INFLUENCE OF POPULATION DENSITY ON COVID-19 MEDICAL WASTE GENERATION IN SELANGOR AND KUALA LUMPUR

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ABSTRACT
The COVID-19 virus is easily spread, which caused the World Health Organization to announce it as a pandemic. During the COVID-19 pandemic, an enormous amount of Medical Waste was generated throughout the world. The sudden increase in medical waste created an additional challenge in medical waste management, especially in an urban area with a high density of population. This paper presents a study on medical waste generation in high-density population areas, specifically Selangor and Kuala Lumpur, to see the influence of population density on medical waste generation during the COVID-19 pandemic. The medical waste generation rate was estimated using Sangkham's equation based on the number of positive cases reported. The results showed that the continuous increase in the number of confirmed COVID-19 cases has increased the number of the medical waste generation rate (Mw). Generally, the trends of Mw for both Selangor and Kuala Lumpur have a similar pattern. Even though Selangor and Kuala Lumpur have similar population densities, Selangor exhibited a much higher Mw rate compared to Kuala Lumpur. The Mw peak during the COVID-19 pandemic for Selangor is 569% higher compared to the value of Mw before the pandemic. This is a highly significant increase compared to the pre-COVID-19 Mw. For Kuala Lumpur, the intra COVID-19 value is 94% higher than the pre-COVID-19 threshold. This is almost double the pre-COVID-19 value but still five times smaller than the Selangor intra-COVID-19 value. Other than that, the Mw dipped under the threshold line (pre-COVID-19 Mw) at the end of the study period. This may even decrease and be maintained below pre-COVID-19 Mw values for the first time in months. According to the findings, it can be concluded that the population density of the area is not a contribution factor to the increase of COVID-19 cases and at the same time, it is not a controlling factor to the COVID-19 medical waste generation. In this case, the medical waste generation rate cannot be predicted based on the population density of the area.

Keywords:
COVID-19, Hazardous Waste, Medical Waste, Generation rate, Population density

INTRODUCTION

At the end of year 2019, the world was shocked by the outbreak of a new type of coronavirus (SARS-CoV-2) known as COVID-19. This virus causes severe respiratory illnesses and has killed millions of lives worldwide. Globally, as of 22 November 2022, there were 635,229,101 confirmed cases of COVID-19, including 6,602,552 deaths, reported to the World Health Organization (WHO). The virus is easily transmitted through direct droplet transmissions such as coughing and sneezing (Lepelletier et al., 2020). Besides the omnipotence of the virus, COVID-19 is also responsible for the large increase of medical waste (Mw) and single-use plastics from personal protective equipment (PPE) and packaging (e.g. face masks, gloves, clothes, goggles, and sanitizer/disinfectant containers). The waste is generated from the countermeasures taken by each government in preventing and reducing the infection of the COVID-19 virus. Generally, COVID-19 waste mainly consists of medical waste (Mw) (Dharmaraj et al., 2021). The term "medical waste" refers to the waste originating from hospitals, clinics and health care facilities and can be categorized into five main classes: medical, radioactive, chemical, general wastes and containers (DOE, 2009).

According to a report by WHO, "Global analysis of healthcare waste in the context of COVID-19: status, impacts and recommendations", vaccination alone has generated 144,000 tonnes of additional waste in the form of syringes, needles, and safety boxes. This amount is not included the

waste generated from the treatment of COVID-19 patients. The large amount of COVID-19 medical waste brings a tremendous burden to the environment and may cause serious public health issues if not properly managed. This creates an additional challenge in medical waste management, particularly in developing countries.

