Prediction of the Epidemic Strength of COVID-19 in the Holy Places of Saudi Arabia during the Forthcoming Hajj Season 2020

Alheadary W¹, Azim MA^{2,3*}

¹Taibah University, Madina, Saudi Arabia

²University of Prince Mugrin, Madina, Saudi Arabia

³Beni-Suef University, Egypt

Corresponding Author: **Mohamed Mostafa A. Azim**

Address: Department of Computer Science, College of Computer and Cyber Sciences, University of Prince, Mugrin, Saudi Arabia; Email: m.zayed@upm.edu.sa; mmazim@ieee.org

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Abstract

The first outbreak of the COVID-19 epidemic in Saudi Arabia was reported on March 2nd, 2020. Every year more than 2 million people come from more than 188 countries to Saudi Arabia to perform pilgrimage (Hajj in Arabic). Therefore, extrapolating the epidemic strength during the Hajj season (end of July) in the holy places has become essential. In this paper, we employ the power of mathematical modeling to infer the epidemic intensity over a 300 days' time span in Saudi Arabia generally and the Holy places specifically. In particular, we obtain the following epidemiological insights such as the number of infections, the daily infection increase, the expected number of death cases, and the epidemic peak. Results indicate that, the epidemic peak has already been reached in both Makka and Madina. In addition, the number of infections will reach its saturation point by the first week of October 2020 as the daily increase in the number of infections will diminish. This means that, Hajj can be conducted safely only by reducing the number of pilgrims and providing suitable sets of preventive and precautionary measures.

Keywords

Coronavirus, COVID-19, Epidemic in Saudi Arabia

Introduction

The outbreak of novel coronavirus (COVID-19) disease was first reported in Wuhan City, China in December 2019. Since then, more than 2.7 million cases have been confirmed with more than 180,000 confirmed deaths worldwide [1]. Meanwhile, pathologists around the globe are working tirelessly to find a vaccine or treatment for the invading virus. Researchers are also working hard to model the virus spreading dynamics and developing mathematical

models to predict the spreading behaviour of the coronavirus. In [2], Toshikazu Kuniya employed the SEIR model to predict the epidemic peak of Coronavirus in Japan. The author found out that, an epidemic peak may reach the early-middle summer. Hiroshi Nishiura [3], studied the infection scenario of the novel coronavirus in on the Diamond Princess. He employed a back-calculation method to estimate the peak time of infection and the estimated number of infections on the ship. Zaho et al., [4] presented

estimates of the basic reproduction number, R_0 , of 2019-nCoV in the early phase of the outbreak of COVID-19 in Wuhan city, China. In this paper, we study the epidemiological situation in Saudi Arabia.

Every year more than 2 million people from more than 188 counties come to Saudi Arabia to perform pilgrimage (Hajj). Moreover, more than 5 million visitors come to perform Umrah. Saudi government spares no effort in seeking to provide them with all support to perform their worship in peace and tranquillity. Therefore, Originating from its keenness to protect the people's health and ensuring their safety, the Saudi Government has taken a stringent set of proactive measures [5] to help control the epidemic situation, including:

- Halting international entry for Umrah and tourism purposes
- Suspending Umrah for nationals and residents
- Suspending group prayers all at mosques
- Postponing Saudi Games
- Shutting land borders except for commercial trucks
- Suspension of all schools, universities and educational institutions
- Suspension of attendance at workplaces in all government agencies
- Closing all malls (except pharmacies and food supply stores)

- Banning of serving food and beverages in restaurants and cafes
- Imposing a 24-hour curfew on major cities.

Based on the Saudi Ministry of Health's statistics [6], even with such stringent precautionary measures adopted by the kingdom, the number of infections in Saudi Arabia is doubling every 6 days as shown in **Table-1**. However, this exponential growth in the total number of infected cases with COVID-19 has been reported by most of the world.

Pilgrimage is the world's largest annual public gathering that is held this year in the period from 29th July to 1st August. Due to the gigantic number of pilgrims assembled in Arafat (an area of approximately 20 km²), the possibility of spreading the virus becomes very high. Therefore, there is an urgent need to forecast the epidemiological situation in the Holy places. This certainly will help decision-makers to determine whether to suspend pilgrimage this year or it can be executed safely.

