calculus, lead to very accurate results or predictions but they are generally very difficult to understand for those who are not sufficiently trained in mathematics. In most of the cases, the conventional models do not lead to mathematical expressions which can be readily used to make predictions. One needs to do numerical calculations (rather than analytical) to arrive at a prediction. In view of the severity and urgency of the crisis caused by COVID-19 outbreak, mathematical models should be constructed in a simple way so that one can easily understand, change (whenever necessary) and employ them widely for the purpose of decision making about infrastructural arrangements and the enforcement of rules to ensure social distancing. The calculations involved in the present study are extremely simple in comparison to the old methods where one needs to solve a set of coupled differential equations, keeping under consideration various factors connected to the society and the constraints of the actual situations caused by the pandemic and the measures to control it.

In the present article, we have discussed the step by step construction of an algebraic structure that allows one to derive an expression representing the time evolution of the number of asymptomatic patients in the country. Like our previously published article (Ref. No. 26), which was based on calculus, this model has an underlying assumption that, due to the lack of tests in sufficient numbers, the statistics regarding the number of patients infected (as declared by the government) are actually the statistics of the symptomatic patients [27, 28]. After detection, most of them are put into isolation, making them incapable of spreading the disease. Therefore, the asymptomatic carriers can be regarded as the main agents of transmission of the virus in the society. The values of parameters, associated with this model, have been obtained by fitting it to the actual data of COVID-19 cases in India. For this purpose we have used the statistics of the cumulative number of infected persons in India, during the period from 01 March 2020 to 10 June 2020, obtained from the government sources [14]. Using this model, we have determined the time evolution of the number of asymptomatic patients over this period. We have graphically shown the positive impact of the imposition of lockdown throughout the country. Predictions have been made regarding the number of infected cases beyond 31 May 2020, the day up to which the lockdown phase continued. This model shows very clearly that a high degree of social distancing has to be maintained to slow down or prevent the transmission of the disease in the country.

2. Mathematical method

Like many other diseases, a patient remains asymptomatic (i.e., showing no symptoms of the disease) for a few days, after being infected with COVID-19 [9, 15, 17]. These patients are capable of spreading the disease through contacts with others.

For the present study, let y_n and y_{n-1} be the numbers of asymptomatic patients on the n^{th} day and the $(n\text{-}1)^{th}$ day respectively, during the span of time under consideration. For the present model, we propose to express y_n in terms of y_{n-1}, by the following equation.

$$y_n = y_{n-1} + \alpha_{n-1} y_{n-1} - \beta_{n-1} y_{n-1} \quad (1)$$

In equation (1), α_{n-1} is the average number of persons who have been infected with COVID-19, on the $(n\text{-}1)^{th}$ day, after coming in close contact with each of these y_{n-1} carriers of the disease. Here β_{n-1} denotes the fraction of y_{n-1} who have undergone a transformation from asymptomatic to symptomatic type on the $(n\text{-}1)^{th}$ day.

It is assumed in the present model that, a patient, after being identified as symptomatic, is put into absolute isolation from the society. It prevents the patient completely from playing any role in the transmission of the disease. It is also assumed that no new asymptomatic or symptomatic carrier has entered the geographical region (during the entire span of time) under consideration.

According to equation (1), α_n is a parameter that decreases as social distancing increases. Its subscript *n* denotes time in days. Therefore, when a lockdown is imposed, α_n is supposed to decrease. Let *a* and *b* be the two values of α_n, during the phases of *no-lockdown* and *lockdown* respectively, with $b < a$. The phase, called Unlock-1 (effective in India since 01 June 2020), is equivalent to a partial lockdown for which the value of α_n has been assumed to be equal to a constant *c* in the present study, with $b < c < a$.

Let us consider a combination of three consecutive periods, of d_1, d_2 & d_3 days, during which we have *no-lockdown*, *lockdown* and *unlock* (partial lockdown) phases respectively in a country. The time dependence of α_n (i.e., its dependence upon *n*), under such situations, can be expressed as,

$$\alpha_n = f_1(n)\, a + f_2(n)\, b + f_3(n)\, c \quad (2)$$

In equation (2), the value of the function $f_m(n)$ is 1 (one) during the period of d_m days, and zero otherwise, where $m = 1, 2, 3$. Thus, the values of α_n are the constants a, b and c respectively, during these three periods of d_1, d_2 & d_3 days respectively.

It means, $\alpha_n = a$ for $1 \le n \le d_1$, $\alpha_n = b$ for $d_1 < n \le d_2$ and $\alpha_n = c$ for $d_2 < n \le d_3$.

Here *a*, *b* and *c* are regarded, respectively, as the indicators of social distancing during *no-lockdown*, *lockdown* and *unlock* phases. Smaller values of these constants (a, b and c) represent greater degrees of social distancing during these three phases respectively.

