MATHEMATICAL MODEL FOR SOCIAL DISTANCING IN MITIGATING THE SPREAD OF COVID-19

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This study investigated the impact of social distancing in mitigating the spread of Covid-19 using height measurement data. A prediction Matheatical model was proposed with which the probability of Covid-19 spread was computed, using social distancing values. The model utilized information from the detection phase of Covid-19 prediction model. case fatality ratio (CFR) of Covid-19 was computed and compared it with that of SARS-CoV and MERS-CoV. The graphical analysis of the epicenter records of world health organization (WHO) regions was obtained. The analysis revealed that as the social distancing values increases, the probability of spread reduces. The CFR of Covid-19 up to 28th April 2020 is 6.94%, compared to the CFR of SARS-CoV (9.6%) and MERS-CoV(34.4%). This analysis revealed that although the CFR of Covid-19 is lower than those of SARS and MERS, the impact of Covid-19 is much greater due to the number of confirmed cases and deaths. This research affirmed that though the CFR of an epidemic could be low, but if the spread is geometric, which could turn exponential due to negligence in all ramifications by world leaders, the effect would be catastrophic to humanity.

Key words: Covid-19, social distancing, prediction model, spread, probability.

INTRODUCTION

This unknown etiology pneumonia outbreak in Wuhan city, Hubei province,China in December 2019 had changed the world's naratives. Wuhan city is the sevent most populus city in China and largely known for local and international transportation network (WHO situation report, 2020a). The outbreak was reported to the World health organization (WHO) on 31st December 2019, by the Chinese authority (Wu et al., 2020; Wang et al., 2020; Wu and McGoogan, 2020; Wu and Luo, 2020; Okwonu et al., 2020a). The outbreak was first associated to the Huanan seafood Wholesale market, where wild animals and other sophisticated repitiles are sold (WHO situation report, 2020a). On 1st January 2020, the market was shutdown for disinfection and fumugation (Chen et al., 2020; WHO situation report, 2020b). The Chinese authority described the outbreak as novel coronavirus (nCoV) on 7th January 2020 and further shared the genetic sequence of the novel coronavirus to other countries to develop diagnostic test kits on 12th January 2020 (WHO situation report, 2020b). At the beginning of the outbreak, 41 confirmed cases of nCoV were reported to the local WHO regional office in China with one confirmed death in Wuhan city (WHO situation report, 2020b). As at 12th January, there was no evidence that the virus could be transmitted from person to person; however, the Chinses authority intensified effort to obtain detailed information on the outbreak and mode of transmission. As of 12th January 2020, the outbreak was within Wuhan city, which implies that it could have been controlled to avoid global outbreak by restricting local and international travels.

The outbreak conincided with the celebration of the annual Chinese New Year on 25th January, which triggered the spread due to people travelling from Wuhan city to other cities (Chen et al., 2020). The rapid spread of the virus in China and other countries could be associated to the migration of over 5 million migrant workers from Wuhan city to other provinces and mainland China between 11th to 23rd January 2020 to celebrate the Lunar New Year (Chen et al., 2020). Due to the increasing number of cases outside Wuhan city, on 23rd January the Chinese authorities initiated travel restrictions and extended the Lunar New year holiday in Wuhan city and other provinces to curb the spread of the virus (Chen et al., 2020). The government also initiated other preventive measures like social distancing and preventive measures such as stay at home, avoid mass gathering and shutting down public and other social institutions (Chen et al., 2020). In previous epidemic outbreak such as the severe acute respiratory syndrome coronavirus (SARS-CoV), social distancing, self isolation and quarantine was applied and it assisted in reducing the spread of the virus (Markel et al., 2007; Glass et al., 2006; Caley et al., 2008, Ferguson et al., 2005; Ahemd et al., 2018; Fong et al., 2020).

Wuhan city became the epicenter of Covid-19 in China. The virus was exported from Wuhan city to the rest of the world due to globalization and migration. On 13th January 2020, Thailand announced the first 2019-nCoV laboratory confirmed case. Thailand became the first country outside China to have reported imported Covid-19 case from Wuhan city (WHO Situation Report, 2020a). Other imported cases of 2019-nCov was reported in Japan and the Korea Republic on 15th and 19th January 2020 (WHO Situation Report, 2020c, 2020d). Due to the reported cases of 2019-nCoV virus in China, the Japanese authority enhanced the secreening process at the point of entry on 3rd January to reduce the spread of the pneumonia related virus (WHO Situation Report, 2020d). As at 20th January 2020, 278 confirmed cases of the novel coronavirus had been reported, with six deaths (WHO Situation Report, 2020d).