In this paper, we will extrapolate the epidemiological situation of the novel coronavirus in Saudi Arabia generally and in the Holy places (Makka and Madina cities) specifically. In particular, we use mathematical modeling to forecast the future number of infections, deaths, percentage increase in infection

Table-1: Weekly Number of Newly Reported COVID-19 Cases in Saudi Arabia [7]

Week No.	Number of Newly confirmed Cases per week	Accumulated Number of Cases
week 1 (2 Mar - 8 Mar)	11	11
week 2 (9 Mar - 15 Mar)	107	118
week 3 (16 Mar - 22 Mar)	392	510
week 4 (23 Mar - 29 Mar)	789	1299
week 5 (30 Mar - 5 Apr)	1,103	2402
week 6 (6 Apr - 12 Apr)	2532	4934
week 7 (13 Apr - 19 Apr)	5550	10484
week 8 (20 Apr - 26 Apr)	8327	18811
week 9 (27 Apr - 3 May)	9845	28656
week 10 (4 May - 10 May)	12358	41014
week 11 (11 May - 17 May)	16331	56835
week 12 (18 May - 24 May)	17450	74795

and death, and predict the epidemic peak of the coronavirus in the Holy places of Saudi Arabia. The rest of this paper is organized as follows. Section-2 presents the model employed in our experiment. Section-3 demonstrates our experimental results. Section-4 exhibits an interesting discussion about our results. Section-5 concludes the paper.

COVID-19 Model Used

Available datasets of COVID-19 show interesting behavior. It usually increases slowly at the beginning then, followed by a very fast increase. Finally, it began to show some sort of leveling off.

In order to model this behavior empirically, the functions must have the same behavior mentioned above. One of the functions that support this behavior is the hyperbolic tangent function given by the following equation [8].

$$N = a_1 \cdot \tanh \left[\frac{(t-a_2)}{a_3} \right] + a_4 \quad (1)$$

Where N is the number of cases, t is the time in days, and a_1 , a_2 , a_3 , and a_4 are the fitting parameters. The initial values of the fitting parameters are set to 1000, 10, 5, and 0 for a_1 , a_2 , a_3 , and a_4 , respectively.

Then, the rate of change in the number of cases (Q) can be calculated as:

$$Q = \frac{dN}{dt} = \frac{a_1}{a_3} \cdot \text{sech}^2 \left[\frac{(t-a_2)}{a_3} \right] \quad (2)$$

Then, the data are fitted to this equation using the Matlab nonlinear fitting facility. The results are shown in section-3.

Results

In this section, we first validate our model in Saudi Arabia. Then, we focus on investigating the epidemiological situation in the Holy cities (Makka and Madina).

Epidemiological situation in Saudi Arabia:

The first outbreak of the COVID-19 epidemic in Saudi Arabia was reported on March 2nd, 2020. Then a surge in the number of infections has been announced along the following weeks as indicated in **Table-1**.

Fig-1 demonstrates the actual data, fitted data, and extrapolated data of the total number of infections in Saudi Arabia. The result shown in **Fig-1** validates the accuracy of our model in estimating the number of infections by matching the actual data, curve-fitting equation, and extrapolated data. **Fig-1** also indicates

Fig-1: Total Number of Infections in Saudi Arabia

that, it is expected to have a saturated number of infections of 350,000 cases by day 250 (7th November).

estimating the number of death cases in Saudi Arabia as the fitted data and extrapolated data is very close to the actual data.

Fig-2 shows that, the used model is very clever in

Fig-2: Number of Death Cases in Saudi Arabia.

Fig-3: Total Number of Infections in Saudi Arabia.

Fig-3 presents the actual mortality rate in Saudi Arabia. The results depicted in **Fig-3** indicate that, the peak mortality rate has been passed on day 36 (April 7th). However, **Fig-3** indicates clearly that, there is a second wave of coronavirus infections in Saudi Arabia that started after day 85 (26th May). It is also notable that, the rate of increase in the mortality rate of the

second wave is significantly lower than that of the first wave.

Epidemiological analysis in Makka and Madina:

In this section, we investigate the epidemiological situation in Makka and Madina cities in terms of the total number of infections, daily infection increase, the

Fig-4: Daily infection increase in Makka.

Fig-5: Daily infection increase in Madina.

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Number of Death Cases, and the mortality rate. Note that, the first infected case was reported on March 10th and March 20th for Makka and Madina, respectively. The period of our analysis is 300 days since March 2nd, 2020.

Fig-4 and **Fig-5** show the total number of infections in Makka and Madina, respectively. The result depicted

in these figures indicates that, the total number of infections will continue increasing until it levels off after 150 days (from the first outbreak) in Makka (August 7th) and (from the first outbreak) in Madina (August 17th). It is worth noting that, the expected total number of infections is 28,000 and 16,500 in Makka and Madina, respectively.

