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COVID-19: Mathematical growth vs. precautionary measures in China, KSA, and the USA

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ABSTRACT

This paper aims to study the relation between precautionary measures that were taken by countries to prevent the spread of COVID-19 and its impact on its mathematical growth. In this paper, we study the development and growth of the epidemic during the first fifty days since its appearance in three countries: China, the Kingdom of Saudi Arabia (KSA), and the United States of America (USA). An optimization process is used to determine the parameters of the closest model that simulates the data during the specified period by using one of the evolutionary computation techniques, the grasshopper optimization algorithm (GOA). The study reveals that the strict precautionary measures of applying isolation and quarantine, preventing all gatherings, and a total curfew are the only way to prevent the spread of the epidemic exponentially as China did. Also, without any measures to slow its growth, COVID-19 will continue to spread steadily for months.

1. Introduction

In 2003 the "Corona" family deviated and mutated in the world, resulting in a new type known as "SARS," then "MERS" Corona appeared in Saudi Arabia in 2012, and most recently The new Corona epidemic (COVID-19) in China that claimed millions around the world. The slow and indiscriminate response to the emergency precautions that had to be taken led to that more than half of the cases, in the first months of appearing the disease, in Europe [1,2]. So, Human errors, indifference, and lack of awareness of the necessary precautions caused the spread of the virus [3]. At the countries level, the United States has become the country most affected by the spread of the virus on its soil, according to Johns Hopkins University map statistics [4–6].

Coronaviruses are a large group of viruses that cause diseases in animals and humans. They often circulate among cats, camels, and bats, and can sometimes evolve and infect people. In animals, Coronaviruses can cause diarrhea in pigs and cows, and upper respiratory disease in chickens. In humans, the viruses can cause mild respiratory infections, like the common cold, but they can lead to serious illnesses, like pneumonia. Coronaviruses are named for the crown-like spikes on their surface. Human Coronaviruses were first identified in the mid-1960s. They are closely monitored by public health officials [7].

COVID-19 appeared on the seafood and poultry market in Wuhan, China, in December 2019. Cases have been detected in most countries around the world, and on March 11, 2020, the World Health Organization described an outbreak as a pandemic, spread from person to person through close contact.

There are three directions to study COVID-19. The first direction is to analyze the impact of the closure on the spread of the COVID-19 epidemic as in Refs. [8–10]. In Ref. [8], through epidemiological models and dynamic systems, the authors analyzed the effect of lockdown on COVID-19 spreading in Tamil Nadu state in India. While In Ref. [9], the exponential and classic (SIR) models based on available data were used to generate regular short and long-term forecasts. Furthermore, data from various geographical areas were compared to determine the effect of social distancing, with the supposition that no group dissemination exists. But in Ref. [10], the authors evaluated the public trust and compliance with precautionary measures of the authorities to tackle the outbreak of COVID-19 in Saudi Arabia. The second direction aims to understand and characterize the psychological and social effects of the COVID-19 epidemic in the general population, identify the risks and preventive factors, and investigate compliance

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with precautionary measures to halt the spread of the virus as in Refs. [11–13].

Finally, in the third direction, prediction models under current public health interventions are proposed to forecast the spread of the COVID-19 pandemic in many countries as in Refs. [14–18]. But, epidemic forecasts have often been a questionable record, in which their failings with COVID-19 have emerged. Bad data input, inaccurate modeling expectations, high estimation vulnerability, lack of epidemiological characteristics, poor historical proof of the impact of available approaches, lack of clarity, mistakes, lack of decisiveness, consideration of either one or a few facets of the problem at hand, lack of experience in sensitive fields, groupthink, and selective reporting are some of the causes of these failures [19].

Many types of research on epidemics have recently been published [20–26]. During the COVID-19 epidemic, the authors' estimated daily reproduction counts in Ref. [20]. [21] presents a dynamic model of COVID-19 and citizens reaction from a section of the Nigerian population using fractional derivative [22]. examines a model for typhoid fever direct and indirect transmission dynamics with three control interventions [23]. proposes and analyzes a compartmental nonlinear deterministic mathematical model for typhoid fever outbreaks and optimal management measures in a community with variable population. A variable in the SEIR set of equations is introduced in Ref. [25] to explore the influence of varying degrees of social separation on the transmission of the disease [26]. provides the first detailed examination of the tracing app properties.