Due to further investigation and epidemiological evidence, it is known that 2019-nCov is transmitted from human to human through droplets from sneezing, coughing and fomites (Auer et al., 2020; Van Dormalem et al., 2020; Yang et al., 2020; Lupia et al., 2020). As more imported cases increases outside China, the world health organization decleared 2019-nCov public health emergence of international concern (PHEIC) on 30th January (WHO Situation Report, 2020e). On 11th Febuary 2020, WHO officially named 2019-nCov as Covid-19, meaning coronavirus disease 2019 (WHO Situation Report, 2020f). As at 11th March, Covid-19 had already raveged 114 countries globally with 118,319 confirmed cases and 4,292 deaths recorded globally. It was on this premise that the Director General of WHO declared Covid-19 pandemic on the 11th March 2020 (WHO Situation Report, 2020g). Globally, 212 countries outside China have confirmed cases of Covid-19 with over three million infections and over two hundred thousand deaths globally (Google news, 2020). Since 11th April 2020, no new country has confirmed cases of Covid-19 to date (28th April 2020) (WHO Situation Report, 2020l).

At present, no vacines or antiviral drugs are available to treat Covid-19 patient. The world health organization has advocated different preventive measures, such as social distancing, avoiding touching the face, cough etiquette, washing hands frequently, avoid mass gathering, stay at home, quarantine and lockdown (WHO Situation Report, 2020h). These preventive measures are classified as non pharmaceutical intervention (NPIs) to reduce the spread of the pandemic globally. Also, travel restriction and boarder clossure are classified as non-pharmaceutical interventions “ (NPIs). NPIs are effective means to slow the spread of an epidemic, locally and internationally, by denying infected person at the point of entry (Ryu et al., 2020). Globally, the world has been locked down due to Covid-19 virus.

This paper investigates the impact of social distancing in mitigating the spread of the virus. It had been suggested that people should maintain 1 m (3 feet) apart. The question is, is 1 m apart enough to reduce the spread of the virus when one Covid-19 carrier sneezes or cough? The possible distance apart values that will reduce the probability of spreading the virus will be investigated.

MATERIALS AND METHODS

From previous studies on influenza pandemics with no vaccines or antiviral drugs, minimizing the rate of spread between infected and uninfected has been subject of discussion in past outbreaks. The control measure often applied at the beginning of must epidemic is the "social distancing", that is minimizing the interactions between infected and uninfected persons, in order to control and reduce the spread of the disease (Bell et al., 2006). Physical or social distancing is a delay mechanism that slows down the spread of epidemic, help to flatten the epidemic curve in order to relieve huge burden on health care facilities (Fong et al., 2020). Physical distancing and other preventive measures against infectious diseases, like Covid-19, are categorized as "non-pharmaceutical intervention" (NPIs). NPIs are often applied at the early stage of epidemic outbreak where vaccine or antiviral drugs are not readily available (Ahemd et al., 2018; CDC, 2019). The main feature of social distancing is to reduce human to human transmission of infectious diseases like H1N1 and Covid-19. It helps relevant government agencies to strategize in curbing further spread and helps to facilitate proper management of health care and personal facilities during outbreak (Markel et al., 2007; Glass et al., 2006; Caley et al., 2008). In developing the Mathematical model for this paper, the Poisson distribution function (1) was studied

$$P(n) = \frac{e^{-\beta}\beta^{n}}{n!}, n = 0,1,2,3,4, \ldots \quad (1)$$

with parameter $\beta,$ such that $\beta > 0$, which total probability is one. It is noted that,

$$e^{\beta} = \sum_{n=0}^{\infty} \frac{\beta^{n}}{n!}$$

The Covid-19 virus test maybe positive or negative when people are tested, it can be considered to be binomial distributed random variable which relies on success and failure. In this case, Equation 1 can be derived as the limit of the binomial distribution when the number of m trials tends to infinity and the probability p of success tends to zero, such that $mp = \beta$ (Rice, 1995). It can be derived further for when

$$m \to \infty, \frac{\beta}{m} \to 0.$$

Using the above discussion on Poisson distribution function, a Mathematical model which mimics the Poisson distribution with the capability to compute the probability of spread using social distancing values was proposed. From Equation 1 above, let $e^{-\beta} = \gamma^{-\pi}$, and $\beta^{n} = \pi^{k}$, then the above modification gives the model (2)

$$G(k) = \frac{[\gamma^{-\pi}\pi^{k}]k^{-1}}{c} \quad (2)$$

Where $G(k)$ denotes the function value of a tuning value k, and π is the proportion of spread from Equation 2 (Okwonu et al., 2020b) and is defined by

$$\pi = \left(\frac{\partial\rho}{n}\right), \ \partial\rho = \sum_{i} X_{i} \leq \bar{X} \text{ and } c = \frac{1}{(1-\pi)}$$

The model uses tuning value (k) to compute the probability of spread when simulated data or real data set is used to train the model. In this model, n in Equation 1 is equal to k in Equation 2.