Currently in Malaysia, there are 144 public hospitals with a total of 42,000 beds and 240 private hospitals with a total of 16,000 beds, which produced Mw of around 33,000 tonnes/annually or 90 tonnes/day with approximately 80% of non-pathogenic waste whereas 15% is pathogenic waste and chemical wastes. Pharmaceutical, sharp, and other waste account for 3%, 1% and 1%, respectively (Ambali et al., 2013). According to Minoglou et al. (2017), the average pre-COVID-19 Mw rate generation in developing and developed countries is 4.2 kg/bed/day and 2.56 kg/bed/day respectively. In Malaysia, the pre-COVID-19 generation rate of medical waste is 1.9 kg/bed/day which is lower compared to the global average reported. There is lower Mw generation rate recorded in a city such as Penang where the generation rate of pre-COVID-19 medical waste with only 0.4 -1.0 kg/bed/day, which is much lower than the national value (Agamuthu & Barasarathi, 2020; Rabeie, 2012).

However, due to the highly transmissive and lethal nature of the COVID-19 disease, medical waste skyrocketed to meet the demand for prevention and treatment of the disease. Any type of medical waste produced from COVID-19 treatments, including materials such as facemasks, medical gowns and medical gloves, is considered pathogenic Mw. According to the World Health Organization (2018), pathogenic Mw includes materials that contain dangerous microbes that can readily transmit to other individuals and hospital staff, if not managed and properly disposed of. These human coronaviruses may also survive up to nine days on inorganic hard surfaces which include plastic, glass, or metal, as shown in research by Kampf et al. (2020).

Currently, the medical waste management (MWM) relating to COVID-19 infections follows the established regulations of MWM detailed by the Federal Government and the DOE. The disposal of Mw is regulated by the Schedule of Waste Regulation (2005), the Environmental Quality Act (1974) and the Ministry of Health's (MOH) standard operating procedures. Malaysia is presently implementing the Environmental Quality Act 1974, with some of the latest modifications. However, due to the high medical waste generation, there would be a threat of unsafe disposal of the waste, especially in highly developing countries with limited treatment facilities (Sangkham, 2020). At the time this study was conducted, in January 2022, Malaysia had recorded a total of 1,113,272 COVID-19 cases and 9,024 deaths. Moreover, there is an exponential increment of cases as a result of the emergence of the highly transmissive delta variant of the virus. Thus, medical waste generation was likely to fluctuate based on these factors. Therefore, the understanding of Mw generation is important to ensure efficient management and disposal of Mw during the pandemic situation can be properly implemented.

In this research, a mathematical equation called Sangkham's equation is used for predicting and simulating the daily COVID-19 Mw generation rate in Malaysian urban areas. Through this method, the Mw generation rates are calculated based on the number of COVID-19 cases. Medical waste has a substantial influence on humans and nature; hence, this study sought to investigate the Mw generated from the most highly populated areas of the states of Peninsular Malaysia, in particular Selangor and Kuala Lumpur. The information on the medical waste generated is useful for the authorities to plan good medical waste management to prevent unsafe disposal, which in turn may increase the risk of spreading of the virus. Other than that, the data obtained from this study also can be used as a baseline if a similar pandemic situation occurs in the future.

METHODOLOGY

Location of study

The focus of this study is to determine the amount of medical waste generated in Kuala Lumpur and Selangor as shown in Figure 1. According to the Department of Statistics Malaysia (DOS) (2018), the population of Selangor is 6,448,400, the largest in Malaysia. It has the biggest economy in Malaysia, therefore, having the most population movement during the pandemic in its 8,104 km^2 of area (DOSM, 2007).

Figure 1: The Map show the location of Selangor and Kuala Lumpur within Peninsular Malaysia (Google Map, January 2022).

There are only four other states that have more than one official city status area besides Selangor. Meanwhile, Kuala Lumpur is the capital and largest city of Malaysia. The Greater Kuala Lumpur metropolitan area is one of the fastest growing regions in Southeast Asia with 7.564 million population in 2018 in a 2,243.27 km^2 wide area (UN DESA, 2018; DOSM, 2011). Kuala Lumpur is the political, economic and cultural centre of Malaysia. These two states have been chosen because they are two of the most urban areas in Malaysia with some of the highest numbers of COVID-19 cases by state.

