COVID-19 Mathematical Epidemic Model for Impact Analysis of Large Scale Social Restriction: The Case Study of Indonesia

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Abstract. Coronavirus disease 2019 (COVID-19) is an infectious disease caused by Severe Acute Respiratory Syndrome Coronavirus 2. There have been 218,382 confirmed cases of COVID-19, including 8,723 deaths in Indonesia till September 15, 2020. To fight Covid-19, the Indonesian Government modified the lockdown policy to become a large-scale social restriction (LSSR) according to the pandemic level in each region. The LSSR was implemented in DKI Jakarta on April 10, 2020, the epicenter of the Covid-19 outbreak in Indonesia. In this article, we propose the Susceptible-Infected-Hospitalized-Recovered (SIHR) epidemic model for impact analysis of LSSR on epidemic conditions and predict the long-term dynamic COVID-19 in Indonesia. This study extends the SIR model by adding a hospitalized compartment. Finally, we analyze the results of our mathematical model, estimate the model of essential parameters, and predict the disease by considering the real Indonesian cases from March 2 to September 6, 2020. Based on the result, LSSR has a good enough impact on solving the pandemic in Indonesia. One of the factors is because there is a significant difference in transmission rate ($\beta$) values. The new normal transmission rate is 75% higher than the LSSR's.

1. Introduction

Coronavirus disease 2019 (COVID-19) from Wuhan, China, is an infectious disease caused by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) [1]. A person can catch this virus from other humans who have been infected. It has spread widely to 215 countries in the world. The spread of this virus can be through cough or breath droplets from someone infected with COVID-19. These droplets can settle on surrounding objects. Someone can become infected if they touch objects with droplets, and then they touch their eyes, nose, or mouth. If a person inhales these droplets, he or she can also be infected [2].

Every country has a different epidemic level. In most countries where the spread of the virus has led to high outbreaks, physical distancing and movement restrictions, known as lockdowns, are imposed to slow the spread of the COVID-19 outbreak. However, several countries have successfully handled the COVID-19 attack without a lockdown, such as South Korea. Instead of locking up entire cities and cutting direct contact, South Korea focuses on rapid and extensive testing and tracing of all
exposed contacts. Testing and tracking have enabled countries to blunt the exponential spread of disease without having to stop all internal movement and access between cities [3]. Early action and implementation of comprehensive public health measures - such as rapid case identification, rapid testing, complete contact tracing, isolation of positive cases, and subnational quarantine have kept the spread of COVID-19 below the threshold [4].

Till September 15, 2020, there have been 28,918,900 confirmed cases of COVID-19, including 922,252 deaths, reported to WHO. There have been 218,382 confirmed cases of COVID-19, including 8,723 deaths in Indonesia [5]. The first confirmed positive COVID-19 case in Indonesia was announced on March 2, 2020, by President Joko Widodo. Two Indonesian citizens living in Depok, West Java, have tested positive for COVID-19. They have interacted with Japanese citizens who were positive for COVID-19 before them [6]. At that time, the Indonesian Government implemented a lockdown policy under Law Number 6 of 2018 on Health Quarantine in anticipation of the spread of COVID-19 [7]. To fight Covid-19, the Indonesian Government modified the lockdown policy to become a large-scale social restriction (LSSR) according to the pandemic level in each region. The LSSR was implemented in DKI Jakarta on April 10, 2020, the epicenter of the Covid-19 outbreak in Indonesia. Technically, the types of community activities regulated in the LSSR Guidelines for the acceleration of handling COVID-19 include dismissing schools (school from home) and workplaces (work from home), restrictions on religious, public places, and socio-cultural activities, and restrictions on transportation modes. After three months of passing through the emergency response period and LSSR, the Indonesia Government began to explore implementing a new normal life and loosening the LSSR [8].

Indonesia is a vast country with different outbreak intros so that the management of epidemics between regions is not the same. Therefore data on confirmed COVID-19 cases is also fluctuating and difficult to predict. Until early September, the confirmed cases were still happening and tended to increase day by day.

Several studies have been conducted to study the spread of COVID-19. Mathematical models have been proposed by authors in their research in several countries, such as China [9][10][11], India [12][13], Italy [14], Mexico [15], Indonesia [16][17]. The simplest way to model the spread of disease in a population is to classify people into different compartments or groups. The compartment model uses a system of differential equations that tracks the population as a function of time and groups them into different groups based on infection status. In [18][19][20], the authors proposed a basic susceptible-infected-recovered (SIR) model. This study extends the SIR model by adding a hospitalized compartment, namely the SIHR model (susceptible-infected-hospitalized-recovered).