To ensure mathematically this behaviour of α_n, as a function of *n*, we have used the following expressions for $f_1(n)$, $f_2(n)$ and $f_3(n)$ respectively.

$$f_1(n) = \frac{(1+\mathrm{Tanh}\,\rho n)[1+\mathrm{Tanh}\,\rho(d_1-n)]}{4} \quad (3)$$

$$f_2(n) = \frac{\{1+\mathrm{Tanh}\,\rho(n-d_1)\}\,[1+\mathrm{Tanh}\,\rho(d_1+d_2-n)]}{4} \quad (4)$$

$$f_3(n) = \frac{\{1+\mathrm{Tanh}\,\rho(n-d_1-d_2)\}\,[1+\mathrm{Tanh}\,\rho(d_1+d_2+d_3-n)]}{4} \quad (5)$$

According to the definitions of $f_1(n)$, $f_2(n)$ and $f_3(n)$, they must ideally behave like rectangular pulses of unit heights. To get such patterns, as accurately as possible, one must choose the value of the constant ρ to be sufficiently large in comparison to the widths of these pulses (i.e., d_1, d_2 and d_3 respectively).

The time dependence of the parameter β_n (i.e., its dependence on n) is due to an assumption that the number of asymptomatic patients may increase at such a rate that the fraction of them, turning into symptomatic ones on a certain day, cannot have a constant value.

Putting $n = n - 1$ in equation (1), one gets,

$$y_{n-1} = (1 + \alpha_{n-2} - \beta_{n-2})y_{n-2} \quad (6)$$

Substituting for y_{n-1} in equation (1) from equation (6), one obtains,

$$y_n = (1 + \alpha_{n-1} - \beta_{n-1})(1 + \alpha_{n-2} - \beta_{n-2})y_{n-2} \quad (7)$$

One can now calculate y_{n-2} from equation (1) (by putting $n = n - 2$) and substitute it into equation (7). Continuing in this fashion, equation (1) takes the following form.

$$y_n = y_1 \prod_{j=1}^{n-1}(1 + \alpha_j - \beta_j) \quad (8)$$

The number of cases (x_k) that become symptomatic from the asymptomatic type, on the k^{th} day, is then given by,

$$x_k = \beta_k y_k = \beta_k\, y_1 \prod_{j=1}^{k-1}(1 + \alpha_j - \beta_j) \quad (9)$$

Therefore, the total number of symptomatic cases recorded till the n^{th} day is given by,

$$z_n = \sum_{k=1}^{n} x_k = y_1 \sum_{k=1}^{n} \beta_k \prod_{j=1}^{k-1}(1 + \alpha_j - \beta_j) \quad (10)$$

In equations (8), (9) and (10), $\alpha_j = f_1(j)a + f_2(j)b + f_3(j)c$, according to equation (2), with $b < c < a$. If the third phase represents a *no-lockdown* state (same as the 1st phase), we have $\alpha_j = f_1(j)a + f_2(j)b + f_3(j)a$. Equation (10) gives us an estimate that needs to be compared with the number of confirmed COVID-19 cases registered in the country up to the n^{th} day. It is the cumulative count of cases (mainly of symptomatic type) of that day.

If no lockdown is imposed, during the entire period under study, we must have $a = b = c$ and therefore, $\alpha_n = [f_1(n) + f_2(n) + f_3(n)]a = a$, according to equation (2). Equation (10) will then have the following form.

$$z_n = \sum_{k=1}^{n} x_k = y_1 \sum_{k=1}^{n} \beta_k \prod_{j=1}^{k-1}(1 + a - \beta_j) \quad (11)$$

Proportions of the symptomatic and asymptomatic patients (with respect to the total number of patients), denoted here by $P(z_n)$ and $P(y_n)$ respectively, are expressed by the following two equations, using equations (8) and (10).

$$P(z_n) = \frac{z_n}{y_n + z_n} = \frac{\sum_{k=1}^{n} \beta_k \prod_{j=1}^{k-1}(1+\alpha_j-\beta_j)}{\prod_{j=1}^{n-1}(1+\alpha_j-\beta_j) + \sum_{k=1}^{n} \beta_k \prod_{j=1}^{k-1}(1+\alpha_j-\beta_j)} \quad (12)$$

$$P(y_n) = \frac{y_n}{y_n + z_n} = \frac{\prod_{j=1}^{n-1}(1+\alpha_j-\beta_j)}{\prod_{j=1}^{n-1}(1+\alpha_j-\beta_j) + \sum_{k=1}^{n} \beta_k \prod_{j=1}^{k-1}(1+\alpha_j-\beta_j)} \quad (13)$$

$P(z_n)$ and $P(y_n)$ can be expressed in percentages by multiplying their expressions with 100.

As an average estimate one can say that, for each symptomatic case there are y_n/z_n or $P(y_n)/P(z_n)$ number of asymptomatic cases, which remain mostly undetected in India due to extremely insufficient number of tests conducted in the country [27, 28].

Combining the cumulative numbers of symptomatic and asymptomatic cases, one gets the total cumulative count of infections in the country on a certain day. Dividing this value by the present population of India (N), one can get the fraction of the population infected with COVID-19. This fraction, denoted by F_n here, is given by,

$$F_n = \frac{y_n + z_n}{N} = \frac{y_1\left[\prod_{j=1}^{n-1}(1+\alpha_j-\beta_j) + \sum_{k=1}^{n} \beta_k \prod_{j=1}^{k-1}(1+\alpha_j-\beta_j)\right]}{N} \quad (14)$$

F_n can be expressed in percentage by multiplying its expressions with 100. $N = 1.36 \times 10^9$.

