Preliminary Evaluation of Global Mass Gatherings Suspension in Saudi Arabia during the COVID-19 Pandemic

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Abstract. Since the early days of the coronavirus (COVID-19) outbreak in Wuhan, China, Saudi Arabia started to implement several preventative measures starting with imposing a travel restriction to and from China. Due to the rapid spread of COVID-19, and with the first confirmed COVID-19 case in Saudi Arabia, further strict measures, such as international travel restriction, and suspension or cancellation of major events, social gatherings, prayers at mosques, and sports competitions, were employed. These non-pharmaceutical interventions aim to reduce the extent of the epidemic due to implications of international travel and mass gatherings on the increase in the number of new cases locally and globally. Since this ongoing outbreak is the first of its kind in the modern world, the impact of suspension mass gatherings on the outbreak is unknown and difficult to measure. We use a stratified SEIR epidemic model to evaluate the impact of Umrah, a global Muslim pilgrimage to Mecca, on the spread of the COVID-19 pandemic by considering several scenarios during the peak Umrah season. The analyses shown in the paper provide insights into the effects of global mass gatherings such as Hajj and Umrah on the progression of the COVID-19 pandemic locally and globally.

Keywords: Infectious diseases · Coronavirus · COVID-19 · Mass gatherings · Umrah · Hajj Travel restriction · Epidemic modeling · SEIR model.

1 Introduction

A novel Coronavirus disease, COVID-19, emerged in Wuhan, China on December 2019. By early 2020, the COVID-19 infections were exported to various countries outside China, including Singapore, Japan, South Korea, Australia, and Germany via international travel [9]. Since then, many countries enforced travel restrictions to and from China to prevent the spread of the virus across the world [10]. However, by March 11, 2020, the World Health Organization (WHO) declared the COVID-19 outbreak as a pandemic [16]. In the early stages of the pandemic, affected countries have responded to the increasing number of COVID-19 confirmed cases by implementing several preventive measures to control the spread of the disease. These measures include travel restriction, isolation of infected populations, quarantine of suspected cases, cancellation of major events, school closure, and public lockdown [3, 4, 8].

While the first travel-related case of COVID-19 in Saudi Arabia was reported on March 2, 2020, traveling to or from China was restricted by the Saudi government on February 6, 2020. Further travel restrictions were issued against several affected countries including Italy, France, Germany, Turkey, and Spain as the COVID-19 outbreak extended outside China affecting several regions across the world. Due to the extensive spread of the disease worldwide, Saudi Arabia decided to suspend the Umrah pilgrimage to Mecca for both international and domestic pilgrims on February 27, 2020.

The two global religious pilgrimages to the holy cities of Mecca and Madinah, Hajj and Umrah, attract millions of Muslims from inside and outside Saudi Arabia. While Hajj, the largest annual international gathering in the world, lasts for a few days during the last month of the Islamic calendar, Umrah, a limited version of Hajj in terms of rituals, can be performed multiple times at any time of the year. According to the Saudi General Authority for Statistics (GSTAT), 2,489,406 pilgrims completed Hajj with 1,855,027 international participants, and 19,158,031 pilgrims performed Umrah throughout the year with 7,457,663 pilgrims arriving from outside Saudi Arabia in 2019. Such mass gatherings can pose a significant threat for further spread of COVID-19 to Saudi Arabia and the home countries of the returning participants.

The risk of disease transmission in mass gatherings (MGs) is associated with the social mixing of a large number of people in confined settings for extended periods of time. In times of pandemics, such as H1N1 pandemic in 2009 [7] and the ongoing COVID-19 pandemic[8], international travel caused by global MGs can contribute to importing and exporting infections across multiple regions in the world in a short time [2]. Due to the increasing health risks associated with MGs, the WHO is working directly with host countries and organizers of these events for effective preparedness and response planning during the ongoing COVID-19 pandemic [17]. Various public health measures, including vaccination requirements, screening at entry points, and event size restriction, can be implemented to contain the spread of diseases at MGs [14]. However, canceling or postponing MGs is a recommended countermeasure to contain the COVID-19 pandemic due to the absence of an approved vaccine for the disease [1, 6].

To study the impact of suspending the Umrah pilgrimage on the trajectory of COVID-19, we propose a stratified population SEIR (Susceptible-Exposed-Infected-Removed) deterministic mathematical model to simulate the transmission of COVID-19 during Umrah pilgrimage among the different groups of pilgrims and the local residents in Mecca. We execute several epidemic scenarios during the holy month of Ramadan on a daily basis. The model was calibrated using the expected international and domestic pilgrims and the daily reported number of COVID-19 cases in Saudi Arabia.

