Original Article

Is there Hope for the Hajj? Using the SIR Model to Forecast COVID-19 Progression in the City of Makkah

Alaa mujallad[1], Haitham khoj[2]

[1] *Department of Nursing, College of Applied Medical Sciences University of Jeddah, Jeddah, Saudi Arabia.*
[2] *Department of Economics, collage of Business and Economics, King Abdulaziz University, Jeddah, Saudi Arabia.*

Abstract - The Hajj is the largest annual gathering in the world and is a very important event for every Muslim. Makkah annually receives three million pilgrims who perform Hajj. Although precautionary measures have been taken in Saudi Arabia to slow down the spread of COVID-19, such as locking down the most affected cities, practicing social distancing, and applying infection-control precautions, the number of cases has increased. The total confirmed number of cases in Makkah was 10,709, with 127 deaths as of May 16, 2020.

Forecasting the COVID-19 progression in the city of Makkah will help policymakers decide if the Hajj will be able to operate this year. Thus, to see a clear picture of the fight against COVID-19 for the economy and healthcare industry in Saudi Arabia, specifically in Makkah, the SIR model will predict COVID-19 progression in the city of Makkah. The Susceptible, Infected, and Recovered (SIR) model has been used to track the transmission dynamics and growth in the city of Makkah. The growth index was calculated according to the data from March 16 until May 9. The estimated vital epidemiological parameters were done, such as forecasting works and transmission rates.

The data showed an interesting result about the peak of the disease progression. It is projected to occur around the 12th day after running the model. According to the model, the peak time will be around the 22nd of May. Then, the number of cases will start to decrease.

Using the SIR model, the result predicts the disease progression peak and an estimated end of COVID-19 in the city of Makkah to help policymakers decide if the Hajj will be able to operate this year.

Keywords - COVID-19, SIR Model, Makkah, Saudi Arabia, Economics, Healthcare, Nursing.

1. Introduction

Uncertainty about COVID-19 leaves people are wondering about returning to their normal lives. Social distancing affects family gatherings and religious rituals. Mosques in Saudi Arabia have been closed to reduce the spread of COVID-19. In Saudi Arabia, Makkah hosts the world's largest annual Muslim ritual gathering, the Hajj. Muslims are waiting for this holy gathering with the hope that they can perform the Hajj, which will be around August 22nd, 2020. Forecasting the disease progression in the city of Makkah will help the policymakers to decide if the Hajj will be able to operate this year. Thus, to see a clear picture of the fight against COVID-19 for the economy and healthcare industry in Saudi Arabia, specifically in Makkah, the SIR model will predict COVID-19 progression in the city of Makkah.

Makkah is considered one of the holiest cities in Islam. Approximately eight in ten people around the world follow a religious group. Muslims are considered the second largest religious group worldwide after Christianity. There are 1.6 billion Muslims around the world 1. From the Muslims' perspective, life's purpose is worshipping God, following the Quran, and being completely devoted to God. Muslims follow two sources in their practical living, the Quran and Sunnah, the practice and sayings of Prophet Mohammad. There are Five Pillars in Islam that all Muslims are obligated to follow. The Five Pillars are: the confession that Allah is the only God and Mohammad is the prophet from God (Shahadah), five prayers at certain times every day, fasting one month in a year (Ramadan Month), practicing charity towards the less fortunate (Zakkat), and a pilgrimage to Makkah (Hajj) 2.

Among the five pillars, one pillar requires Muslims to travel to the city of Makkah for the Hajj. The Hajj is the largest annual gathering in the world and is a very important event for every Muslim. Makkah annually receives three million pilgrims who perform Hajj 3. The duration of the

Hajj is around 7 to 14 days and involves a walking pilgrimage between some areas in Makkah. Thus, the Hajj season impacts the growing Makkah population because some pilgrims stay illegally in Saudi Arabia and may work 4.

