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Jakarta COVID-19 Forecast with Bayesian PIRD Multiwave Model

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ABSTRACT

Governments have to consider both socioeconomic and health conditions in handling the COVID-19 pandemic. To help them in understanding possible scenarios behind the numbers and deciding optimum policy, this study proposed a Bayesian protected-infected-recovered-dead (PIRD) multi-wave model. Compounds of the Richards curve are used to understand how many pandemic waves possibly occur, how significant is the occurrence of every single wave, and dynamic in every single wave. The model also estimated the mortality rate due to the COVID-19 pandemic and the duration between infection to death, also infection to recovery. We fitted Jakarta's COVID-19 data from 3 March 2020 to 25 November 2021 with help of OpenBUGS. We learned that their pandemic should consist of at least two waves, expected to have three waves already. By letting social restriction be looser together with decreasing number of new infection cases, Jakarta could have its fourth and even fifth pandemic wave that starts around mid-May to mid-July 2022 and reach its peak around January to February 2023. Vice versa, they could enter the endemic phase around the end of August 2022 until the beginning of February 2023 and finally have zero COVID-19 new infection around mid-January until mid-June 2023 by having stricter social restrictions.

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1. INTRODUCTION

Since its first case was detected on 17 November 2019 in Wuhan (Romagnani *et al*., 2020), and the first case outside China was found in Thailand on 13 January 2020 (Suntronwong *et al*., 2020), the COVID-19 pandemic worried and disrupted lives of a global society. Quick spread in both local and international transmissions (Whitworth, 2020) influenced social distancing and created misery due to substantial effects on the environment, energy, society, economy, also global protective measures.

As remote work increased stress and reduces work-life-balance (Sandoval-Reyes & Idrovo-Carlier, 2021), remote education caused learning loss especially related to handwriting fluency and quality, and the other struggle occurred, "new normal" living is introduced as long as a society keep to wear their masks (Rab *et al*., 2020) also have their vaccination and regular physical activity exercise. Even some countries permit their citizens to stop wearing a mask after getting fully vaccinated (https://www.everydayhealth.com/coronavirus/fully-vaccinated-people-no-longer-need-to-wear-masks-in-most-cases-cdc-says).

When the economy started to recover and back into the growth pathway (Yap, 2020), many new cases which previously went down started to rise again and the next COVID-19 wave is unavoidable. Countries go back to struggling conditions (Horton, 2021) as more people are looking for testing (Vedhara, 2021), and more patients need medical treatment (https://www.reuters.com/world/asia-pacific/indonesia-has-enough-oxygen-covid-19-patients-health-minister-2021-06-25), and even another lockdown. It is learned that some areas already have more than two waves of COVID-19 pandemic, for example, South Korea (Shim, 2021) and Iran (Heidari & Jafari, 2021) with four waves, also Pakistan (Kamran, 2021) and Afghanistan (Nemat & Asady, 2021) with three waves.

Indonesian government claimed that their country has one of the best COVID-19 handling in the world (https://en.tempo.co/read/1506693/indonesias-covid-19-handling-among-the-best-in-the-world-ministry) and it is quite supported by fact that Centers for Disease Control and Prevention (CDC) of United States per 22 October 2021 listed them as level one country which has lowest risk of COVID-19 spread, when nearest neighbors such as Singapore and Malaysia are still listed as level one country which has highest risk of COVID-19 spread (https://www.kompas.com/tren/read/2021/11/23/195500165/indonesia-masih-di-level-1-covid-19-versi-cdc-bagaimana-negara-tetangga-?page=all). However, not long after Jakarta as its capital city implemented lowest level for enforcement of restrictions on community activities (called Pemberlakuan Pembatasan Kegiatan Masyarakat in Bahasa Indonesia), the level is raised back one step (https://www.cnbcindonesia.com/news/20211130170458-16-295577/waspada-status-ppkm-dki-jakarta-naik-jadi-level-2) and even ever be considered to be raised again during year-end period (https://prfmnews.pikiran-rakyat.com/nasional/pr-133141184/pemerintah-tetapkan-ppkm-level-3-mulai-24-desember-hingga-3-januari-begini-aturan-nataru-2022). It is interesting to know if the raised level is only intended for prevention of new cases spike due to long holiday and new Omicron variant, or government understood later that Jakarta implemented too loose social restriction and influenced number of new cases to rise again.