The training phase of the prediction model is defined as:

$$\gamma = (\vartheta\rho \times \delta) \quad (3)$$

where $\vartheta\rho = (X_{i} - \bar{X})^{k}$and $\delta = \frac{1}{\sqrt{S}}$ and S denotes the standard deviation where X_{i} is independent random data set. This equation is designed using information similar to Figures 1 and 2 respectively. Equation 3 trains the model by computing difference between two points, similar to Figures 1 and Figure 2 respectively. The output in Equation 3 is applied as input to Equation 2. The tuning values k are applied to validate the trained model which computes the probability $G(k)$ of spread. The values of $G(k)$ will be presented graphically to illustrate the output of the model in the study.

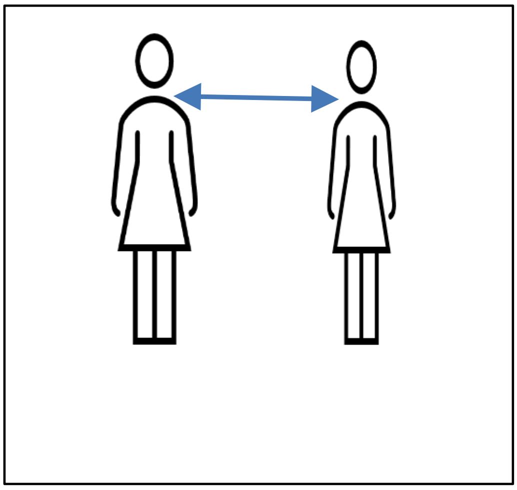

Figure 1. Equal height .

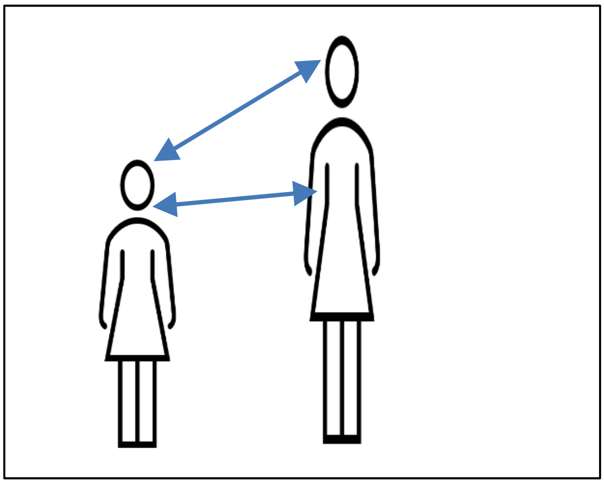

Figure 2. Height variation.

RESEARCH DESIGN AND RESULTS

The data set used for the standing height and seating height position was reported by Okwonu et al. (2020b). It consists of 918 height measurements and 459 seating height measurements. The data set were measured in meters (m). For easy analysis, let $W(h)$ be the standing height and $Q(pk)$ denotes the seating height of people in public places. The focus of the analysis is to investigate whether height measurement and social distancing values can be used to train and validate the Mathematical model in order to compute the probability of spread of infectious disease like Covid-19. When information similar to the ones in Figures 1 and 2 are applied to Equation 3, the model computes the height variations and assigns the values to each data point. These values are the height difference between two people. The output values from Equation 3 are used as input value for Equation 2. The physical distancing value (k) is applied to validate the trained model$G(k)$. In this paper the values of k used are $k = 0,1,1.5,2, 2.5,3,3.5, 4,4.5, 5$; the measurement unit of k is in meter (m). By simulation study in Figure 3 it was noted that, it is very easy for people of equivalent height to transmit the virus faster when one of them is infected and sneezes or coughed in queue or gathering involving three or more people within 1 m (3 feet) apart. On the other hand, the simulation study in Figure 4 showed that the rate of spread of the virus when maintaining physical distancing of 1 m is minimal when coughing etiquette similar to Figure 3 is observed. On the simulation study in Figures 3 and 4 the impact of social distancing values in reducing the spread of the Covid-19 virus was investigated.