Makkah's population is 2,042,000, without counting a large number of undocumented residents 5. Since the discovery of oil in Saudi Arabia, general development has increased around 1960. Then, Saudi Arabia has become an attractive country in which to live. The Saudi way of life has adopted higher standards to boost the economy; the Saudi cities developed, and new jobs opened. Although Saudi Arabia has a strong economy, it suffers from a local workforce shortage. Due to the economic difficulties in some Arab and South East Asian countries, Saudi Arabia has been the best country to immigrate to work in for the last two decades 6.

Historically, pilgrims who came to Makkah brought many diseases, such as cholera, plaque, and smallpox, frequently occurring in overcrowded places. The holy places are frequently packed with people. That's why epidemics happen many times. In the nineteenth century, Makkah became the station of cholera between Bangal and Egypt. Cholera arrived in Makkah from countries with cholera pandemics, such as Java and Singapore, and it killed 15,000 people out of 90,000. The effects- of cholera traveled with pilgrims to their own countries, causing 60,000 deaths in Egypt 7. Due to the disease that travelled with the pilgrims, Saudi Arabia's health officials issued visa requirements for entry for Hajj and Umrah. The requirements include vaccination against pandemic influenza A (H1N1), yellow fever, bubonic plaque, meningococcal meningitis, and poliomyelitis 8. Applying these requirements reduced the spread of diseases among the pilgrims. However, COVID-19 has no approved treatment and vaccination to prevent its spreading 9.

Containing COVID-19 is not easy across Saudi Arabia, especially in the city of Makkah, due to the undocumented immigrants who have been living there for decades. Undocumented immigrants in Saudi Arabia are categorized into four groups. The first group came for Hajj, or Umrah, and extended their stay in Makkah without permission. The second group came for a working visa and stayed longer after violating their work contract. Third are the people who were smuggled from neighboring countries such as Yemen. The fourth group is children born from illegal immigrants; their status in Saudi Araba was considered illegal 10.

The government's actions effectively prevented the spread of the disease among those who violated their stay in Saudi Arabia. The Saudi government announced that all undocumented immigrants would be screened for COVID-19 and provided the treatment they needed for free without asking about their length of stay. Moreover, the health officials targeted the areas with high numbers of undocumented immigrants to test the largest amount of people there. Makkah now has the most COVID-19 patients among the Saudi cities, but with these actions from the government, the number is expected to go down by 11.

COVID-19 is highly contagious, which means it can spread very fast. The total confirmed cases in Saudi Arabia is 52,016, with 302 deaths (WHO) as of May 16, 2020. Although precautionary measures have been taken in Saudi Arabia, such as locking down the most affected cities, practicing social distancing, and applying infection control precautions (MOH), the number of cases has increased. The total confirmed cases in Makkah is 10,709, with 127 deaths (MOH).

Investigating various epidemic models, the main purpose is to understand the mechanism of disease progression. There are many forecasting models, and the SIR model is one of the models that have a proven history of predicting many infectious diseases. Susceptible, Infected, and Recovered (SIR) is a frequently used model that tracks the transmission dynamics and growth amongst the population. The SIR model estimates vital epidemiological parameters, such as forecasting works and transmission rates 12. It supports using a mathematical procedure that has dealt with various infectious diseases and applying it to COVID-19 to have an evidence basis for forecasting.

2. Materials and Methods

Based on the nature of COVID-19 and the characteristic of the virus, SARS-CoV-2, that causes the disease, a SIR model is a good fit to forecast the end period of COVID-19. The growth index will be calculated according to the data from March 16 until May 9. Susceptible, Infected, and Recovered are the main state variables of the model. The susceptible will be the whole population of the city of Makkah because this disease is highly contagious, closer to 2000000. This data was taken from an authoritative source (Ministry of health). The infected and the recovered are secondary data taken from (The Ministry of health).