Why outbreaks like Coronavirus spread exponentially, and how to stop its spread. COVID-19 grows exponentially, like most epidemics, during the initial phase of an epidemic. This so-called exponential curve has experts worried; where the number of cases doubles every three days [27]. But this exponential increase varies from country to country (according to the exponential growth rate) based on the steps taken to control the spread of the disease. However, the epidemic suitable growth model for a given country could vary from exponential growth to any other growth model according to the procedures. From this motivation, this paper explores the relationship between precautionary measures taken to prevent the spread of the epidemic and its impact on the mathematical growth of COVID-19 and the increase in the number of infections with it is studied. Three countries are used in this study, which are China, KSA, and the USA. In mathematics, there are many growth equations such as exponential growth, geometric growth, and logarithmic growth. An optimization process is used to determine the parameters for each growth model by using one of the evolutionary computation techniques, the grasshopper optimization algorithm (GOA).

This study follows the first direction of the COVID -19 types of research. Many studies in this direction have only been performed in a single area or country. These studies are very significant and many publications exist in them to date because of their significance and because the disease and the nature of its dissemination differ from time to time. The novelty in this study is that three nations have been analyzed, each taking different measures. Fig. 1 shows the graphical representation of this study.

The main objectives of this study are:

1. Find out the relationship between precautionary measures and the growth of the epidemic.
2. Determine the effect of adherence to precautionary measures on the growth rate of the epidemic or not.
3. Use one of the evolutionary computation techniques to determine the parameters for each mathematical growth model.
4. Determine what is the best move for countries to control the spread of infection before any vaccine appears or there are rumors that affect following the instructions and procedures taken in each country.

The mathematical contribution of this study is that the mathematical growth of COVID-19 is affected by precautionary measures, where taking moderate precautions measures and the dedication of people in adopting them reduces the exponential rate of growth of the epidemic. Finally, the study reveals that strict precautionary measures are the only way to prevent the spread of the COVID-19 exponentially, and without any measures to slow COVID-19 growth, it will continue to spread steadily for months.

The paper is organized as follows: Preliminaries about the growth models are described in Section 2. Section 3 presented the proposed methodology. Section 4 shows the results with discussions. Finally, section 5 presents the conclusion and future works.

2. Preliminaries

This section sets out the basic principles of some of the growth models, which are geometric growth, exponential growth, and logarithmic growth.

2.1. Exponential growth

Exponential growth is a specific way that a quantity may increase over time. It occurs when the instantaneous rate of change of a quantity concerning time is proportional to the quantity itself. Described as a function, a quantity undergoing exponential growth is an exponential function of time, that is, the variable representing time is the exponent.

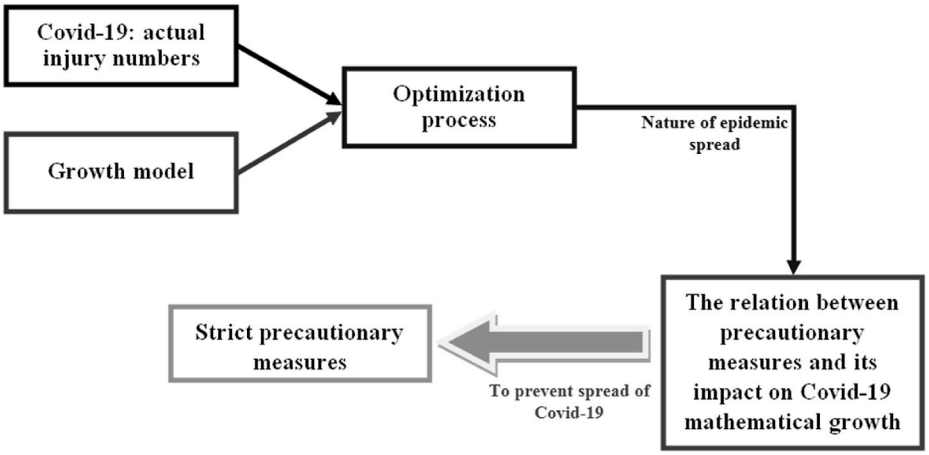

Fig. 1. Graphical representation for mathematical growth vs. precautionary measures for this study.

The formula for the exponential growth of a variable E at the growth rate R, as time n goes on in discrete intervals (that is, at integer times 0, 1, 2, 3, …), is

$$E_n = E \cdot e^{Rn}; \tag{1}$$

where $E = E_0$ is an initial value and R is the growth rate.

The exponential growth function Eq. (1) satisfies the linear differential equation:

$$\frac{dE}{dn} = RE \tag{2}$$

This differential equation says that the change per instant of time of E at time n is proportional to the value of E_n, and E_n has the initial value E_0.

In this study, E_n is the total Coronavirus cases at day n, and E_0 is an initial value for fitting the curve.

2.2. Geometric growth

In mathematics, a geometric growth is a sequence of numbers where each term after the first is found by multiplying the previous one by a fixed, non-zero number called the common ratio. For example, the sequence 2, 6, 18, 54, … is a geometric progression with a common ratio of 3. Similarly, 10, 5, 2.5, 1.25, … is a geometric sequence with a common ratio of 1/2.