Data Collection

The number of daily cases data for each state was gathered from government websites (https://covidnow.moh.gov.my/cases/ and https://covid-19.moh.gov.my/terkini/) for a duration of one year, from October 2020 until October 2021 (MOH, 2020).

COVID-19 Medical Waste Generation Prediction

There are two Mw generation rates in this study: MWGR and Mw. MWGR is the generation rate in kg/bed/day, while Mw is the generation rate in tonnes/day. In this study, a given MWGR will be used as a fixed variable in the equation in order to obtain the Mw.

Using Sangkham's mathematical formula (2020), the value of Mw generated was calculated by multiplying the medical waste generation rate (MWGR) value in kg/bed/day with the daily number of confirmed cases. This results in the waste generation rate in kg/day. To convert from kg/day to tonne/day, the previous value will be divided by 1,000. From the current body of knowledge, there is insufficient literature regarding MWGR in urban areas of Malaysia, therefore the value of 3.95kg/bed/day reported by Abu-Qdais et al. (2020) was adopted in this study.

The 3.95 kg/bed/day value is a relatively high value compared to the pre-COVID-19 values of high-income and low-income countries alike (WHO, 2020), and Abu-Qdais' MWGR was formulated by issuing a survey to the hospital management in a Jordanian hospital. Therefore, this value was related to the number of hospitalized COVID-19 patients, and not including the un-hospitalized cases. However, the MWGR value was still used by Sangkham because the population density and development level of the Jordanian area is similar to that of Selangor and Kuala Lumpur. In addition, this value is higher than the pre-COVID-19 values mentioned above. Therefore, it is suitable to use this value to differentiate this study from pre-COVID-19 medical waste generation studies. These are the considerations that have been made by Sangkham et al. in order to assume this value to be used in this Malaysian medical waste generation study.

The following is Sangkham's (2020) equation that was used to estimate the medical waste generated from the COVID-19 cases (Equation 3-1; Table 1 and Table 2). The medical waste, Mw was calculated in tonnes/day:

$$Mw = \frac{N\,DC \times MWGR}{1000} \qquad (3\text{-}1)$$

Where NDC is the number of daily COVID-19 cases, MWGR represents medical waste generation rate in kg/bed/day. This Mw accounts for all the waste produced from diagnosis, treatment and testing sample of COVID-19 patients. This investigation depends on the reliability of COVID-19 confirmed case statistics and the information made publicly available.

The data obtained were plotted into two graphs of the medical waste generation in tonnes/day against time in days and weeks. A weekly moving average was calculated from the daily data using Microsoft Excel. The weekly moving average was then used to calculate the monthly moving average. The monthly moving average was used to create a graph superimposed on the weekly graph.

RESULTS AND DISCUSSION

COVID-19 Medical Waste Generation Rate Estimation

Table 1 shows the descriptive analysis of minimum, maximum and mean value of the daily Mw generation in Selangor and Kuala Lumpur from October 2020 to October 2021. This result was correlated with the number of daily confirmed cases in each state presented in Figure 2. It can be seen that the Mw generation rate in Selangor ranged from 0.05135 tonnes/day to 34.7284 tonnes/day while Kuala Lumpur recorded 0.00395 tonnes/day to 11.376 tonnes/day. The mean averages of Mw generation in Selangor and Kuala Lumpur are 7.11385 tonnes/day and 1.90002 tonnes/day respectively. Interestingly, even though Selangor and Kuala Lumpur have similar population densities, the Mw generated in Selangor is 3.7 times higher than in Kuala Lumpur. The result demonstrated that population density is not the determining factor that influenced the number of confirmed cases which also reflected the amount of Mw generated in the respective state. Similar findings were also reported by Al-Omran et al., (2021) and ADB (2020).

Table 1: The minimum, maximum, mean and standard deviation of the daily Mw generation in Selangor and Kuala Lumpur from October 2020 to October 2021.