Kermack and Mckendrick first introduced the SIR model (1927) 13, where they have three components susceptible, infected, and recovered as the disease spread. In our study, we employ a SIR model to predict the peaks of cases before they decrease over time. The importance of our study is to give a prediction to all Muslims worldwide whether they can complete one of the five pillars of Islam (Hajj). Additionally, according to the Ministry of Tourism, 75% of hotel rooms are in Makkah and Medina, which economically negatively impacts the tourism sectors and increases the unemployment rate. However, a study found it is cost-efficient to lock down travel during a flu pandemic if the death rate is high or above average 14. Today, the number of cases in Makkah is still

increasing at a sustainable rate because of the preventive measure that health officials are taking to control the spread of the virus. While everyone is hoping to end COVID-19 or at least control the number of cases, it's important to forecast and predict the length of time to lessen the lockdown and open gradually. So, a population of N   in our study was divided into (S) susceptible, (I) infected, and (R) recovered

where: N = S +I + R   (1)

So, where rewrite it as a function of time as follows:
S = S(t) number of susceptible individuals over time,
I = I(t) number of infected individuals over time, and
R = R(t) number of recovered individuals over time.

Thus, Susceptible differential equation

$$dS/dt= -\beta s(t)I(t) \qquad\qquad (2)$$

The Recovered Differential Equation. R (t)

$$dR/dt= -Yi(t) \qquad\qquad (3)$$

At the initial condition at initial time {S (0), I (0), R (0)} where parameter β = 1.7 per day is the infection transmission rate and parameter Υ = .32 the recovery rate. Parameter β represents the rate of Susceptible who get infected over time, and parameter Υ represents the recovery rate of infected. By running the simple SIR model, we can forecast when is the peak time of COVID -19 in Makkah over time where t = 70.

3. Results and Discussion

In this section, the results of the SIR calculations were presented. The period was 70 days as the study in China calculated their sample of 70 days 15. We have S (0) = .9999 of the population is susceptible and starting infected at I (0) = 0.0001, which was a percent of population infected, and recovery rate is zero R (0) = 0. We compared our findings with China's cases, which presented similar results to the constant parameters for the SIR model used to forecast the COVID-19 epidemic in China. The following table 1 shows the state variable parameters for the SIR model in the city of Makkah, Saudi Arabia. It is important to declare that Saudi Arabia is implementing a lockdown of all activities and ordering individuals to stay at home, which we did not consider in our study.

**Table 1. Summary of constant parameters for SIR model to forecast the epidemic COVID-19 in Makkah**

Place	Makkah
Population	2000000
Susceptible rate	.9999
Infection rate	.0001
Recovered	0

The data presented in graph 1 is the daily number of cases reported in Saudi Arabia and the daily number reported in Makkah from 3/16/2020 to 5/09/2020. Both curves indicate the increasing number over time, with 673 being the daily average of infected people in Saudi Arabia and the average daily cases in Makkah being 145.
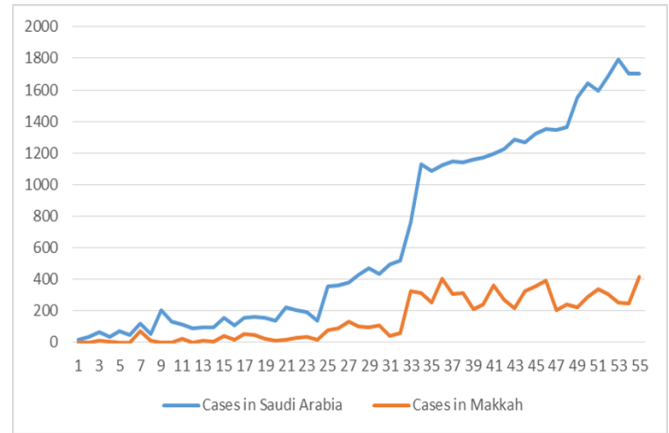
**Graph 1. Number of daily cases in Saudi Arabia VS Makkah**