The *n-th* term of a geometric progression is given by:

$$G_n = GR^{n-1}; \tag{3}$$

where $G = G_0$ is an initial value and R is the common ratio. Geometric growth (with a common ratio R not equal to −1, 1, or 0) shows exponential growth or exponential decay.

In this study, G_n is the total Coronavirus cases at day n, and G_0 is the initial value for fitting the curve.

2.3. Logarithmic growth

Logarithmic growth is the inverse of exponential growth and is very slow. In mathematics, logarithmic growth describes a phenomenon whose size or cost can be described as a logarithm function of some input. In microbiology, the rapidly growing exponential growth phase of cell culture is sometimes called logarithmic growth. During this bacterial growth phase, the number of new cells appearing is proportional to the population. This terminological confusion between logarithmic growth and exponential growth may be explained by the fact that exponential growth curves may be straightened by plotting them using a logarithmic scale for the growth axis [28].

The formula for logarithmic growth of a variable L, as time n goes on in discrete intervals (that is, at integer times 0, 1, 2, 3, …), is

$$L_n = L_0 \cdot \log_R(n); \tag{4}$$

where R is the base of the number system used, e.g. 10 for decimal arithmetic. In this study, L_n is the total Coronavirus cases at day n, and L_0 is the initial value for fitting the curve.

Finally, because these growth models deal with days $(n = 1, 2, \ldots)$, we may classify them as discrete.

3. Methodology

In this section, we show the methodology used to determine the growth model of COVID-19. First, the actual data recorded for the number of corona infections and the mathematical model whose equation is to be calculated are entered in the optimization process. Second, the method of optimization determines the parameters for each growth model by minimizing the sum of the square of the difference between the actual data and the growth model. This difference is considered as the objective function in the optimization process [29–33]. Finally, a comparison is made between the growth model and the actual data, and whether or not there is a discrepancy between them. Fig. 2 explains the methodology for this study to determine the growth model of COVID-19.

Until now, many evolutionary computation techniques (ECTs) have been proposed in the literature and have been successfully applied to optimization processes. Examples of PBAs models are: genetic algorithm (GA) [34,35], particle swarm optimization (PSO) [36–38], artificial bee colony (ABC) [39], bacterial foraging (BF) [40], cat swarm optimization (CSO) [41], glowworm swarm optimization (GSO) [42], firefly algorithm (FA) [43], krill herd algorithm (KHA) [44], sine cosine algorithm (SCA) [45] and grasshopper optimization algorithm (GOA) [46], salp swarm algorithm (SSA) [47], gradient-based optimizer (GBO) [48], and harris hawks optimization (HHO) [49], etc.

Grasshopper optimization algorithm (GOA) is one of the novels ECTs which is based on the swarming nature of grasshoppers proposed by Mirjalili [50]. It mainly depends on the forces of social interaction to find the globally optimum values of the optimization problem. Due to its easy deployment and high accuracy, robustness, and effectiveness, it is widely used in a variety of optimization problems and, therefore, has been used in this study in the optimization process. The flow chart of GOA is shown in Fig. 3.

As in Fig. 3, The algorithm initially has a population of random (grasshoppers) solutions; where the position of the i-th grasshopper in d-dimensional space is denoted as X_i and represented as $X_i = (x_{i1}, x_{i2}, \ldots, x_{id})$.

The grasshopper's positions are updated according to the following equations:

$$X_i = c\left(\sum_{\substack{j=1 \\ j\neq i}}^{N} c\frac{ub_d - lb_d}{2} s\left(\left|x_j^d - x_i^d\right|\right)\frac{x_j - x_i}{d_{ij}}\right) + \widehat{T}_d, \tag{5}$$

$$s\left(\left|x_j^d - x_i^d\right|\right) = fe^{\frac{-\left|x_j^d - x_i^d\right|}{l}} - e^{-\left|x_j^d - x_i^d\right|},$$

$$d_{ij} = \left|x_j - x_i\right| \ \forall i = 1, \ldots, N_{grasshoppers};$$

where X_i is the position of the *i-th* grasshopper, ub_d and lb_d are the upper bound and the lower bound in the dth dimension respectively, x_i^d and x_j^d are the *i-th* and the *j-th* grasshopper in the dth dimension respectively, s is a function to define the strength of social forces, f is the intensity of attraction, l is the attractive length scale, d_{ij} is the distance between the *i-th* and the *j-th* grasshopper, $\widehat{T}_d$ is the value of the dth dimension in the target (the best grasshopper among all the grasshopper in the population found so far) and c is a decreasing coefficient proportional to the number of iterations and is calculated as follows.

$$c = c_{\max} - t\frac{c_{\max} - c_{\min}}{T}, \tag{6}$$

where $c_{\max}$ is the maximum value, $c_{\min}$ is the minimum value, t indicates the current iteration, and T is the maximum number of iterations.