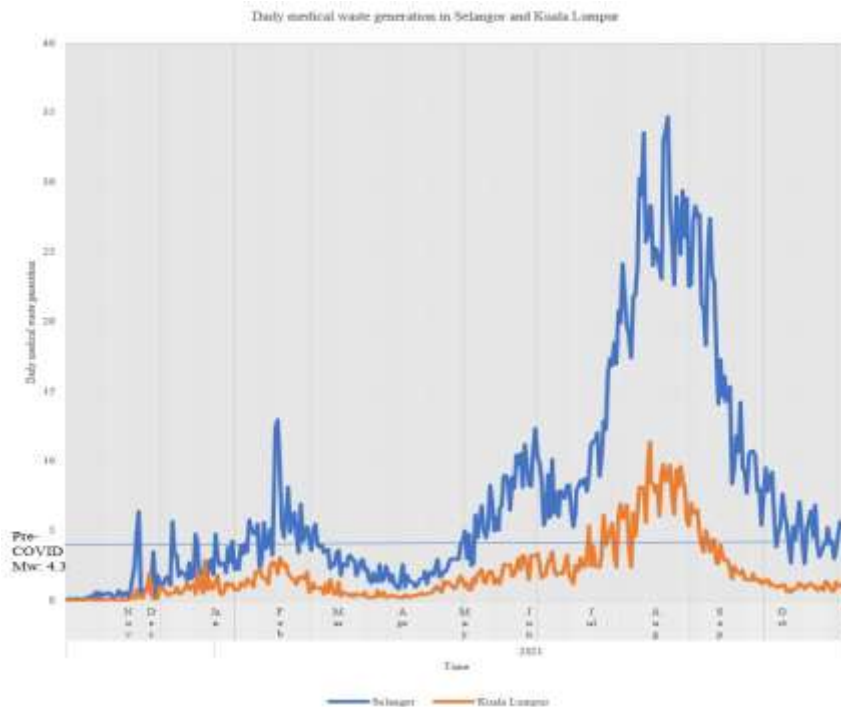|	Minimum	Maximum	Mean	Standard Deviation
Selangor	0.05135	34.7284	7.11385	7.773488
Kuala Lumpur	0.00395	11.376	1.90002	2.16488

Figure 2: Graph of daily medical waste generation rate in Selangor and Kuala Lumpur from October 2020 to October 2021.
(Source: MOH, 2020)

The Trends of COVID-19 Medical Waste Generated in Selangor and Kuala Lumpur

The COVID-19 infections generated a huge amount of medical waste within the analysed period. The trend of medical waste generated can be seen in Figure 3. Generally, the trends and fluctuations for both Selangor and Kuala Lumpur follow approximately the same shape, with the rate for Kuala Lumpur being lower than Selangor. The graph shows a fluctuation of Mw generation in an upward trend from October 2020 until July 2021 as the COVID-19 cases in Malaysia had been rising from the start of the pandemic.

There are two prominent peaks of Mw in February and August 2021 as can be seen in Figure 3. The second peak (34.7284 tonnes/day for Selangor and 11.376 for Kuala Lumpur) shows eight and two times increase from the pre-COVID-19 Mw generation rate. From July until August 2021, the rates had reached higher than 20.0 tonnes/day for Selangor.