For the present article, we have used the following functional form of β_j.

$$\beta_j = A\, j^{\lambda} + (\beta_1 - A) j^{\mu} \quad (15)$$

This form of β_j has been empirically chosen to have a linear combination of two terms having allometric scaling with j, where the scaling exponents are λ and μ respectively.

For $A = 0$ we have $\beta_j = \beta_1\, j^{\mu}$ and, for $A = \beta_1$ we get, $\beta_j = A\, j^{\lambda} = \beta_1\, j^{\lambda}$.

In equation (15), A, β_1, λ and μ are constants. The variable j denotes time (expressed in days). The parameters λ and μ determine how fast β_j changes for any change of j. Substituting for β_j in equations (8), (10) and (11), respectively, from equation (15), one gets,

$$y_n = y_1 \prod_{j=1}^{n-1} \left[1 + \alpha_j - A\, j^{\lambda} + (\beta_1 - A) j^{\mu}\right] \quad (16)$$

$$z_n = y_1 \sum_{k=1}^{n} \beta_k \prod_{j=1}^{k-1} \left[1 + \alpha_j - A\, j^{\lambda} + (\beta_1 - A) j^{\mu}\right] \quad (17)$$

$$z_n = y_1 \sum_{k=1}^{n} \beta_k \prod_{j=1}^{k-1} \left[1 + a - A\, j^{\lambda} + (\beta_1 - A) j^{\mu}\right] \quad (18)$$

Equations (16) and (17) represent the time evolution of the numbers of asymptomatic and symptomatic patients for a span of time consisting of phases *with* & *without* lockdown. Equation (18) expresses the time evolution of the number of symptomatic patients over a span where no lockdown has been imposed.

3. Results and discussion

Figure 1 shows the variation of the number of symptomatic patients versus time, based on the data of the cumulative number of infections recorded by the government (from 01 March 2020 to 10 June 2020) and also the data generated by the present model using equation (17). The parameter values, required for the best match between our predictions and the observations are: $y_1 = 100$, a = 0.2, b = 0.1, c = 0.15, $\beta_1 = 0.03$, μ=-0.01, A = 0.02, λ=-0.005.

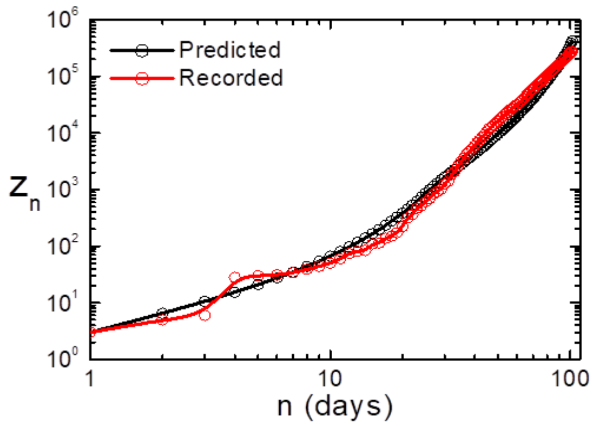

Figure 1 Number of symptomatic patients as a function of time. Red circles represent cumulative COVID-19 counts registered in India from 01 March 2020 (n = 1) to 10 June 2020 (n = 102). Black circles represent $z_n$values obtained from the present model. Parameter values required for the best fit of theoretical model to the observations are, $y_1 =$ 100, a = 0.2, b = 0.1, c = 0.15, $\beta_1 = 0.03$, $\mu = -0.01$, A = 0.02, $\lambda = -0.005$.

This particular set of values has been used for making all predictions based on this model. Although this is not an unique set, we have found that only very small deviations from this set lead to a sufficiently impressive agreement (as shown by Figure 1) between our mathematical model and the set of actual data of COVID-19 infections registered in India during the span from 01 March 2020 to 10 June 2020.

Figure 2 shows the time evolution of the cumulative numbers of asymptomatic and symptomatic (recorded) patients, during the period from 01 March 2020 to 10 June 2020. Most of the asymptomatic cases remain undetected in India due to extremely insufficient number of tests [27, 28]. For calculating the number of asymptomatic cases, using equation (16), we have used the parameter values given in the discussion about Figure 1.

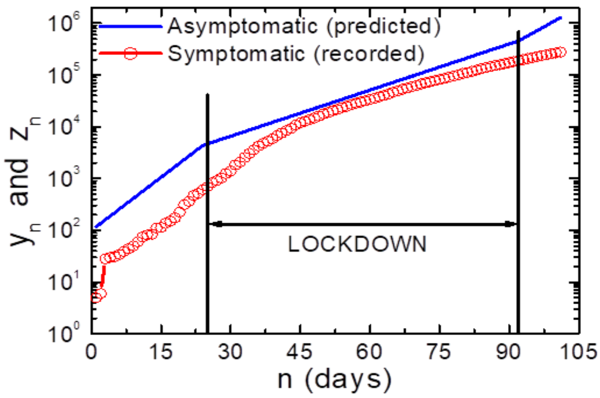

Figure 2 Numbers of asymptomatic and symptomatic (recorded) patients, as functions of time, over the period from 01 March 2020 (n = 1) to 10 June 2020 (n = 102). Asymptomatic cases, based on our model, have been calculated by using the parameter values required for the best fit of theoretical predictions to the actual data. These values are given in the caption for Figure 1.