To better understand the speed of COVID-19, we calculate the growth index. Graph 3 shows our calculation of the growth index of COVID -19 from the first reported date of 3/16/2020 to 5/9/2020, and it is clear that we had a big spike after the 5th day of the first reported case. On average, the growth index is 1.7.
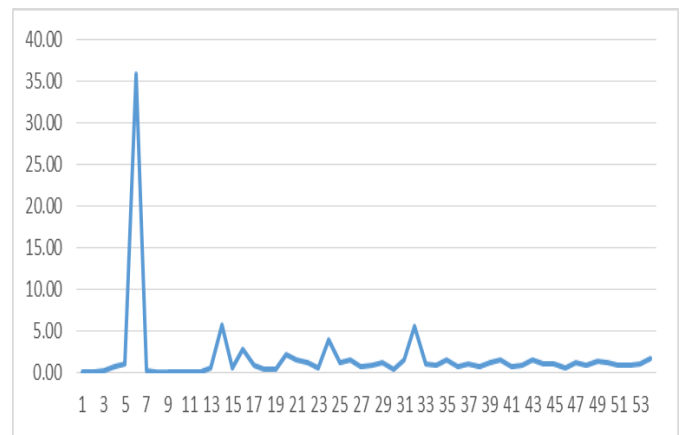
Graph 2. Growth index of Daily Cases

Fig. 1 shows the dynamics of the three variables, S, I, and R. We observe that the susceptible curve decreases over time due to the assumption that the birth rate = 0. Also, we assumed that once susceptible people are infected, they will never return to a state variable of susceptible. The infected curve shows that the number of infected people will reach the peak in 15 days before it starts to decrease. The recovery curve starts low before it increases dramatically as the number of recovered individuals accumulates and rises above the infected curve. The intersection between the recovery

curve and infected curve assumingly will be in 18 days, the beginning of June. The data showed an interesting result about the peak of the disease progression. It is estimated to occur around the 15th day after running the model. According to the model, the peak time will be around the 22ed of May. Then, the cases will decrease until the 30th day, around the 15th of June.
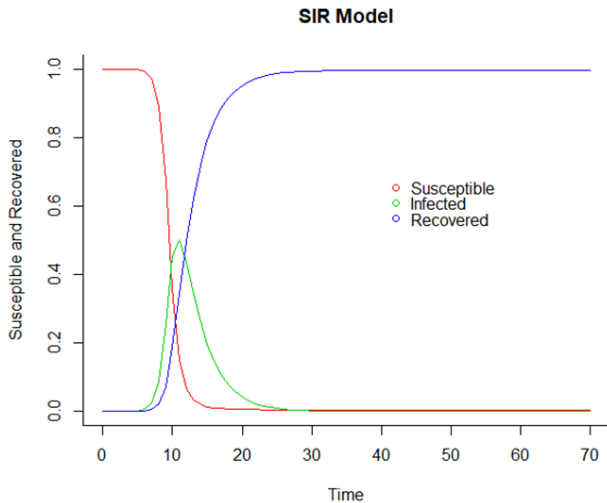
Fig. 1 The SIR Model to Forecast COVID-19 Progression in the City of Makkah

This study has been done at a very important time in the ongoing COVID-19 pandemic. The study's main goal was to estimate the disease progression in the city of Makkah and to help the policymakers to decide if the Hajj will be held this year. One of the important features of a SIR model is the feature of identifying simultaneously with model parameters, which can detect and forecast positive infected people of the ϒ factor that relates to the actual number of infected individuals in the sample population 16. For the accumulated data of Saudi Arabia, the recovery rate is 32%, and the real mortality rate of the infection is .5% as of May 9 (Ministry of Health). The data covers 70 days since the emergence of the first infected person in the city of Makkah, Saudi Arabia, on March 16th (Ministry of Health). The parameters have been used according to this data. The model and the parameters allowed us to forecast the time needed to predict the end time of COVID-19 in Makkah or at least when the curve would be flattened. The other countries that had a decline took around three months. So, the time was estimated to be around 70 days. An important note about the study is that it did not consider Saudi Arabia imposing prevention measures during the period we are covering. Another important note is that on the 22nd of March, the number jumped significantly on the growth index, which the 72 reported cases can explain at a hotel in Makkah (Ministry of Health). The findings provide significant outcomes for health authorities to ensure the availability of all resources they might need. Also, it helps them to forecast when the curve will flatten and apply their economic and health policies accordingly. Figure 1 predicted that the curve would flatten in 20 days within the constraint that nothing changes. As of the 27th of February, Saudi Arabia stopped Umrah visas, which was early prevention to slow down the spread of the virus and decrease the number of infected people.