Fig-6: Daily infection increase in Makka.

Fig-7: Daily infection increase in Madina.

Fig-6 and **Fig-7** demonstrate the mortality rate in Makka and Madina, respectively. The mortality rate is defined as the number of death cases relative to the number of confirmed cases in a given day [9]. The mortality rate plot shown in **Fig-6** indicates that, the mortality rate is made not stable yet and passing through the second wave of coronavirus infection. However, the good news is that, the reported maximum mortality rate in Makka is below 2% which is in a safe margin compared to the global mortality rates (4.3% to 11%) as reported in [10-12]. On the other hand, the mortality rate plot shown in **Fig-7** confirms that, the situation in Madina is far better than that in Makka as the mortality rate in Madina is converging to zero.

Fig-8 and **Fig-9** show the daily infection increase in Makka and Madina, respectively. The Results in **Fig-8** and **Fig-9** indicate that, the fitted daily infection increase of coronavirus in Makka and Madina is very similar as they begin with an exponential increase up to a peak point after which the increase in the daily infections starts falling down.

Fig-8 and **Fig-9** indicate also that, the daily infection increase has already passed its epidemic peak value in both Makka after 75 days (24th May) and Madina after 70 days (29th May) and it is expected to continue falling down up to zero by day 200 in both Makka (26th September) and Madina (6th October). It is also notable that, the value of the daily infection increase in Makka is significantly higher than that in Madina. For example, on day 100, the infection increase rates are 275 and 103 in Makka and Madina, respectively.

The result shown in **Fig-10** presents that, the number of death cases in Makka starts increasing linearly from day 50 and it is expected to continue up to day 150 (7th August) and then it levels off at day 200 (26th September) with 600 death cases. On the other hand, **Fig-11** depicts that, the expected behavior of the number of death cases in Madina is increasing with the increase in time. However, the rate of increase in the number of death cases is sharply higher in Makka than that in Madina. For example, on day 100, the number of death cases in Makka is 330 while in Madina is 100 death cases. Most notable that, the number of death cases will continue increasing in Makka until it levels

Fig-8: Daily infection increase in Makka.

off after day 200 (26th September). However, the reason behind the excess of the number of death cases in Makka than that in Madina needs an elaborate

study as it requires further investigations and it is behind the scope of this paper.

Fig-9: Daily infection increase in Madina.

Fig-10: Number of Death Cases in Makka.

Fig-11: Number of Death Cases in Madina.

Discussion

Based on the results depicted in section-3, we can extrapolate the following:

- The total number of infections will saturate after (August 7th) in Makka and after (August 17th) in Madina.
- The expected increase in daily infections will diminish after 200 days (26th September) at maximum in Makka and (6th October) in Madina.
- The epidemic peak of the infection increase has already been passed in both of Makka and Madina (19th May) and it is expected to diminish in Makka by (26th September) and Madina by (6th October).
- The expected impact of the coronavirus after 300 days from its outbreak is the loss of life for 600 people in each of Makka and Madina. However, by quarantine, personal cleaning, and social distancing, these numbers can be further reduced. Note that, due to the lack of detailed mortality information numbers in both Holy cities, the actual figures may vary from the expected ones.

Based on our analysis that spans 300 days from the first outbreak of the virus (up to 4 January 2021), we conclude that, the coronavirus epidemic will diminish by the first week of October 2020 in Makka and Madina. However, more than 70% of the epidemic strength has passed. This means that Pilgrimage can be executed safely this year (by the end of July) given that suitable preventive and precautionary measures are applied while reducing the number of pilgrims.

Conclusions

The Holy places of Saudi Arabia are expected to receive more than 2 million people by the end of July 2020 for performing pilgrimage. Such assembly may be catastrophic if the coronavirus is still spreading in the Holy places. Therefore, we are in an urgent need for studies that forecast the epidemiological situation. In this paper, we introduced using a mathematical model that depends on the hyperbolic tangent function for extrapolating the epidemic; results indicate that both Makka and Madina will be free of the epidemic by the first week of October. By now, only 70% of the epidemic strength has passed. Therefore, executing hajj with traditional numbers of pilgrims could be

catastrophic. So, by reducing the number of Pilgrims and employing a suitable set of preventive and precautionary measures, pilgrimage can be conducted safely.

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