Figure 3 shows the time evolution of the cumulative number of symptomatic patients, under the situations of *lockdown* and *no-lockdown*, during the period from 01 March 2020 to 10 June 2020, where lockdown remained effective from 25 March 2020 to 31 May 2020. To calculate the number of symptomatic cases under the *no-lockdown* situation, using equation (18), we have used the parameter values given in the discussion regarding Figure 1. In this plot, the data of symptomatic cases under lockdown (represented by red circles) are actually the cumulative number of confirmed COVID-19 cases obtained from government sources [14]. According to these curves, the number of infected persons would have been 100 times the value that it had reached on 31 May 2020 (the last day of lockdown), if the lockdown had not been imposed.

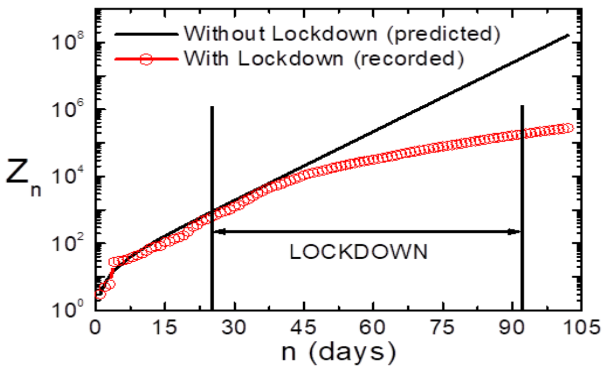

Figure 3 Cumulative count of symptomatic patients as a function of time, with & without lockdown, over the period from 01 March 2020 (n = 1) to 10 June 2020 (n = 102). Symptomatic cases, without lockdown, have been calculated by using the parameter values required for the best fit of theoretical predictions to actual observations. These values are given in the caption for Figure 1.

Figure 4 shows the time evolution of the cumulative number of symptomatic cases, based on equation (17), during three phases: 1) pre-lockdown, 2) lockdown, 3) unlock (partial lockdown), for a span of 120 days (since 01 March 2020), where lockdown continues from the 25th day to the 92nd day. Red circles represent the cumulative counts of the COVID-19 cases registered in India [14]. According to the predictions (blue curve), this number is expected to be nearly one million on the 120th day (i.e., 28 June 2020). The parameter values, used for this calculation, have been obtained from the discussion about Figure 1.

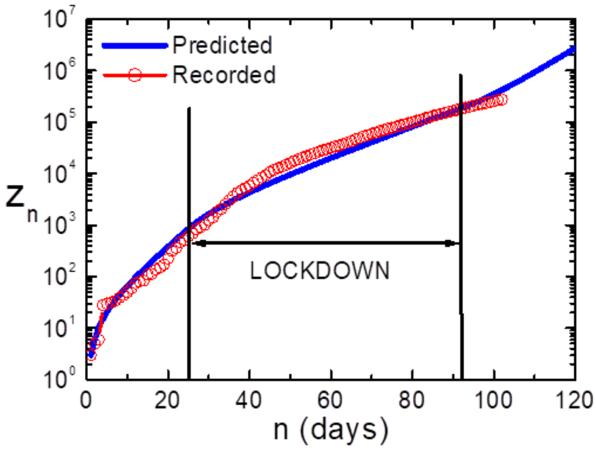

Figure 4 Predictions regarding symptomatic cases as a function of time, for three phases: 1) pre-lockdown, 2) lockdown, 3) unlock (partial lockdown), over a span of 120 days since 01 March 2020 (*n* = 1). Red circles represent the cumulative COVID-19 data till 10 June 2020. Lockdown was effective from *n* = 25 to *n* = 92. Parameters used for prediction are given in the caption for Figure 1.

Figure 5 shows our prediction for y_n, for a hypothetical situation, for three values of the parameter *b*, over a period of 120 days, where lockdown is effective from the 25th to the 120th day. Smaller values of *b* represent greater social distancing during lockdown. Here we have, $c = b, d_1 = 24$ and $d_2 + d_3 = 96$, as per equation (2). Thus, $d_1 + d_2 + d_3 = 120$. The parameters, other than *b* and *c*, are given in the discussion about Figure 1. For a sufficiently low value of *b*, the number of asymptomatic patients starts decreasing with time, immediately after the imposition of lockdown.