2 Data and Methods

2.1 Umrah Data

The Umrah season starts approximately one month after Hajj and stays open until two to three weeks after the month of Ramadan, for almost 9 to 10 months. Based on collected data, the peak period of the Umrah season is during the month of Ramadan, the 9$^{\text{th}}$ month of the Islamic year, with 40-43% of the total pilgrims performing Umrah during this month. Like Hajj, during their visit, international pilgrims are allowed to visit the holy city of Madinah. While the rituals of Umrah can be performed in less than two hours, international and domestic pilgrims can stay in Mecca for a period of one day up to three weeks. Detailed Umrah data was obtained from GSTAT for the past four Umrah seasons, between 2016 and 2019. We used the average number of domestic and international pilgrims for the past four Umrah seasons during the month of Ramadan to estimate the expected number of participants in the 2020 Umrah season.

2.2 Saudi COVID-19 Situation Data

With the first confirmed COVID-19 case reported in Saudi Arabia on March 2, 2020, the number of confirmed cases gradually moved to over 1000 new COVID-19 cases within a month. The cumulative number of COVID-19 cases, reported by the 5^{th} of August in Saudi Arabia, reached 284,227 cases, including 34,083 active cases, 3,056 deaths attributed to COVID-19, and a total of 247,088 recoveries. Out of these reported numbers, Mecca has observed 29,319 confirmed cases representing 10.32% of the total confirmed cases in Saudi Arabia. The number of deaths in Mecca reached 540 cases, to be the second highest city in Saudi Arabia.

On February 6, 2020, the Saudi government made the first decision in response to the COVID-19 outbreak in China by banning travel to and from China. As the disease continues to rapidly spread across the world, more intensive non-pharmaceutical measures were implemented, such as border closure, cities lockdown, and full curfew nationwide. These public health interventions enforced by the Saudi government to ensure the safety of the citizens and residents in Saudi Arabia. By international travel restrictions, suspension of Umrah, and restricting the 2020 Hajj season to a limited number of domestic pilgrims, the Saudi government made courageous decisions to contain the global threat of COVID-19, and prevent importing the disease to the country, or causing further spread across the world. Figure 1 shows the daily updates of the number of COVID-19 cases from the start date of the ongoing COVID-19 epidemic in Saudi Arabia, March 2, 2020, until end of July 2020, illustrating the timeline of implementing and lifting some of the major prevention measures.

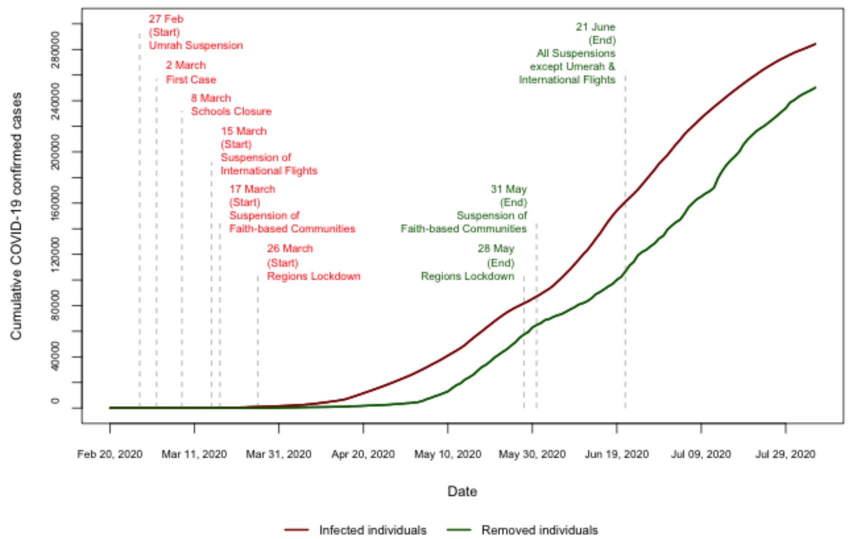

Fig. 1: Daily updates of number of case throughout the COVID-19 epidemic (3/2/2020-8/2/2020) in Saudi Arabia, and the immediate response of Saudi government, showing when the measure was implemented (red) and when it was lifted (green).