3.1. Recommendation for the economy

Economically, the city of Makkah depends mainly on Hajj and Umrah. Last year, the number of pilgrims for the Hajj was 2,489,406, the number of pilgrims for the Umrah was 7,457,663 (Ministry of Hajj and Umrah), and its revenue was roughly 50 billion riyals 17. Many accommodations, such as hotels, and car services, will not be in service because of the preventive measures and lockdown ordered by the health authority. According to Kouchi, Nezhad, and Kiani (2018) 18, there is a one-way causality relationship between economic growth as the number of pilgrims increased in the short-term, indicating a one-digit increase in the number of pilgrims increased, the non-oil GDP growth increased by of .84 SAR. The impact of the lockdown touches all local businesses, restaurants, car rentals, hotel rentals, and many family businesses that only work for Hajj season. Our study predicts that the Hajj season can be held as the number of cases slow down or increase at a sustainable level along with a slowdown of COVID-19 worldwide. However, we might face difficult times during this Hajj season in all economic sectors. Still, it is more cost-efficient than putting pressure on the health care system in Saudi Arabia. To elaborate more on the impact of covid-19 on the economy, Fernandes (2020) 19 predicts two scenarios: The first scenario is mild, where GDP growth decreases by 3-6% depending on the country. In the second scenario, GDP can decrease by 10 % - 15%. As a result, this is a global crisis in that all countries suffering from the COVID-19 outbreak slow down all economies worldwide. As Hajj is not only about the supply side but also has demand side, and our demand is from other Muslim countries where that are also facing economic difficulty, they might stop traveling the Hajj this year. It might be a slowdown on the demand and supply sides. We believe our predation of the SIR model can help policymakers and give them an estimation of when the number of cases is slowing down if everything remains constant.

3.2. Recommendations for the Healthcare Industry

Since COVID-19, the number of cases has continued to grow globally. Political leaders are calling for social distancing to decrease the rate of transmission. The purpose of social distancing is to flatten the curve to spread out cases over more time with a lower peak, which will help reduce the burden on healthcare facilities. The positive effects of social distancing will take weeks to months to show their effectiveness; therefore, personal protective measures (PPM),

ventilators, and healthcare providers are needed due to the many patients daily. Ensuring the safety of healthcare providers must be a priority in the fight against COVID-19. One of the positive actions of the Saudi Arabian government was that it encouraged industries to maximize the availability of PPM supplies for the citizens and healthcare providers. Lack of adequate PPM will lead to sick staff, decrease the number of healthcare providers, and endanger the performance of the healthcare system 20. When COVID-19 was newly discovered in China, a study showed that 23 healthcare providers among 3,387 had died from COVID-19 after they contracted the virus while practicing their duties as healthcare professionals caring for COVID-19 patients 21. Due to the shortage of healthcare providers, losing more providers will add more burden to the healthcare system in Saudi Arabia.