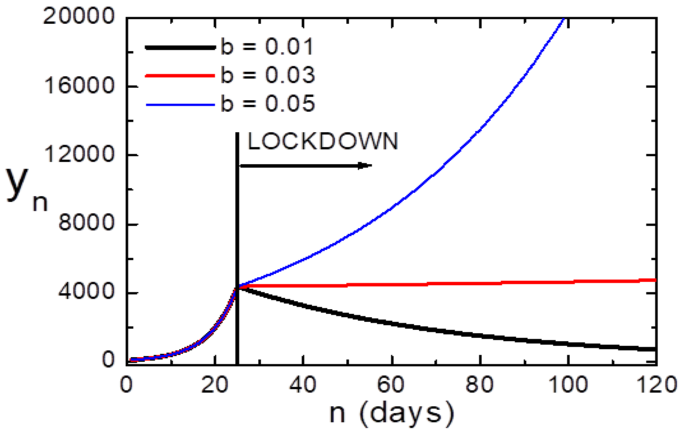

Figure 5 Number of asymptomatic patients (in a hypothetical situation) as a function of time for three values of the parameter *b*, for a period of 120 days, where lockdown continues from the 25th to the 120th day. Smaller values of *b* represent greater social distancing during lockdown. Here we have *c* = *b*. Other parameter values are given in the caption for Figure 1.

Figure 6 shows our prediction for z_n, for a hypothetical situation, for three values of the parameter *b*, over a period of 120 days, where lockdown is effective from the 25th to the 120th day. Smaller values of *b* represent greater social distancing during lockdown. Here we have, $c = b, d_1 = 24$ and $d_2 + d_3 = 96$, as per equation (2). Thus, $d_1 + d_2 + d_3 = 120$. The parameters, other than *b* and *c*, are given in the discussion about Figure 1. For a sufficiently low value of *b*, the cumulative number of symptomatic patients shows a decreasing slope, immediately after the imposition of lockdown, indicating a decrease in the number of daily reported cases.

The values of the parameter *b*, used for Figures 5 and 6, are much smaller than the value (i.e., *b* = 0.1) obtained by fitting our model to the actual data (Figure 1) regarding the cumulative number of confirmed COVID-19 cases in India. Smaller values of *b* correspond to higher degrees of social distancing. These figures clearly manifest the importance and effectiveness of social distancing in reducing the rate of transmission of the disease.

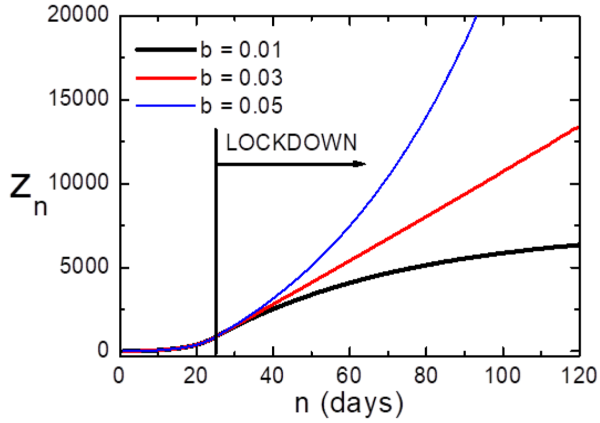

Figure 6 Number of symptomatic patients (in a hypothetical situation) as a function of time for three values of the parameter b, for a period of 120 days, where lockdown continues from the 25th to the 120th day. Smaller values of b represent greater social distancing during lockdown. Here we have c = b. Other parameter values are given in the caption for Figure 1.

Figure 7 shows the time evolution of the proportions of symptomatic and asymptomatic patients, based on equations (12) and (13) respectively, for a period of 120 days (since 01 March 2020), where lockdown is effective from the 25th to the 92nd day. We have used the parameter values mentioned in the discussion about Figure 1. According to these curves, the smallest ratio of the numbers of asymptomatic to symptomatic cases is around 7/3. It means that for every three symptomatic cases, there are at least seven asymptomatic cases.

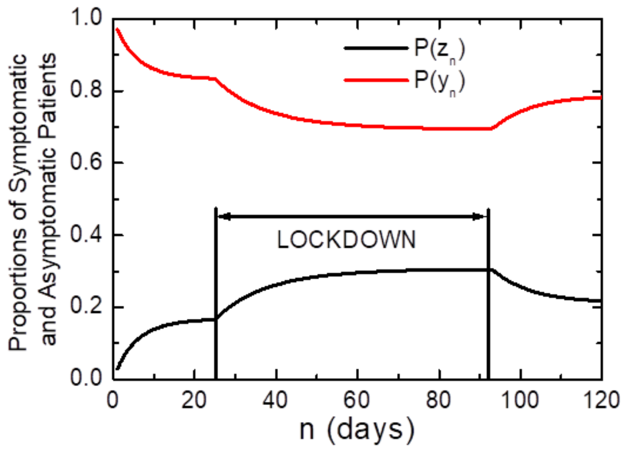

Figure 7 Proportions of symptomatic and asymptomatic patients (relative to the total number of patients) as functions of time, over a period of 120 days since 01 March 2020. Lockdown continued from 25 March 2020 (n = 25) to 31 May 2020 (n = 92). Parameter values, used for this calculation, are given in the caption for Figure 1.