According to the clusters list (MOH,2020), Selangor and Kuala Lumpur had a ratio of 2.3:1 for the number of clusters that emerged inside the states: 1310 and 559 clusters respectively. Although the number of clusters found in Kuala Lumpur is half that in Selangor, the difference between their Mw generated do not follow the same ratio. This difference is much higher than the ratio. This shows that for every cluster in Selangor, the Mw generated is higher than the Mw generated for one cluster in Kuala Lumpur. The weekly and monthly moving averages of the daily Mw were calculated and shown in Figure 3. The averages were calculated to better portray the trends in Mw.
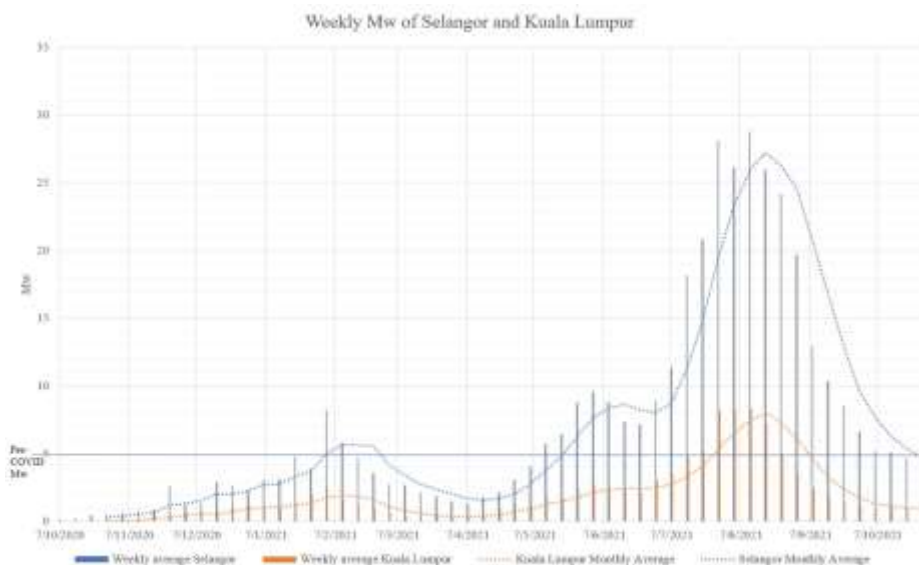

Figure 3: Weekly and monthly average medical waste generation rate in Selangor and Kuala Lumpur from October 2020 to October 2021.

The blue columns represent the weekly Mw for Selangor, while the orange column represents the weekly Mw values for Kuala Lumpur. The blue and orange lines represent the rolling 30 days moving average of the Mw values in both states. The blue threshold line is the value of medical waste generation rate estimated before the COVID-19 pandemic. The threshold value is based on the Mw in Selangor (Razali & Ishak, 2009).

As can be seen in Figure 3, the trend moved generally upwards as the COVID-19 cases in Malaysia had been rising from the start of the pandemic, save for the commencement of the first lockdown when the cases decreased. The general trends and fluctuations for both Selangor and Kuala

Lumpur followed approximately the same shape, where the rate for Kuala Lumpur was lower than Selangor. In 2021, the rates reached higher than 20.0 tonnes/day.

To understand the trends of M_w based on the value of M_w before COVID-19, the blue threshold line in Figure 3 represents the pre-COVID-19 M_w. The M_w peak during COVID-19 for Selangor is 569% higher than the value of M_w before COVID-19 (from 4.3 tonnes/day to 28.7724 tonnes/day). This is a highly significant increase compared to the pre-COVID-19 M_w. For Kuala Lumpur, the intra-COVID-19 value is 94% higher than the pre-COVID-19 threshold (from 4.3 tonnes/day to 8.34522 tonnes/day). This is almost double the pre-COVID-19 value but still 5 times smaller than the Selangor intra-COVID-19 value.

To discuss the M_w fluctuations, the movement control orders (MCOs) or lockdowns mandated by the Malaysian Government must be included in the discussion, as the M_w estimation in this study is directly correlated with the number of COVID-19 cases. From the start of the pandemic to January 2021 and March to May 2021, the intra-COVID-19 values are below the pre-COVID-19 threshold line. The first duration matches the duration of the conditional movement control order (MCO) and recovery phase, meaning the M_w was low from the start of the pandemic up until the MCO reached the conditional and recovery stages on 1 May 2020, until 11 January 2021 (Bernama, 2020; Rodzi, 2021). The low generation rate (0.05 - 5.00 tonnes/day for Selangor and 0.05 - 1.50 tonnes/day for Kuala Lumpur) in the beginning is closely related to the movement control order (MCO) commencement. This means that the COVID-19 infections were not rampant yet up until the second MCO was mandated.