In Figure 5, $W(h)$ represents standing height, while $Q(pk)$ denotes seating height. It was observed that the probability of mitigating the spread of Covid-19 based on the two measured data set is lower in $W(h)$ than $Q(pk)$. The implication is that controlling the spread is earsier for standing position than people seating. The analysis of $Q(pk)$ is that the virus can spread faster among people seating, for instance religious gathering like the ones observed in South Korea, Tablighi in Malaysia, India and Pakistan, international gathering like the incidence in Singapore and Bavaria in Germany (Bostock, 2020; Ryall, 2020; Kuhn, 2020; Aljazeera News Report 2020a, b, c). These incidence and seating positions during this outbreak enhanced the spread of the virus locally and internationally, so controlling it using social distancing value will surely mimic the contrary. From Figure 5, it was observed that without substantial distance between people and other preventive measures such as cough etiquette not observed, the probability that an infected person can infect other uninfected people is very high, this is observed when $k = 0$ with probabilities $Q(pk) = 0.95$ and $W(h) = 0.9$ respectively. It was observed that as the distance between two people increases, the probability of spreading the virus reduces. This implies that 2 to 3 m will dimish the rate of spread if implemented and monitored. This analysis showed that social

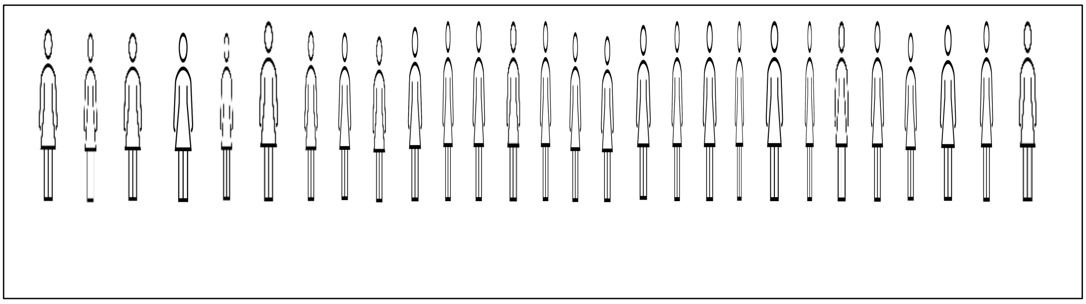

Figure 3. Simulation of equal height.

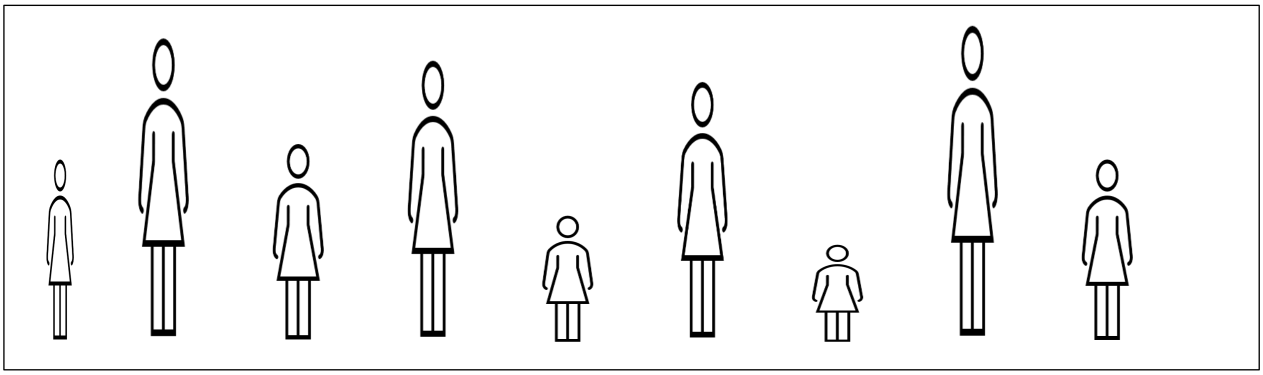

Figure 4. Simulation of varying height.