Figure 8 shows the time evolution of the percentage of Indian population infected (symptomatic + asymptomatic), over a period of 120 days (since 01 March 2020), where lockdown is effective from the 25th to the 92nd day. Equation (14) has been used for this calculation. The parameter values, used for this purpose, are the ones mentioned in the discussion about Figure 1. This curve shows that, on the 120th day (i.e., 28 June 2020), nearly 1% of the population will be infected with COVID-19, either symptomatically or asymptomatically. The present population of India is 1.36×10^9.

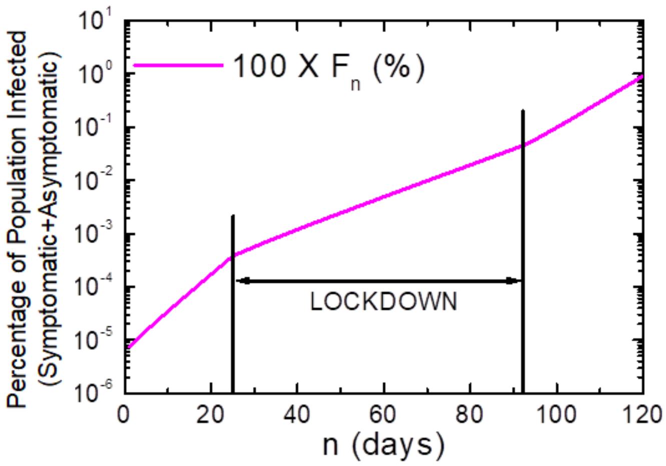

Figure 8 Percentage of Indian population infected (symptomatic + asymptomatic), over a period of 120 days since 01 March 2020. Lockdown continued from 25 March 2020 (n = 25) to 31 May 2020 (n = 92). The present population of India is 1.36×10^9. Parameter values, used for this calculation, are given in the caption for Figure 1.

Figure 9 shows the time evolution of the parameter α_n over a period of 120 days since 01 March 2020. Lockdown continued from the 25th to the 92nd day during this span and the unlock phase (a partial lockdown) was in effect from the 93rd day onwards. Higher degrees of social distancing correspond to smaller values of α_n. The parameters a, b and c of equation (2) are found to be 0.2, 0.1 and 0.15 respectively by fitting our model (eqn. 17) to the data for confirmed COVID-19 cases registered in India. Thus, α_n has these three values during pre-lockdown, lockdown and unlock periods respectively. Figures 5 & 6 show that much more social distancing (than what prevails presently in India) is required to stop the transmission of the disease completely.

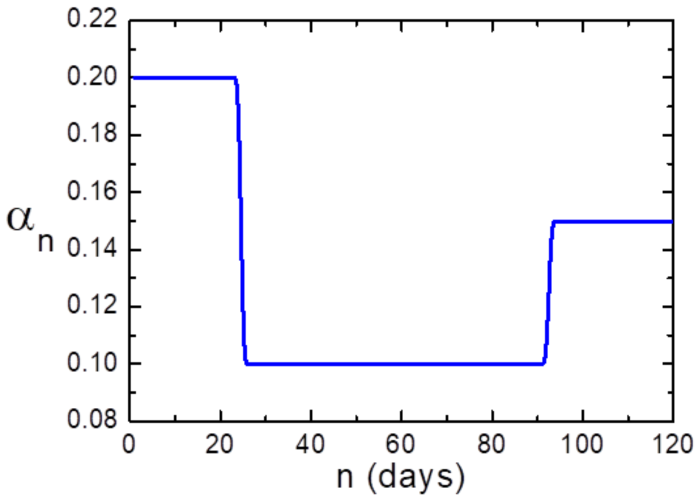

Figure 9 Time dependence of the parameter α_n over a period of 120 days since 01 March 2020. Lockdown continued from the 25th to the 92nd day. Smaller values of α_n correspond to more stringent social distancing. Its values are 0.2, 0.1 and 0.15 during pre-lockdown, lockdown and unlock periods respectively, as obtained by fitting our model to the data of COVID-19.

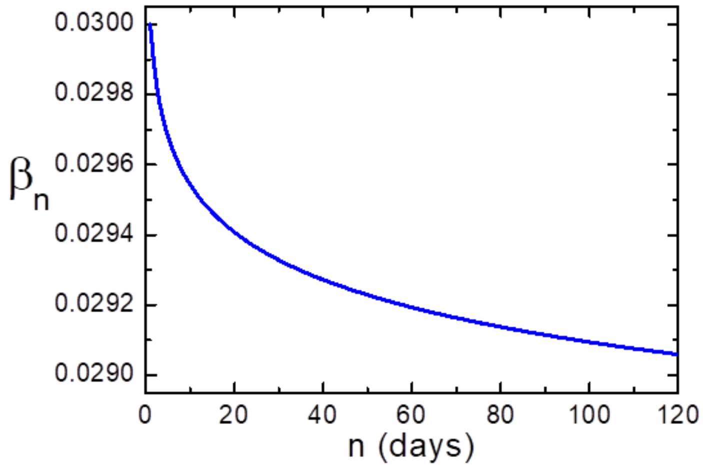

Figure 10 Time dependence of the parameter $\boldsymbol{\beta_n}$ over a period of 120 days since 01 March 2020. Lockdown continued from the 25th to the 92nd day. Its values are based on equation (15), using the parameter values given in the caption for Figure 1. These values have been obtained by fitting our model to the data of COVID-19 infections in India from 01 March 2020 to 10 June 2020.