From January to March 2021 and May to October 2021 the intra-COVID-19 values are above the threshold line. However, it seems as though the M_w after October decreased to below the threshold for the first time in months. If the COVID-19 hospitalizations and quarantined cases decreased after October and cases caused by further COVID-19 variants turned out to cause less symptomatic, the M_w may even decrease and be maintained below pre-COVID-19 values from the time of writing (The Economist Newspaper, 2022). Although, the more long-term future M_w will depend on government and consumer efforts for the reduction of the use of non-reusable test kits and a shift towards relatively more reusable diagnostic devices.

From 3 May 2021 until 15 June 2021, the Malaysian Government reimposed a third MCO in both Selangor and Kuala Lumpur in response to the spike in COVID-19 cases. Schools were closed and social and religious activities were banned. After that, on 15 June 2021, a four-phase National Recovery Plan (NRP) was introduced to help the country emerge from the COVID-19 pandemic. Exactly starting from the MCO 3.0 continuing into the NRP and through to the present time, the M_w increased to over the threshold line and reached the peak value and decreased gradually again to the threshold line (Figure 3).

CONCLUSION

Generally, the trends of M_w generation for both Selangor and Kuala Lumpur followed approximately the same shape. Even though Selangor and Kuala Lumpur have similar population densities, Selangor exhibited a much higher M_w generation rate compared to Kuala Lumpur. The mean M_w generation in Selangor and Kuala Lumpur were 7.11385 tonnes/day and 1.90002 tonnes/day respectively. The M_w generation rate in Selangor ranged from 0.05135 tonnes/day to 34.7284 tonnes/day while Kuala Lumpur recorded 0.00395 tonnes/day to 11.376 tonnes/day. The M_w peak during COVID-19 for Selangor is 569% higher compared to the value of M_w before COVID-19 (from 4.3 tonnes/day to 34.7284 tonnes/day). This is a highly significant increase compared to the pre-COVID-19 M_w. For Kuala Lumpur, the intra-COVID-19 value is 94% higher than the pre-COVID-19 threshold (from 4.3 tonnes/day to 8.34522 tonnes/day). This is almost double the pre-COVID-19 value but still five times smaller than the Selangor intra-COVID-19 value. Other than that, exactly starting from the Movement

Control Order 3.0, continuing into the National Recovery Plan, and through to the present time, the Mw has increased to over the threshold line and reached the peak value and decreased gradually again to the threshold line. The Mw may even decrease and be maintained at below pre-COVID-19 Mw generation values for the first time in months if the COVID-19 pandemic ceases.

The rise in the rate of medical waste generation poses additional issues in waste management. The method of treatment and disposal is different according to the characteristics of the waste. All medical instruments and materials used for COVID-19 treatment are considered highly infectious. Aside from transmission in medical settings, the virus can also be transmitted during the various phases of medical waste management (pre-treatment, sorting, storage, delivery, retrieval, transportation, and removal). This demands a more efficient and advanced waste management system to properly dispose of infectious waste.

Healthcare workers must pay careful attention to the control and prevention of medical waste generation. Proper planning, standardisation, and identification of specific medical waste management standards must be explored to decrease the possibility of COVID-19 propagating in hospitals, residential, municipalities, and public spaces. To guarantee proper retrieval procedures, municipal solid waste administrators should arrange designated bins for the handling of contagious or hazardous refuse in crowded areas. All required measures are needed, and realistic guidance should be offered, in order to avoid the transmission of SARS-CoV-2. These recommendations must also consider the impact towards economic and societal factors.

This requires an understanding of the generation rate of medical waste at the national and global levels. More research needs to be done to improve the overall waste management system and ways to decrease COVID-19 medical waste. The long-term future of the Mw will depend on government and public efforts.

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