The solution code is implemented in MATLAB. The simulations have been executed on an Intel® Core ™i5 CPU M430 @ 2.27 GHz processor, installed memory (RAM): 6.00 GB.

4. Results and discussion

It is understood that epidemics or most of them are increasing exponentially, but this exponential increase varies from country to country (according to the exponential growth rate) based on the steps taken to control the spread of the disease. However, the epidemic suitable growth model for a given country could vary from exponential

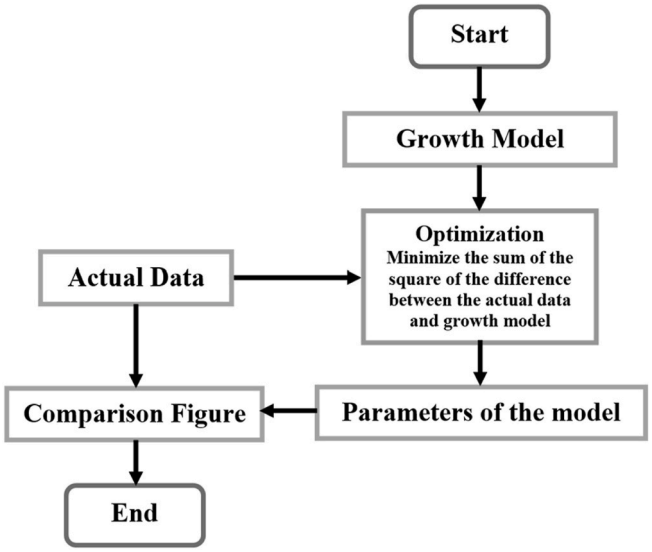

Fig. 2. The methodology to determine the growth model of COVID-19.

growth to any other growth model according to the procedures, as we see in this section.

In this section, the description regarding the COVID-19 dataset used, the results, and discussions are presented. The COVID-19 dataset was gathered from Worldometer's website [6] that manually analyzes, validates, and aggregates data from thousands of sources in real-time and provides global COVID-19 live statistics for a wide audience of caring people around the world. In this study, data for three countries, China, KSA, and the USA, were chosen during the first fifty days since the appearance of the first infection. In China, the period from January 22, 2020 to March 11, 2020 was studied, and in the KSA, the period from March 2, 2020 to April 20, 2020 was studied, while in the USA the period from February 25, 2020 to April 4, 2020 was studied. The justification for looking at the data from the first appearance of the infection to fifty days is to determine what is the best move for countries to control the spread of infection before any vaccine appears or the presence of rumors that affect following the instructions and measures taken in each country.

In these countries, different scenarios have been used to contain the outbreak. For China, it was implemented quarantine and isolation using strict precautionary measures, as it quarantined about 60 million people in Hubei province and imposed severe travel restrictions. KSA tried to combine the idea of social separation and repression using curfews (not most of the time) as a precaution. USA has taken precautionary measures similar to those taken by KSA, but slowly. In addition, The American people underestimated these measures to the point that they demonstrated against these measures. In this study, we try to know the effect of the measures taken by these countries to contain the disease on the growth curve of the number of infections.

Figs. 4–12 show a representation of the growth of the number of COVID-19 infections in China, KSA, and the USA respectively. From the Figures, we find that the exponential growth and the geometric growth are the same in each country because the common ratio R in the geometric growth is not equal to −1, 1, or 0, which leads to the emergence of geometric growth as exponential growth.

For China, we find, as shown in Figs. 4–6, that the closest representation of the number of infections during the first fifty days is logarithmic growth. While the closest representation of the growth of the number of infections in both KSA and USA during the period specified for the study, as shown in Figs. 7-9 and 10-12 is the exponential growth. This confirms that the reduced precautionary measures did not prevent the epidemic from growing exponentially, as it is well known that the exponential model is better suited for short-term forecasts of any epidemic. But the difference between the KSA and USA is that the KSA people committed themselves to apply the precautionary measures, which made the exponential growth rate R equal 0.1001, while the lack of commitment by the USA people to the precautionary measures led to that the rate of growth R in the exponential growth equal to 0.1579.

In addition, Fig. 13 shows that if China took the same measures as KSA and the USA, the numbers of COVID-19 infections were developing and increasing exponentially with a growth rate R equal to 0.1151.

From the above, it is evident that strict precautionary measures by applying isolation and quarantine, preventing all gatherings, and a total curfew are the only way to prevent the spread of the epidemic exponentially as China did, especially when no vaccines are discovered. This was confirmed by the World Health Organization that the success of China's efforts to contain the emerging Coronavirus, based on the number of infections announced by Beijing, is caused by the use of strict force to prevent gatherings. Also, without any measures to slow its growth, COVID-19 will continue to spread steadily for months.