Figure 10 shows the time evolution of the parameter β_n over a period of 120 days since 01 March 2020. Lockdown continued from the 25th to the 92nd day during this span and the unlock phase (a partial lockdown) was in effect from the 93rd day onwards. This parameter has been calculated with the help of equation (15), using the values of A, β_1, λ and μ mentioned in the discussion about Figure 1. These values have been obtained by fitting our model (eqn. 17) to the data of COVID-19 infections in India from 01 March 2020 to 10 June 2020. This figure shows that β_n decreases with time at a rate that becomes smaller with time. It indicates that the fraction of asymptomatic patients turning into the symptomatic type on the any day (say n^{th} day) decreases with n.

The results of the present study that highlight vividly the effectiveness of lockdown, are in agreement with the findings of several other recent studies based on different mathematical methods [19, 22, 23, 25].

The results, depicted by Figures 2 & 7 of this article, are consistent with the findings of a recent study [21]. According to these figures, the ratio of asymptomatic to symptomatic patients decreases with time during the lockdown period. This is mainly due to the reduction in the rate at which the number of asymptomatic carriers increases, caused by social distancing enforced in the country during the lockdown period.

The incubation period for COVID-19 has been found to be nearly 1 to 14 days [14]. A person does not develop symptoms during this period, after being infected. The mean incubation period is around 6.4 days [15]. The value of the parameter a has been found to be 0.2 in the present study. By definition, this is the average number of persons infected per day by a patient during the incubation period. Thus, the average number of persons infected by a patient, is 1.28 (i.e., $a \times$ average incubation period), since he or she is put into isolation after being symptomatic. The maximum number of persons infected by such a carrier is 2.8 (i.e., $a \times$ maximum incubation period). This parameter (a) seems to have a connection to the basic reproduction number (R_0), which is yet to be explored. The values of R_0 are found to be in the range from 1.4 to 3.5 [15]. In a recent mathematical model on coronavirus transmission in India, R_0 has been taken to be 1.5 and 4.0, under two different conditions [17].

4. Conclusion

This mathematical model is based on an assumption that a patient is quarantined immediately after developing the symptoms of COVID-19. Thus, a symptomatic carrier is totally prevented from spreading the disease. This cannot be entirely true under the present circumstances. The infection in the body of a person, who has developed some symptoms, can remain undiagnosed due to mainly two reasons. One of the reasons is that some of the symptoms are very much similar to those of other diseases (caused by influenza viruses). The other reason is obviously the lack of testing facilities in the country. The present model of algebraic analysis or prediction can be improved by taking into consideration the role played by the symptomatic patients in the transmission of the disease. Another aspect, which has a plenty of scope for modification, is the functional form of β_j of equation (15). Apart from this form, one may choose many other functions that can represent the time dependence (i.e., dependence upon j here) of this parameter. A limitation of our calculation is that the values of the parameters a, b and c, have been assumed to remain constant over certain periods of time (d_1, d_2 & d_3 respectively). In reality, the social mixing or distancing patterns may vary continuously with time during the outbreak of such a disease. In spite of such limitations, the predictions made by this model are in reasonable agreement with the actual records, for a certain set of parameter values. Based on this set, the most important finding of the present study is that, the social distancing has to be maintained as stringently as possible, which is quite evident from the Figures 5, 6. The value of the parameter b, whose smallness is an indicator of social distancing during lockdown, needs to be sufficiently decreased, to cause y_n to fall with time and to flatten the curve for z_n.

Compliance with ethical standards

Acknowledgments

The author of this article is extremely thankful to all researchers whose studies have inspired him to carry out the research required for this work.

Disclosure of conflict of interest

There is no conflict of interest associated with this article.

References

[1] Hui DS, Azhar EI, Madani TA, Ntoumi F, Kock R, Dar O, et al. (2020). The continuing 2019-nCoV epidemic threat of novel coronaviruses to global health -The latest 2019 novel coronavirus outbreak in Wuhan, China. Int J Infect Dis, 91, 264–266.

[2] Yang J, Zheng Y, Gou X, Pu K, Chen Z, Guo Q, et al. (2020). Prevalence of comorbidities and its effects in patients infected with SARS-CoV-2: a systematic review and meta-analysis. Int J Infect Dis, 94, 91–95.

[3] Website of the World Health Organization (WHO). https://www.who.int (Last accessed on 11 June 2020)

[4] Savarino A, Boelaert JR, Cassone A, Majori G and Cauda R. (2003). Effects of chloroquine on viral infections: an old drug against today's diseases? Lancet Infect Dis, 3(11), 722–727.

[5] Colson P, Rolain JM and Raoult D. (2020). Chloroquine for the 2019 novel coronavirus SARS-CoV-2. Int J Antimicrob Agents, 55(3), 105923, 1-2.