2.3 Methodology

To evaluate the implications of the suspension of the Umrah global mass gathering in Mecca, we used the mathematical SEIR model. In the SEIR epidemic model, the underlying population is categorized into four compartments based on the infectious status of individuals. Here, the state variables at time t are: $\mathbf{S}(\mathbf{t})$, the number of susceptible individuals who have not got the disease but can be infected, $\mathbf{E}(\mathbf{t})$, the number of exposed individuals who were infected by the disease but still not infectious, $\mathbf{I}(\mathbf{t})$, the number of infectious individuals who become infectious and able to transmit the disease to other susceptible individuals, and $\mathbf{R}(\mathbf{t})$ which reflects the removed individuals and has no role in the progress of the disease transmission in the population. To model COVID-19 spread, we moved into the removed compartment individuals who are completely recovered, isolated either self-isolated or by public health officials, or died from the complications of the disease. We did not assume acquiring permanent immunity to

COVID-19 due to the conflict reports about recurrent COVID-19 infection after recovery. Individuals are assumed to stay in exposed and infectious states throughout the whole incubation and infectious periods respectively.

We implemented two versions of the model, assuming: (1) a homogeneous population, and (2) a stratified population. In both models, the population is assumed to be static, where dynamic factors like immigration, emigration, deaths and births are not taken into account. So that $S(t) + E(t) + I(t) + R(t) = N$, where N is the population size. The homogeneous SEIR model is described as follows:

$$\begin{aligned}
\frac{dS}{dt} &= -\beta S(t)\frac{I(t)}{N} \\
\frac{dE}{dt} &= \beta S(t)\frac{I(t)}{N} - \sigma E(t) \\
\frac{dI}{dt} &= \sigma E(t) - \gamma I(t) \\
\frac{dR}{dt} &= \gamma I(t),
\end{aligned}$$

where, β is the transmission rate that measures the chances of transmitting the disease when an infected and a susceptible individuals come in contact. This transmission rate is defined as the product of the average contact rate and the transmission probability. The duration of the incubation period and infectious period are denoted by $1/\sigma$ and $1/\gamma$, respectively. To study the impact of the diversity among the population of pilgrims and residents in Mecca during Umrah, we stratified the population in Mecca during the month of Ramadan into three sub-populations: international pilgrims, domestic pilgrims, and local residents. The stratified SEIR model can be described as follows:

$$\begin{aligned}
\frac{dS_i}{dt} &= -\sum_{j=1}^{k} \beta_{ij} S_i(t)\frac{I_j(t)}{N_j} \\
\frac{dE_i}{dt} &= \sum_{j=1}^{k} \beta_{ij} S_i(t)\frac{I_j(t)}{N_j} - \sigma E_i(t) \\
\frac{dI_i}{dt} &= \sigma E_i(t) - \gamma I_i(t) \\
\frac{dR_i}{dt} &= \gamma I_i(t)
\end{aligned}$$

In the stratified SEIR epidemic model, β_{ij} is the transmission rate from population i to population j. We assumed in this stratified model that susceptible individuals in any sub-population can be infected by an infectious individual from any sub-population including within the same sub-population. Therefore, β_{ij} in this model represents the adjusted transmission rate from group i to group

j. The constant transmission rate is adjusted by a contact factor C_{ij} that controls the number of contacts between the two sub-populations i and j. Specifically, we differentiated the interactions among the different sub-populations with a higher contact rate (65%-75%) within a group and a lower number of contacts (25%-35%) directed to susceptible individuals in other groups.

The infection-related parameters for both SEIR models were inferred from published reports and studies about COVID-19 epidemiology [13]. We assumed the incubation period to be 5 days ($\sigma = 0.2$) and the infectious period to be 11.5 days ($\gamma = 0.087$) long. Since preforming Umrah and praying inside the Grand holy mosque in Mecca is the main purpose of international and domestic visitors arriving in Mecca, the contact rate was estimated in the range of 7-10 based on previous studies tracking the movements of pilgrims at the grand mosque [5].

The reported values of the basic reproduction number,R_0, for COVID-19 (R_0 = 2.3-3.0 [12]) can be used to infer the transmission probability of the disease based on the relation between R_0 and the transmission rate where $R_0 = \beta/\gamma$. However, reported R_0 values were calculated based on COVID-19 contact tracing data obtained in specific settings. The severity of the COVID-19 pandemic and the growing numbers of new cases around the world, suggests high transmission rates for studying the spread of the disease in mass gatherings. Therefore, we assumed the transmission rate β to vary in a range of 0.2 to 0.7 with a constant contact rate and varied values of disease transmissibility. These values of β resulted in a variation in the corresponding values of R_0 to range from 2.3 to 8.05.