A comparative study was performed in this section to determine whether the precautionary measures affect the mathematical growth model of Coronavirus in the early days of its emergence or not. An optimization process was used to calculate the model closest to the

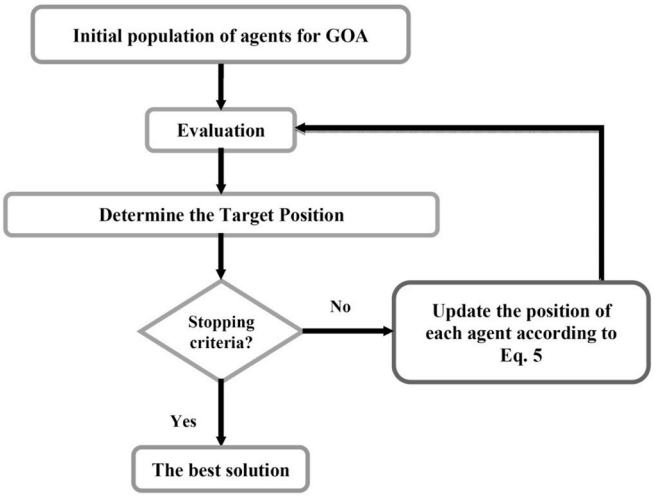

Fig. 3. The flowchart of Goa.

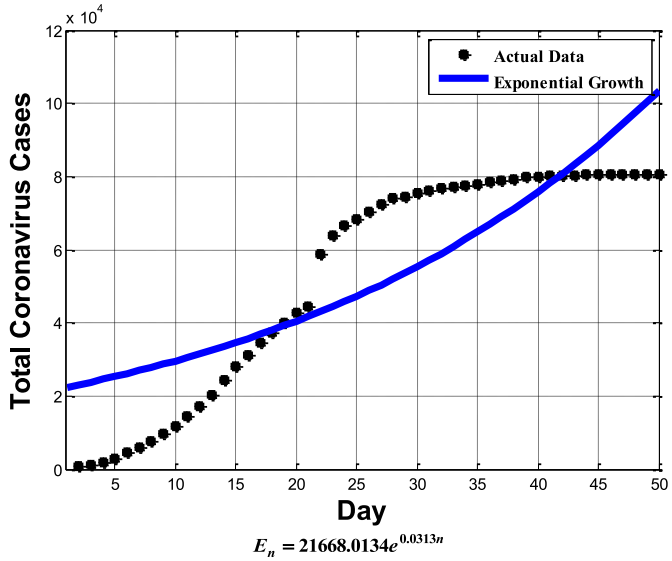

Fig. 4. Exponential growth model for COVID-19 in China.

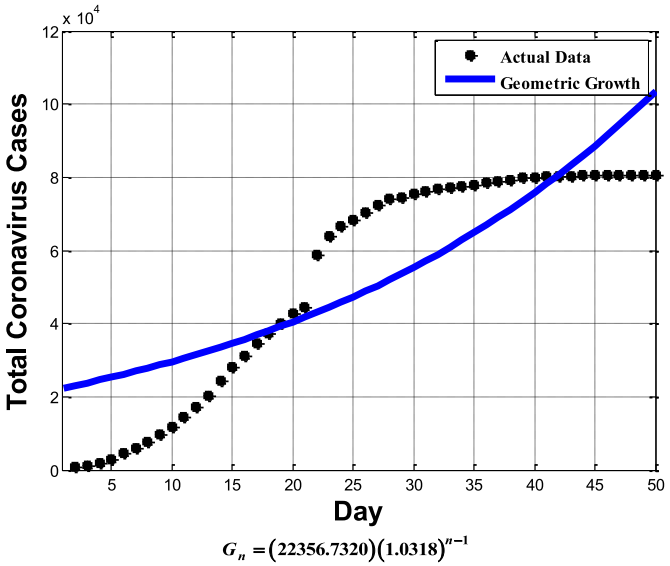

Fig. 5. Geometric growth model for COVID-19 in China.