[6] Gu J, Han B and Wang J. (2020). COVID-19: Gastrointestinal Manifestations and Potential Fecal–Oral Transmission. Gastroenterology, 158, 1518–1519.

[7] Liu J, Liao X, Qian S, Yuan J, Wang F, Liu Y, et al. (2020). Community Transmission of Severe Acute Respiratory Syndrome Coronavirus 2, Shenzhen, China, 2020. Emerg Infect Dis, 26(6), 1320-1323.

[8] Chan JFW, Yuan S, Kok KH, To-Wang KK, Chu H, Yang J, et al. (2020). A familial cluster of pneumonia associated with the 2019 novel coronavirus indicating person-to-person transmission: a study of a family cluster. The Lancet, 395(10223), 514-523.

[9] Li Q, Guan X, Wu P, Wang X, Zhou L, Tong Y, et al. (2020). Early Transmission Dynamics in Wuhan, China, of Novel Coronavirus–Infected Pneumonia. N Engl J Med, 382, 1199-1207.

[10] Huang C, Wang Y, Li X, Ren L, Zhao J, Hu Y, et al. (2020). Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. The Lancet, 395(10223), 497-506.

[11] Burke RM, Midgley CM, Dratch A, Fenstersheib M, Haupt T, Holshue M, et al. (2020). Active Monitoring of Persons Exposed to Patients with Confirmed COVID-19 - United States. MMWR Morb Mortal Wkly Rep, 69(9), 245-246.

[12] Ong SWX, Tan YK, Chia PY, Lee TH, Ng OT, Wong MSY, et al. (2020). Air, Surface Environmental, and Personal Protective Equipment Contamination by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) From a Symptomatic Patient. JAMA, 323(16), 1610–1612.

[13] Scientific Brief, Published by the *World Health Organization* (WHO). Title: Modes of transmission of virus causing COVID-19: implications for IPC precaution recommendations. Published on 29 March 2020.

WHO reference number: WHO/2019-nCoV/Sci_Brief/Transmission_modes/2020.2

[14] Website of the Ministry of Health and Family Welfare, Government of India. https://www.mohfw.gov.in (Last accessed on 11 June 2020)

[15] Chatterjee P, Nagi N, Agarwal A, Das B, Banerjee S, Sarkar S, et al. (2020). The 2019 novel coronavirus disease (COVID-19) pandemic: A review of the current evidence. Indian J Med Res, 151(2), 147-159.

[16] Agarwal A, Nagi N, Chatterjee P, Sarkar S, Mourya D, Sahay RR, et al. (2020). Guidance for building a dedicated health facility to contain the spread of the 2019 novel coronavirus outbreak. Indian J Med Res, 151(2), 177-183.

[17] Mandal S, Bhatnagar T, Arinaminpathy N, Agarwal A, Chowdhury A, Murhekar M, et al. (2020). Prudent public health intervention strategies to control the coronavirus disease 2019 transmission in India: A mathematical model-based approach. Indian J Med Res, 151(2), 190-199.

[18] D Biswas and S Roy. (2020). Analyzing COVID-19 pandemic with a new growth model for population ecology. DOI:10.13140/RG.2.2.34847.92324/1

[19] Arti MK and K Bhatnagar (2020). Modeling and Predictions for COVID 19 Spread in India. DOI:10.13140/RG.2.2.11427.81444

[20] T Kaur et al. (2020). Anticipating the novel coronavirus disease (COVID-19) pandemic. DOI:10.1101/2020.04.08.20057430

[21] S Mukhopadhyay and D Chakraborty. (2020). Estimation of undetected COVID-19 infections in India. DOI:10.1101/2020.04.20.20072892

[22] A. Rajesh et al. (2020). COVID-19 prediction for India from the existing data and SIR(D) model study. DOI:10.1101/2020.05.05.20085902

[23] R Ranjan. (2020). Predictions for COVID-19 Outbreak in India Using Epidemiological Models. DOI:10.1101/2020.04.02.20051466

[24] S Ghosh. (2020). Predictive Model with Analysis of the Initial Spread of COVID-19 in India. DOI:10.1101/2020.05.02.20088997

[25] M. Bhatnagar. (2020). COVID-19: Mathematical Modeling and Predictions. DOI: 10.13140/RG.2.2.29541.96488

[26] Roy S and Roy Bhattacharya K. (2020). Spread of COVID-19 in India: A Mathematical Model. Journal of Science and Technology, 5(3), 41-47.

[27] WORLDOMETER data regarding the number of infections, deaths, tests etc. https://www.worldometers.info/coronavirus/?utm_campaign=homeAdvegas1?%22%20%5Cl%20%22countri

(Last accessed on 11 June 2020).

[28] Statistics and Research: Coronavirus (Covid-19) Testing.

https://ourworldindata.org/coronavirus-testing (Last accessed on 11 June 2020)

How to cite this article

Roy S. (2020). An algebraic interpretation of the spread of COVID-19 in India and an assessment of the impact of social distancing. World Journal of Advanced Research and Reviews, 6(3), 245-256.