3 Results

We executed several epidemic scenarios to study the impact of Umrah during the month of Ramadan by simulating the SEIR model for 30 days from the start day of Ramadan (April 23, 2020). First, we tested the assumption of homogeneous population (10,127,944 individuals) in Mecca without applying any interventions, or restrictions on the movements of individuals, or on the number of the international or domestic pilgrims. Then, we examined the stratified version of the SEIR model assuming heterogeneous interactions among the different sub-populations of pilgrims (952,495 international and 7,133,343 domestic pilgrim) and the residents in Mecca (2,042,106 individuals). We used data on confirmed cases in Saudi Arabia prior to the start date of Ramadan to initialize the COVID-19 outbreak in Mecca. We assumed that the Saudi government imposes a visa restriction for international pilgrims to provide a COVID-19 PCR negative certificate. Hence, the infected individuals in the population are limited to domestic pilgrims and residents of Mecca.

Using the homogeneous SEIR model, we executed several simulations of the COVID-19 epidemic with different transmission rates. As shown in Figure 2, our simulation of the spread of COVID-19 in Mecca using homogeneous mixing without any interventions predicted an increasing cumulative number of cases, including infectious and removed individuals, from 66,372 case (Figure 2: A) to

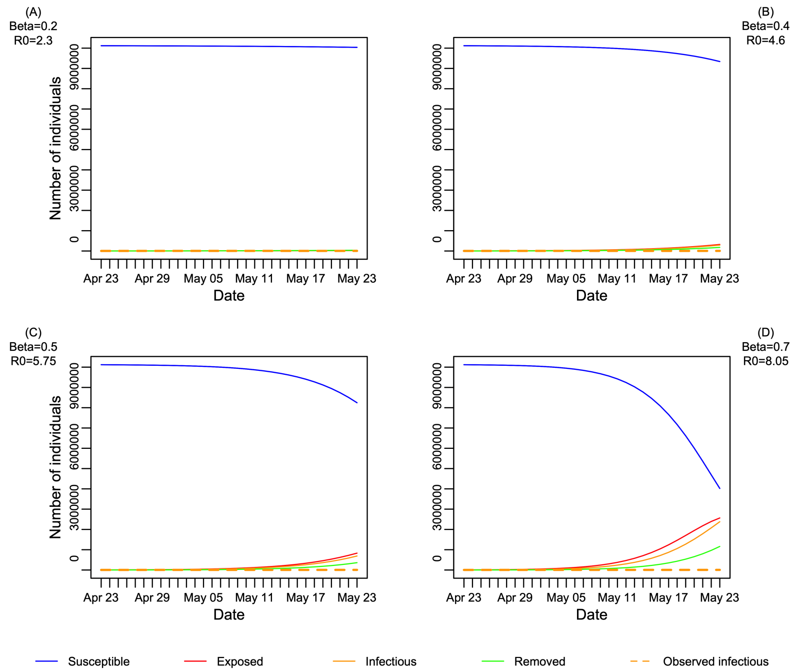

Fig. 2: Estimated total number of infected individuals using the homogeneous SEIR model with different values of β during the month of Ramadan in Umrah season without interventions.

3,542,159 case (Figure 2: D) by the end of Ramadan. For more analysis of the impact of the heterogeneous interactions between the Umrah pilgrims and residents in Mecca, we simulated several COVID-19 epidemic scenarios using the stratified SEIR model applying the same sensitivity analysis of the transmission rate in the homogeneous SEIR model. However, as we considered a heterogeneous contact rate C_{ij} among individuals in the different sub-populations, we scaled the value of β by the maximum eigenvalue of the normalized contact matrix [11]. Figure 3 shows the epidemic curves for each sub-populations under the different values of β. As shown in the figure, the three sub-populations showed similar trends in their epidemic curves, which can be due to the similar distribution of contact rates between sub-populations. While we introduced the heterogeneity between the different sub-populations, we maintained homogeneous mixing within the same sub-population.

Results shown in Figure 3 illustrate the effect of interactions among the different sub-populations of domestic pilgrims, international pilgrims, and residents on the disease spread among residents of Mecca. The simulation showed higher estimated cumulative cases compared to the observed COVID-19 cases in Mecca with the suspension of Umrah during the month of Ramadan. The predicted total number of infected individuals among the residents of Mecca increased from 22,951 (1.12%) to 826,285 (40.46%) when using $\beta = 0.2$ and $\beta = 0.7$, respectively. As expected the simulation of the outbreak during Umrah estimated much higher cases than the reported cases of 14,132 (0.69%) individuals in Mecca. By the end of the epidemic simulation, the estimated number of infected (infectious and exposed) domestic pilgrims ranged from 42,612 (0.60%) to 3,736,758 (52.38%). The simulation predicted total number of infected international pilgrims going back to their home countries with the disease ranged from 5,351 (0.56%) to 498,511 (52.34%). We can assume, based on the obtained results, that lower values of the transmission rate can represent the best-case scenario, and the higher values represent the worst-case scenario of the disease spread during Umrah in Mecca. These numbers reflect a significant impact of Umrah on further spread of the disease across multiple regions in the world. As by May 23, 2020 (End date of Ramadan), a total of 5,103,006 new COVID-19 cases reported by WHO [15] which can be increased by a potential 498,511 new cases related to Umrah. However, since the population of international pilgrims are not stratified further based on country of origin or region, simulation of extended agent-based SEIR model is needed to explore the disease spread at regional and global levels.