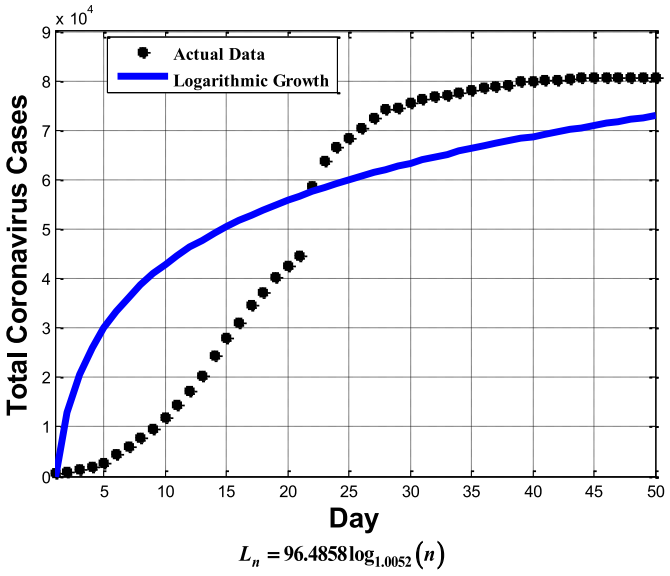

Fig. 6. Logarithmic growth model for COVID-19 in China.

spread of Coronavirus in three countries, namely China, KSA, and the USA. In the optimization process, one of the modern methods of evolutionary algorithms was used, which is the grasshopper optimization algorithm (GOA), because of their advantages. The optimization process worked to determine the parameters of the growth model by minimizing the sum of the square of the difference between the actual data for the spread of the virus during the first 50 days of emergence and the growth model. It was observed that the optimization method can determine the parameters of the mathematical growth model with precision. The mathematical growth model was also found to be influenced by the precautionary measures taken in each country. In China, strict measures limited the spread of the virus and change its nature of growth exponentially to its growth like logarithmic growth. While in both KSA and the USA, it was found that the precautionary measures followed did not affect the nature of the virus's growth. But people's commitment to these measures and their accurate implementation reduces the growth rate r of the virus, as it happened in the KSA. Finally, it can be said that social distancing and adhering to precautionary measures is the only way to limit the spread of the Coronavirus in its early appearance as

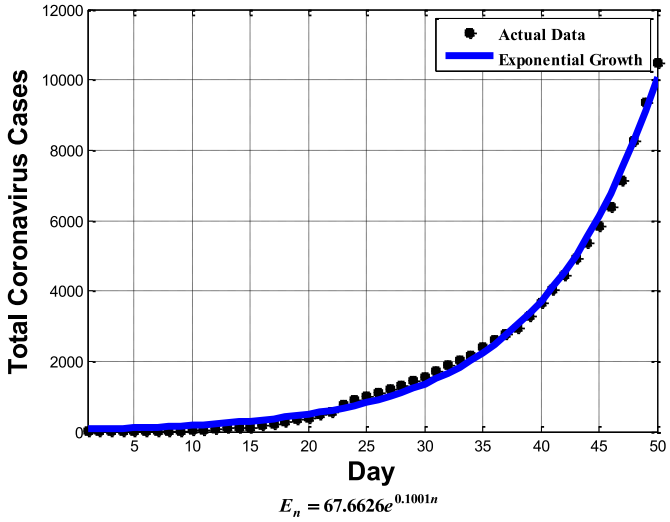

Fig. 7. Exponential growth model for COVID-19 in KSA.

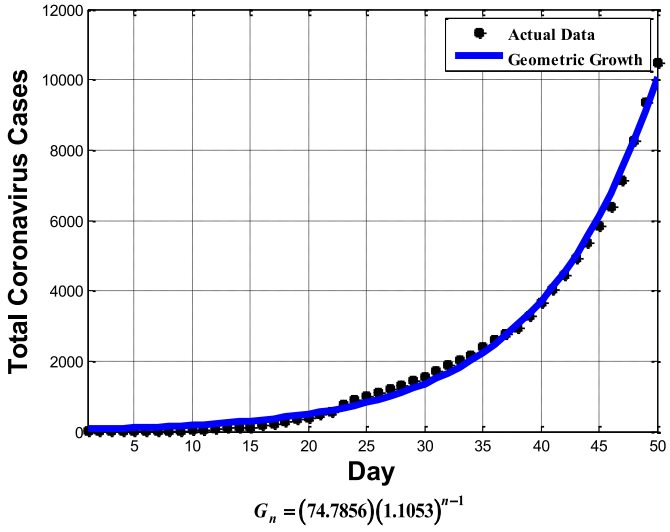

Fig. 8. Geometric growth model for COVID-19 in KSA.