Increasing the number of medical staff, especially nurses, is highly needed due to the nursing shortage that Saudi Arabia faces. The healthcare sector is one priority for the newly Crowned Prince Mohammed bin Salman in his 2030 vision to the nation; the Minister of Health emphasized that nursing is the top priority to achieve the vision of the Kingdom of Saudi Arabia, pointing out that 50% of the total workforce in the health sector are nurses (Ministry of Health, 2019). Saudi Arabia is experiencing issues with its health care system due to the insufficient number of Saudi nurses to meet its needs. This nursing shortage is related to many factors, including the life expectancy of the Saudi population, which has increased from age 69 in 1990 to age 76 in 2012. Also, the annual population growth rate in Saudi Arabia has increased by 2.5% each year from 1990 to 2012, and that will lead to a growing demand for healthcare 22. Furthermore, although the overall number of nurses in Saudi Arabia is 140,389, only 51,350 are Saudi nurses. Thus, the representation of Saudi nurses among all the other registered nurses in Saudi Arabia is only 36.6% 23.

To overcome the nursing shortages, or at least to increase the number of nurses around the globe, many agencies have been created to support hospitals with part-time nurses to fill shortages. Part-time nurses are beneficial to reduce nursing shortages and are cost-effective because

the nurses are paid hourly or by shift without the incentives given to the permanent nurses 24. Some social issues also impact the nursing shortages, such as the Saudi Arabian culture and how most nurses are women. The part-time work will give them more flexibility to take care of their children and gradual exposure to the workload stressors. Moreover, as healthcare providers are always at risk of getting sick while dealing with patients, part-time work will give them more time to recover from work. Finally, the culture of Saudi Arabia is family-centred, so working too many night shifts will not allow the nurses to be engaged with many family occasions. That is why part-time nurses allow for a better adjustment to the considerations of family and friends 25.

Lastly, Saudi Arabia started to take advantage of the hotels there. Saudi Arabia has 230,000 hotel rooms; 75% of the hospitality investments are in Makkah and Madinah 26. Due to the COVID-19 pandemic, Umrah was postponed to an unspecified date, 27. If the number of cases increases and the hospitals are packed with patients, mild cases could stay at the hotels until discharge. Taking care of mild cases does not require many healthcare workers to provide them with medical necessities. Moreover, certain buildings are empty during the year and can only be rented to groups during the Hajj season. These buildings could be used for quarantine and mild COVID-19 cases.

The economy and the healthcare industry have been most affected by this pandemic. Solidarity is now needed in the fight against COVID-19 to resume normal life, attend family gatherings, and perform religious rituals. Using the SIR model, the result predicts the disease progression peak and an estimated end of COVID-19 in the city of Makkah to help policymakers decide if the Hajj will be able to operate this year.

4. Conclusion
Using the SIR model, the result predicts the disease progression peak and an estimated end of COVID-19 in the city of Makkah to help policymakers decide if the Hajj will be able to operate this year. Moreover, recommendations were given for the economy and healthcare industry to implement solutions.

References
[1] Bock, D. L., & Del Rosario M, "The Table Briefing: Ministering to Hospital Patients," *Bibliotheca Sacra,* vol. 171, no. 682, pp. 226-232, 2014.

[2] Mohammadi N, Evans D, & Jones T, "Muslims in Australian Hospitals: The Clash of Cultures," *International Journal of Nursing Practice*, vol. 13, no. 5, pp. 310-315, 2007. Doi: 10.1111/j.1440- 172X.2007.00643.

[3] Ascoura I. E., "Impact of Pilgrimage (Hajj) on the Urban Growth of Mecca," *Journal of Educational and Social Research*, vol. 3, no. 2, pp. 255-263, 2013.

[4] "Arab News," 2009.

[5] "World Population," 2020.

[6] Alghatany M., L. Kumar, and H. Khormi, "Are Immigrants More Likely to be involved in Criminal Activity in Saudi Arabia?," *Open Journal of Social Sciences*, vol. 403, pp. 170–186, 2016. https://doi.org/10.4236/jss201643023.

[7]   Henderson RJ, "Problems of Pilgrimages," *Postgrad Med J,* vol. 1975, no. 51, pp. 845–847, 1975.

[8]   WHO, "Health Conditions for Travellers to Saudi Arabia for the Pilgrimage to Mecca (Hajj)," *Wkly Epidemiol Rec.,* vol. 84, pp. 477–480, 2009.