We proposed dynamical coefficients to quantify the variation of infectivity and intervention policies to adjust the pandemic's social responses in our model. Then we simulate the results about advancing or postponing, reinforcing, or weakening relevant systems. Through mapping the containment policies into measurable interval coefficients to observe their influence on the epidemic, the results of our model introduce statistical pieces of evidence that such systems can effectively suppress or even block the outbreak of COVID-19. Finally, we analyze the results of our mathematical model, estimate the model of important parameters, and predict the disease by considering the real Indonesian cases from 2 March to 6 September 2020.

2. Development of Model

In this study, we proposed SIHR (Susceptible-Infected-Hospitalized-Recovered) model to analyze the impact of LSSR on epidemic conditions and predict the long-term dynamic COVID-19 in Indonesia. This study extends the SIR model by adding a hospitalized. Several studies have been conducted to study the spread of COVID-19. Mathematical models have been proposed by authors in their research in several countries, such as China [11], India [13], Italy [14], Mexico [15], Indonesia [17] [18][19]. The compartment model uses a system of differential equations that tracks the population as a function of time and groups them into different groups based on infection status. The purpose of this study was to analyze the impact of LSSR on epidemic conditions and predict the long-
term dynamic COVID-19 in Indonesia. To achieve this goal, we divide the human population into four categories based on their health status can be seen in Figure 1.

![Susceptible, Infected, Hospitalized, Recovered diagram](image)

**Figure 1.** Transmission diagram of COVID-19

Susceptible ($S(t)$) are individuals who have not been infected but can become infected. Infected ($I(t)$) are individuals who are infected with COVID-19 and are able to infect other people. Hospitalized ($H(t)$) are individuals who have been hospitalized for COVID-19. Recovered ($R(t)$) are individuals who no longer have the COVID-19 virus. Therefore

$$N(t) = S(t) + I(t) + H(t) + R(t).$$

(1)

The Table 1 contains a description of each parameter used in the model.

**Table 1.** Description Of Parameters

| Notation | Description       |
|----------|-------------------|
| $\beta$  | Transmission rate |
| $\mu$    | Death rate        |
| $\varepsilon$ | Hospitalized rate |
| $\alpha$ | Recovery rate of I class |
| $\delta$ | Recovery rate of H class |
| $A$      | Recruitment rate  |

We make the following assumptions for the formulation of the model.

1. Disease induced death only exists for individuals in $I$ and $H$.
2. Infected individuals in hospitals have a chance to recover faster than infected individuals who have not received medical treatment.
3. Recovered individuals have a long-term immunity to COVID-19. So that they don't return to class S.
4. The hospitalized rate of LSSR is higher than the new normal. When the number of infected patients increases day by day, the number of hospitals and medical personnel capable of handling COVID-19 patients is increasingly limited.

Using the transmission diagram given in figure 1 and the aforementioned assumptions, the model to describes the transmission of COVID-19 is expressed as the following systems of equation as follows.

$$\frac{dS}{dt} = A - \beta SI$$

$$\frac{dI}{dt} = \beta SI - (\mu + \alpha + \varepsilon)I$$
\[
\frac{dH}{dt} = \epsilon I - (\mu + \delta)H \\
\frac{dR}{dt} = \alpha I + \delta H
\]

with the initial conditions \( S(t) > 0, I(t) > 0, H(t) \geq 0, R(t) \geq 0 \).

3. Results and discussions

Indonesia is the largest archipelago country in the world, consisting of 17,504 islands [21]. Indonesia is ranked the fourth most populous country in the world with 274 billion people after China (1.44 billion people), India (1.38 billion people), and the United States (331 million people) [22]. Till September 15, 2020, there have been 28,918,900 confirmed cases of COVID-19, including 922,252 deaths, in the world. There have been 218,382 confirmed cases of COVID-19, including 8,723 deaths in Indonesia [5]. Based on this, Indonesia ranks 9th in Asia and 25th globally with the most COVID-19 infection cases [23].

In this section, we analyze the results of our mathematical model, estimate the model of essential parameters, and predict the disease by considering the real Indonesian cases from March 2 to September 6, 2020. The real data used in this article downloaded from the official website of the Indonesian Task Force for Handling COVID-19 (https://covid19.go.id/peta-sebaran). The LSSR was start implemented on April 10, 2020. Technically, the types of community activities regulated in the LSSR Guidelines for the acceleration of handling COVID-19 include dismissing schools (school from home) and workplaces (work from home), restrictions on religious, public places, and socio-cultural activities, and restrictions on transportation modes. So for about three months, most people carry out their activities from home. During that time, the community had meetings, studies, seminars, and online discussions using conference applications such as Zoom and Google Meeting. Restaurants only provide a takeaway service using a delivery service application such as Go-Food and Grab-Food. Religious places are also closed so that people worship from home. School and campus students learn from home by watching video tutorials from teachers and lecturers or having online discussions using conference applications. Several major cities have been locked down, so that inter-city transportation means are also restricted. The government has prohibited going to their hometown during Eid al-Fitr. Those policies were done to reduce the spread of COVID-19 in Indonesia. After three months of passing through the emergency response period and LSSR, on June 2, 2020, the Indonesia Government began to explore implementing a new normal life and loosening the LSSR.