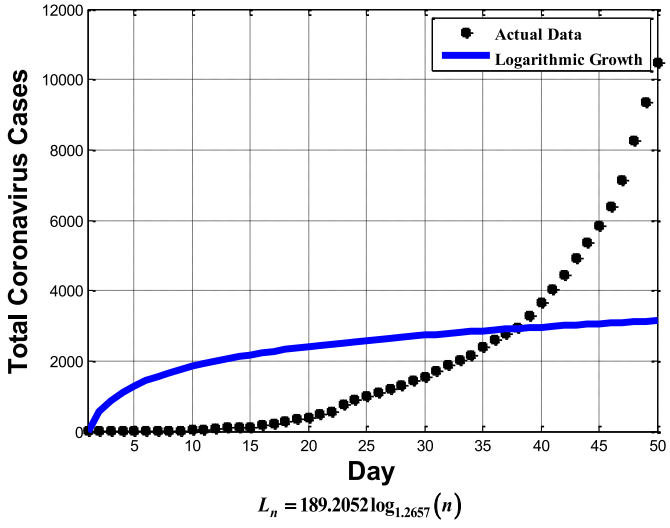

Fig. 9. Logarithmic growth model for COVID-19 in KSA.

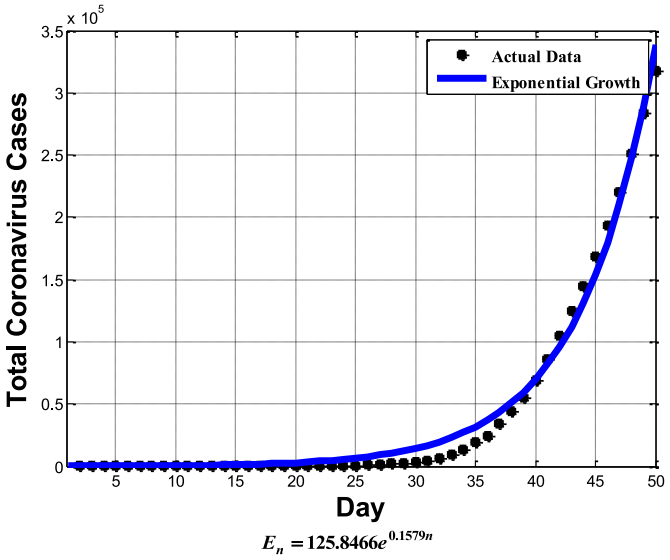

Fig. 10. Exponential growth model for COVID-19 in the USA.

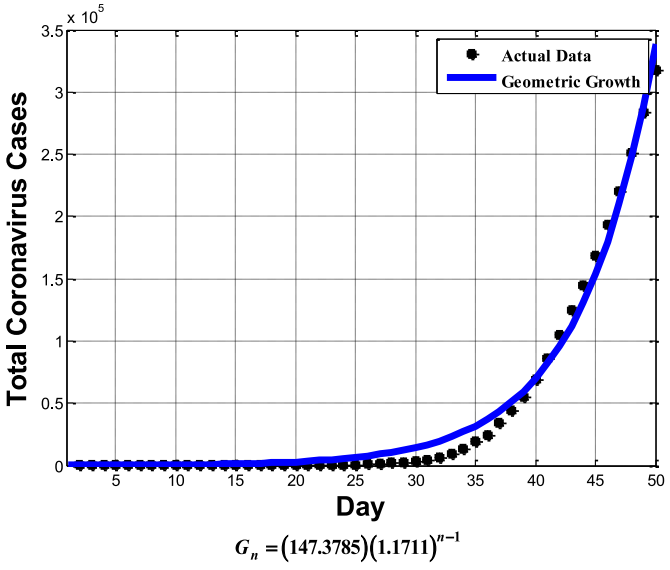

Fig. 11. Geometric growth model for COVID-19 in the USA.

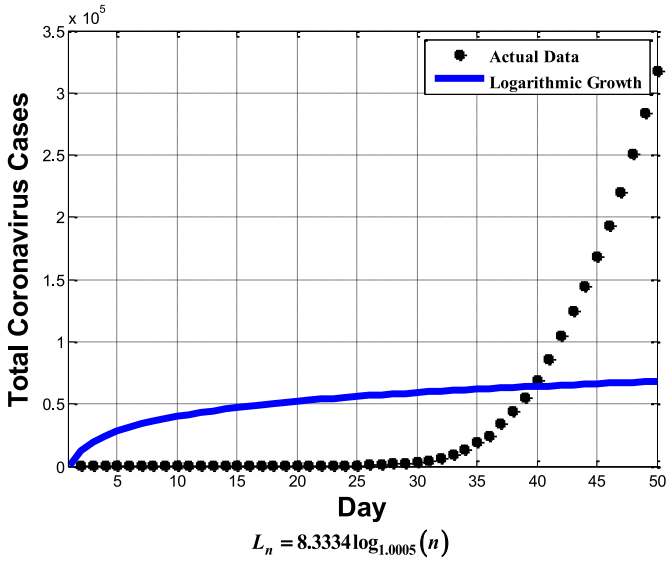

Fig. 12. Logarithmic growth model for COVID-19 in the USA.