4 Conclusion

Modeling the COVID-19 epidemic during Umrah, a global religious gathering in Saudi Arabia reveals important insights into the effectiveness of the suspension of mass gatherings during the spread of highly contagious diseases. The results suggested that the suspension of Umrah prevented an increase in the number of international and local COVID-19 cases compared to preforming Umrah without isolation of infected pilgrims, or any restrictions in terms of the size of the pilgrims' population and social distancing. Early decisions of suspending global mass gatherings, limiting the number of attendees, or restricting the participation to a specific population or group, are recommended during the spread of infectious diseases. Several factors, including the timing of implementing these measures, the size and type of the gathering, and the demographics of the expected attendees, need to be taken into account in future modeling of the COVID-19 outbreak to evaluate the potential effectiveness of any public intervention on mass gatherings. Mathematical epidemic models can provide a preliminary assessment of the implications of mass gatherings in times of epidemics. Further development of the methodology described in this study can be explored using stochastic agent-based models to simulate the COVID-19 pandemic in mass gatherings for effective evaluation of the impact of these settings at an individual level. Agent-based epidemic modeling can include detailed attributes about the participating population and provide an estimation of the optimal size in these gatherings to ensure social distancing and control the spread of the disease during the event.

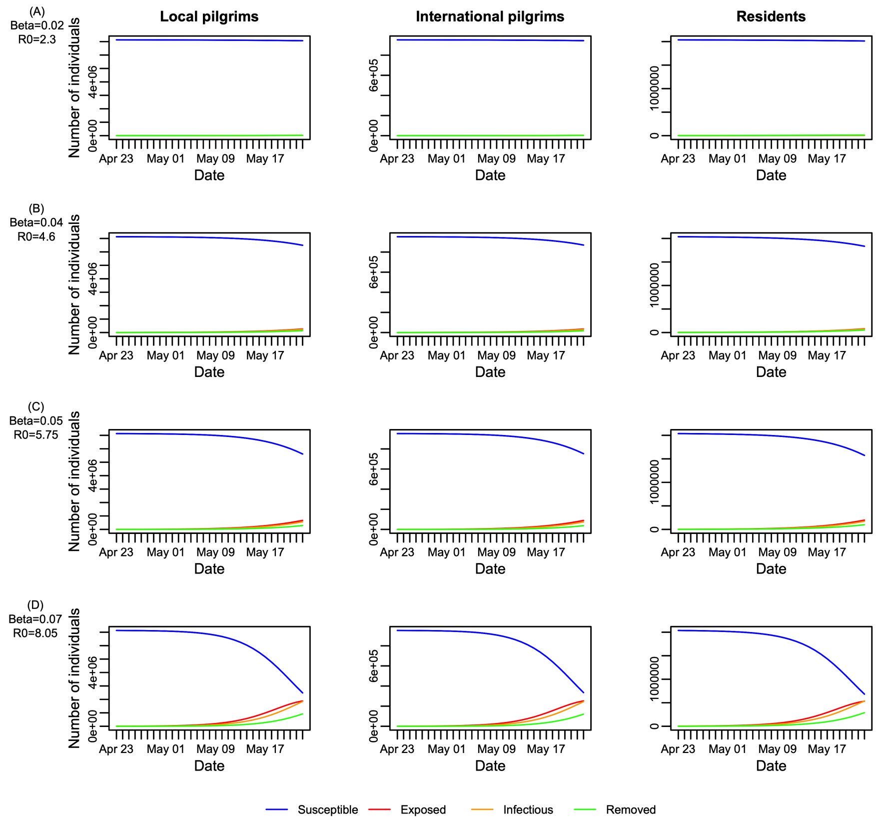

Fig. 3: Predicted total number of infected individuals using the stratified SEIR model with different values of β during the month of Ramadan in Umrah season without interventions.

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