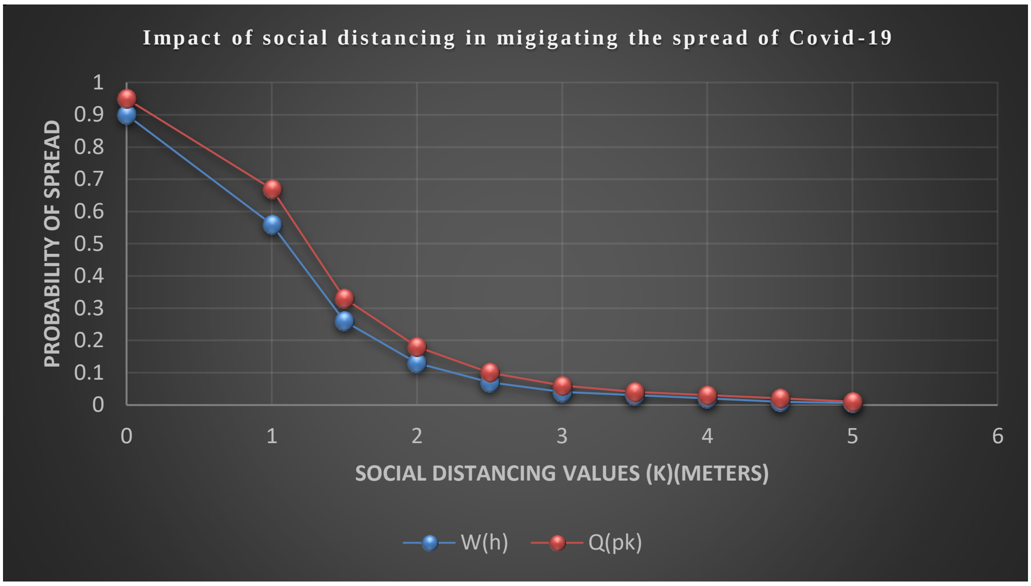

Figure 5. Impact of social distancing values in reducing the spread of Covid-19.

distancing can be used to mitigate the spread of Covid-19. The implication of this is that people of similar height should stay far apart if no option is available when in a queue or mass gathering during pandemic of infectious disease that can be transmitted via sneezing and coughing. Figure 6 shows the global epicenter of Covid-19 in each of the six regions of World Health Organization (WHO). It indicates the number of infected people and number of deaths

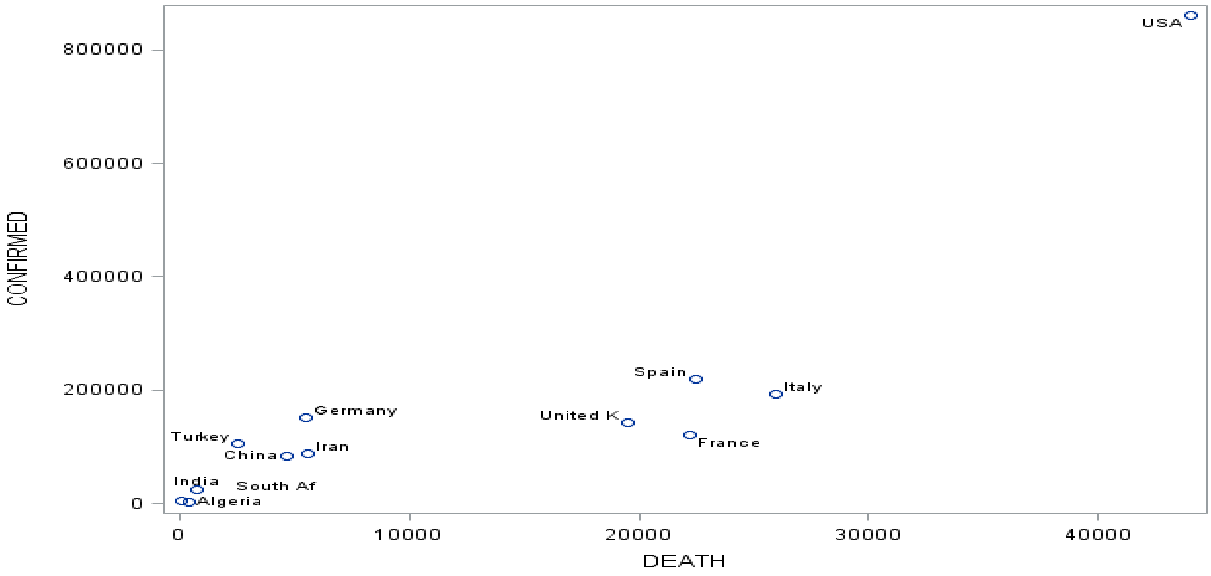

Figure 6. Covid-19 global epicenter.