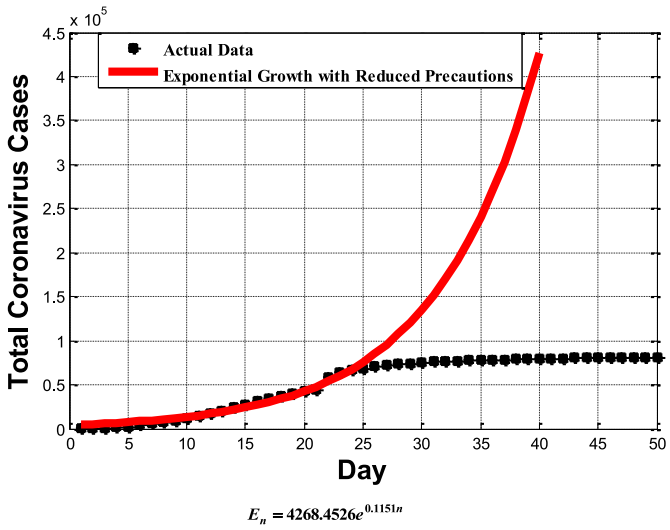

Fig. 13. COVID-19 exponential growth in China with reduced precaution.

shown in Fig. 14.

Finally, stringent preventative measures such as isolation and quarantine, prohibition of all meetings, and total curfews are the only way to prevent any epidemic from spreading considerably in the future, especially when no vaccinations have been discovered. In other words, in the absence of vaccines or public knowledge, any epidemic will continue to spread exponentially for several months if no efforts are taken to prevent its spread.

5. Conclusion

In this paper, the effect of precautionary measures on mathematical growth and the spread of epidemic COVID-19 has been studied. The study was applied to three countries; China, KSA, and the USA, during the first fifty days since the appearance of COVID-19. The reason for choosing to study this period is to determine what is the best move for countries to control the spread of infection before any vaccine appears or the presence of rumors that affect following the instructions and precautionary measures taken in each country. An optimization process is used to determine the parameters of the closest model that simulates the data during the specified period by using one of the evolutionary computation techniques, the grasshopper optimization algorithm (GOA). In China, it is found that the strict precautionary measures of applying isolation and quarantine, preventing all gatherings, and a total curfew led to the transition of the epidemic's development from the exponential model to its growth in a manner close to the logarithmic model. While it was found in KSA and the USA that COVID-19 grew exponentially like most epidemics during the first phase of the spread without taking strict precautionary measures. But, taking moderate precautionary measures and people's commitment to implementing them reduces the exponential growth rate of the epidemic, as happened in KSA, while not adhering to their implementation increases the growth rate of the epidemic, as happened in the USA. Finally, we can conclude that stringent precautionary measures are the only way to avoid the spread of the outbreak exponentially, whereas COVID-19 can continue to spread continuously for months without any measures to limit its rise.

The study's limitation is that this model can only be used at the beginning of a virus's manifestation when there are no vaccinations and no viral mutations. So, in future research, I will aim to consider the same

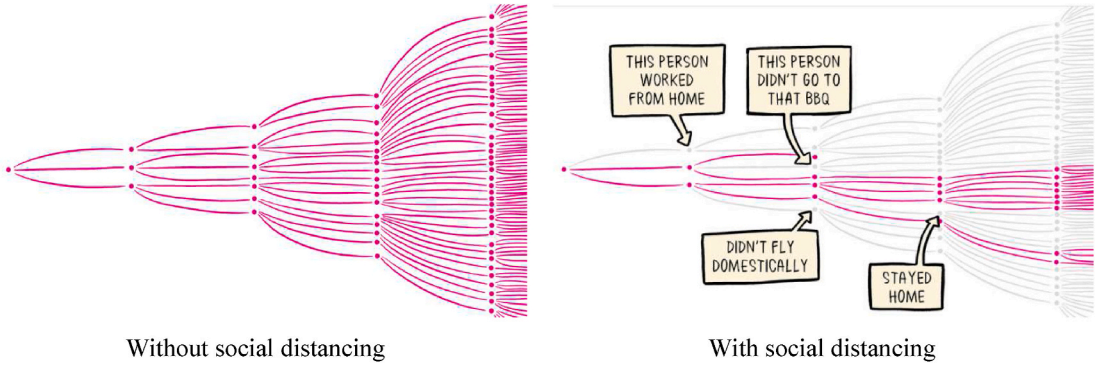

Fig. 14. Influence of social distancing on Coronavirus spread.

models with the presence of vaccines and take into account people's behaviors, fears, and the mutation of the virus. Furthermore, because the model for this study is general, it may be utilized and applied for any other disease spread from the beginning of its manifestation, without any additional factors.

Compliance with ethics requirements

This article does not contain any studies with human or animal subjects.

Acknowledgment

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