The Figure 2 illustrates the differences in Indonesia's pandemic conditions between the LSSR period and the new normal when viewed from the number of confirmed and positive COVID-19 patients.

From Figure 2a, it can be seen that the number of confirmed increases increases rapidly in the new normal period. This is because the local government is increasingly aggressively conducting COVID-19 tests on the community. Furthermore, from Figure 2b it can be seen that in the new normal period there was an increase in the number of infected individuals which was higher than in the LSSR period. This is because the intensity of community contact in the new normal period is higher than the intensity of contact during the LSSR period. The easing of the LSSR also resulted in the relaxation of lockdowns in several regions. This has resulted in high mobilization from the red zone of COVID-19 to the green zone of COVID-19, and vice versa.
Figure 2. (a) Daily confirmed COVID-19 in Indonesia, (b) Daily cumulative number of infected COVID-19 in Indonesia

Therefore, in the next step, we estimate these parameters’ value using real data and mathematical models, as listed in system (2). We divide the real data into two parts: data for the LSSR period from March 2 to June 1, 2020, and data for the new normal period from June 2 to September 6, 2020 (the last data collection day). From the real data, we obtain the other parameter values as listed in the following Table 2.

Table 2. Parameters Values

| Parameter | LSSR | New Normal | Unit       |
|-----------|------|------------|------------|
| μ         | 0.035| 0.0555     | Per day    |
| ε         | 0.5  | 0.25       | Per day    |
| α         | 0.001| 0.001      | Per day    |
| δ         | 0.02 | 0.02       | Per day    |
| A         | 2,000| 2,000      | Person per day |

Several parameter values differ between the LSSR period and the new normal period according to the assumptions we used when constructing the model. The LSSR death rate is lower than the new normal. This is because the number of infected patients during the LSSR period was lower in the new normal period so that mortality during the LSSR period was lower. On the other hand, the hospitalized rate of LSSR is higher than the new normal. When the number of infected patients increases day by day, the number of hospitals and medical personnel capable of handling COVID-19 patients is increasingly limited. The recruitment and recovery rate of I and H class are assumed to be the same. From the results of data simulation using Matlab, we obtain a graph comparing pandemic conditions between the LSSR period and the new normal period can be seen in Figure 3.
Based on Figure 3, in both periods, the number of infections increased day by day. However, the number of hospitalized patients during the LSSR period increased higher than the new normal period. During the LSSR period, the number of treatments in Indonesia could still accommodate almost all COVID-19 patients. However, in the new normal period, the number of treatments was limited due to the higher number of infections. The number of hospitalized patients increased in September because the number of recovered patients also increased quite rapidly so that over time the number of treatments increased as well.

From the previous explanation, it is known that the transmission rate ($\beta$) is an essential parameter in the COVID-19 mathematical model. Next, we calculate $\beta$ value using the simulation results of the previous model for each data set. Based on the first equation of system (1), we get

$$\beta = \frac{1}{sr} \left( A - \frac{dS}{dt} \right)$$

(3)

where $t$ denotes the time in days and

$$dS = \Delta S = S(t + 1) - S(t).$$

(4)

Then, a significant difference in $\beta$ values is obtained from these calculations, as listed in the following table.

| Parameter | LSSR          | New Normal       |
|-----------|---------------|------------------|
| $\beta$   | 5.214196498951317 x 10^{-7} | 6.878624326294266 x 10^{-7} |

Based on Figure 4, LSSR has a good enough impact on solving the pandemic in Indonesia. One of the factors is because there is a significant difference in transmission rate ($\beta$) values. Based on table 3, the new normal transmission rate is 75% higher than the LSSR's. This causes the effectiveness of transmission to be higher, and the disease will become more widespread. From the results of this study, it is predicted that the disease will disappear in October 2020 if the LSSR conditions are applied. However, due to the implementation of new normal conditions in June 2020, it is predicted that the disease will begin to disappear at the end of February 2021.
4. Conclusions

Until September, the confirmed cases of COVID-19 in Indonesia were still happening and tended to increase day by day. Based on the result, LSSR has a good enough impact on solving the pandemic in Indonesia. One of the factors is because there is a significant difference in transmission rate parameter. The intensity of community contact in the new normal period is 75% higher than the intensity of contact during the LSSR period. This causes the disease will become more widespread. From the results of this study, it is predicted that the disease will disappear in October 2020 if the LSSR conditions are applied. However, due to the implementation of new normal conditions in June 2020, it is predicted that the disease will begin to disappear at the end of February 2021.

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