based on the epicenter countries selected for this analysis. Generally, the United States of America is the global epicenter of Covid-19 using the two variables, confirmed cases and deaths. As at 28th April 2020, Algeria had the highest number of Covid-19 deaths in the Africa region; while South Africa had the highest number of confirmed cases. Based on Figure 6 and utilizing information from the six WHO regions, the case fatality ratio (CFR) due to Covid-19 is 6.94% as at 28th April 2020. The CFR of SARS-CoV and MERS-CoV are 9.6 and 34.4% (WHO Situation Report, (2020i), WHO Situation Report (2020j), WHO Situation Report (2020k) higher than that of Covid-19. However, the impact of Covid-19 is very huge due to the number of confirmed cases (3,041,764) and deaths (211,167) in over 213 countries and territories including China under 120 days of outbreak (Google News, 2020). The other two coronaviruses (SARS an MERS) invaded only 30 and 27 countries globally with 8,098 and 2,494 confirmed cases and 774 and 858 deaths reported in these two outbreaks in 2002 and 2012 respectively. In general, Covid-19 is more infectious than the other two coronaviruses.

ANALYSIS AND DISCUSSION

The results presented in Figure 5 indicate that social distancing values from 2 m and above can help reduce the spread of infectious disease like Covid-19. This finding corroborate the discussions by centers for disease control and prevention whom advocated 2 m (six feet) apart for physical distancing to reduce the spread of infectious disease like Covid-19 (CDC,2020). In Glass et al. (2006) social distancing simulation design was conducted after simulating pandemic transmission network for the 1957-1958 Asian flu. It was observed that the implementation of the social distancing concept helped mitigated the effect of the spread of the Asian flu. It was observed that social distancing helped to reduce the spread of the 1918-1919 influenza pandemic in Sydney Australia by 38% (Caley et al., 2008; Bell et al., 2006). The analysis in Figure 5 corroborate the findings of previous studies, implying that physical distancing helped in mitigating the spread of infectious disease like Covid-19 (Bell et al., 2006; Qualls et al., 2017). Barrios et al. (2012) and Bischoff et al. (2013) observed that maintaining physical distance of at least 2 m will help reduce transmission of infectious disease. The results in this study corroborate the findings of Barrios et al. (2012) and Bischoff et al. (2013). Although height data was used to train the model and applied social distancing values to validate the model which showed significant results in reducing the spread of infectious disease like Covid-19. The analysis of Figure 5 showed positive impact in reducing the rate of spread of infectious disease such as

Covid-19. The movement control order (MCO) in Malaysia is part of NPIs, which help in reducing the rate of spread and transmission from person to person. The MCO was a positive decision in positive direction.

The case fatality rate (CFR) of Covid-19 is 6.94% till 28th April 2020 is lower than the CFR of SARS-CoV(9.6%) (WHO situation report, 2020j) and MERS-CoV (34.4%) (WHO situation report, 2020k). However, the impact is higher in terms of number of confirmed cases (3,041,764) and number of deaths (211,167) across 213 countries including China; whereas, SARS-CoV affected only 30 countries with 8,098 confirmed cases and 774 deaths and MERS-CoV affected 27 countries globally with 2,494 confirmed cases and 858 deaths. From this analysis, Covid-19 is more infectious, and the global risk is high. This study recommends that 2 to 3 m should be adopted to effectively reduce the spread of the virus. However, social distancing is a delay mechanism for the virus not to spread exponentially. Using social distancing to reduce the spread of the virus is not an end itself because second wave, third waves may occur when people resume normal life and social activities. It is a non-pharmaceutical approach to reduce the burden on limited health care facilities and provide opportunities for health care workers or managers to study the nature of the disease and embrace the challenges of an outbreak of a new epidemic. It is imperative for people to adhere strictly to the NPIs when vaccine is not available for a pandemic such as Covid-19.

Conclusion

The study revealed that social distancing is an effective way to control and reduce the spread of the virus and flatten the epidemic curve. The analysis in Figure 5 validates the above claim and corroborated the results of previous studies. Based on Figure 5, 2 to 3 m is recommended to effectively reduce the spread of the Covid-19 virus or any infectious disease that is transmitted from human to human. Applying social distancing to reduce the spread of an epidemic is not a final solution; it is just a delay tactics. Reoccurrence is inevitable in the absence of vaccine. To date, the CFR of Covid-19 is lower compared to that of SARS-CoV and MERS-CoV. However, the impact of Covid-19 globally is huge in terms of number of confirmed cases, deaths and the countries invaded globally.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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