[9]   Ning L, Liu L, Li W, et al., "Coronavirus (SARS-CoV-2) Infection in a Renal Transplant Recipient: Case Report," *Am J Transplant,* 2020.

[10]   Alsharif, Fahad L. City of Dreams, "Disappointment and Optimism: The Case of Nine Communities of Undocumented African Migrants in the City of Jeddah".

[11]   Ministry of Health of Saudi Arabia (MOH)

[12]   W.-K. Ming, J. Huang, C. J. P. Zhang, "Breaking Down of the Healthcare System: Mathematical Modelling for Controlling the Novel Coronavirus 2019- nCoV Outbreak in Wuhan, China, 2019. Doi:10.1101/2020.01.27.922443.

[13]   Kermack, W. O. and McKendrick, A. G, "*Contributions to the Mathematical Theory of Epidemics*," Proceedings of the Royal Society of Edinburgh, Section A. Mathematics, vol. 115, pp. 700–721, 1927.

[14]   J´erˆome Adda, "Economic Activity and the Spread of Viral Diseases: Evidence from High-Frequency Data," *Quarterly Journal of Economics*, vol. 131, no. 2, pp. 891–941, 2016. Doi:10.1093/qje/qjw005.

[15]   Pan A, Liu L, Wang C, et al., "Association of Public Health Interventions with the Epidemiology of the COVID-19 Outbreak in Wuhan," China, JAMA, 2020. doi:10.1001/jama.2020.6130

[16]   G.C. Calafiore, C. Novara, C. Possieri, "A Modified SIR Model for the COVID-19 Contagion in Italy," arXiv preprint arXiv:2003.14391, 2020.

[17]   Alarabiya news.

[18]   Kouchi, A. N., Nezhad, M. Z. and Kiani P, "A Study of the Relationship between the Growth in the Number of Hajj Pilgrims and Economic Growth in Saudi Arabia," *Journal of Hospitality and Tourism Management*, vol. 36, pp. 103-07, 2018.

[19]   Dr. Haga Elliman, "Determinants of Energy Consumption in Saudi Arabia and its Role in Decreasing the Misuse of Environmental Resources," *SSRG International Journal of Economics and Management Studies,* vol. 7, no. 3, pp. 46-56, 2020. *Crossref,* https://doi.org/10.14445/23939125/IJEMS-V7I3P107

[20]   Fernandes, Nuno, "Economic Effects of Coronavirus Outbreak (COVID-19) on the World Economy," 2020. [Online]. Available: https://ssrn.com/abstract=3557504 or http://dx.doi.org/10.2139/ssrn.3557504.

[21]   Ranney, Megan L., Valerie Griffeth, and Ashish K. Jha, "Critical Supply Shortages – The Need for Ventilators and Personal Protective Equipment during the Covid-19 Pandemic," *The New England Journal of Medicine*, 2020. [Online]. Available: https://www.nejm.org/doi/full/10.1056/NEJMp2006141.

[22]   Zhan M, Qin Y, Xue X, Zhu S, "Death from Covid-19 of 23 Health Care Workers in China," *N Engl J Med*, 2020. Doi: 10.1056/NEJMc2005696.

[23]   Alghamdi M., & Urden L, "Transforming the Nursing Profession in Saudi Arabia," *Journal of Nursing Management*, vol. 24, no. 1, pp. E95– E100, 2015.

[24]   Aboshaiqah A, "Strategies to Address the Nursing Shortage in Saudi Arabia," *International Nursing Review*, vol. 63, pp. 499– 506, 2016.

[25]   Seo, S., & Spetz J, "Demand for Temporary Agency Nurses and Nursing Shortages," *Inquiry*, vol. 50, pp. 216– 228, 2010.

[26]   Halger, Maarten, Steffen & Hans, 2013.

[27]   Ministry of Tourism of Saudi Arabia.

[28]   Ministry of Media of Saudi Arabia.