2. LITERATURE REVIEW

COVID-19 is a pandemic caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). It has the unique characteristic of SARS when patients suffer a decrease in peripheral T cell subsets. Patients with COVID-19 can develop pneumonia, severe symptoms of acute respiratory distress syndrome, and multiple organ failure due to uncontrolled inflammatory

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responses (Yang *et al.*, 2020). COVID-19 spreads faster in the area with low temperature, a higher ratio of old than working-age people, number of international tourists, high level of physical contact, and low vitamin D serum levels (Notari & Torrieri, 2021).

Five initial COVID-19 variants of concern are Alpha, Beta, Gamma, Delta, and Omicron, in which Delta is the most fatal and Omicron is the most infectious one which is responsible for the latest pandemic hit worldwide. Omicron has three subvariants, which are the original BA.1 with around 90% proportion of cases in the beginning stages, later also coming BA. 2 surpassing BA. 1 and the less known BA. 3. First Omicron case is identified around November 2021 in Botswana (Karim & Karim, 2021) and its risk classification is considered as very high by WHO (Burki, 2021). Delta targets the lower respiratory tract when BA. 1 is more likely to infect and replicate in the upper one.

Less Omicron patients are treated in hospitals than in previous variants. They also need significantly less oxygen therapy, mechanical ventilation, admission to intensive care, and length of stay (Maslo *et al.*, 2022). Although its lower severity is due to less efficient replication and fusion (Zhao *et al.*, 2021), BA. 1 has a faster transmission and a 5.4-fold higher reinfection risk than delta. BA. 2 has more growth rate and transmission than BA. 1 when BA. 3 has slower transmission due to the lack of six additional mutations owned by BA. 1. Omicron is also harder to cure due to the lower neutralization rate by several monoclonal antibodies than previous variants, such as bamlanivimab, imdevimab, casirivimab, tixagevimab, cilgavimab, and sotrovimab. Moreover, BA. 2 variants are more difficult to test and identify with the PCR method due to a lack of signature deletion, then needs specific PCR named S-gene target failure (SGTF) to differentiate it from the Delta variant.

Vaccine effectiveness against the Omicron variant is considerably good, even though it is still lower than the delta variant. Two doses of primary course and a one-time booster give effectiveness over 60% up to nine weeks after receiving the booster, when it drops down before 10% at 25 or more weeks (Andrews *et al.*, 2022). Later the two Omicron subvariants, BA.1 and BA. 2, mixed to introduce a new recombinant variant called XE that is more transmissible but also will die off relatively quick (Islam, 2022). Then, Zhang *et al*. (2022) proposed and developed a newer mRNA vaccine which is lipid nanoparticle-encapsulated and can be stored in a refrigerator for up to six months.

The first case of COVID-19 in Indonesia is found in March 2020 and related to the Amigos dance club in Jakarta. There is still a significant proportion of Indonesian travelers who did not cancel their international trips (Iin Rachmawati, 2020) until the Indonesian government responded by issuing some policies related to physical distancing and large-scale social restrictions. The acceptance rate for the COVID-19 vaccine is considerably high compared to other countries and PeduliLindungi mobile application has helped Indonesia to pass the peak period and anticipate newer COVID-19 variants.

COVID-19 vaccines used for Indonesians are including Sinovac (Heriyanto *et al.*, 2021), AstraZeneca, Moderna, Pfizer, and Sinopharm. Together with COVID-19 test results, vaccine logs and certificates are uploaded into the PeduliLindungi application (Tanra & Tusholehah, 2022) which has similar features to Trace Together in Singapore and My Sejahtera in Malaysia. PeduliLindungi is also required to check-in when visiting public places to make sure that the visitor is negative for COVID-19 and already got at least two doses of vaccination (Locarso, 2022). The success of Indonesian COVID-19 handling is also due to volunteers working for emergency hospitals (Helmi *et al.*, 2021), remote learning (Husni Rahiem, 2021), teleworking (Novianti & Roz, 2020), and postponement of public events may cause physical contact (Zahrotunnimah, 2021).

3. METHODS

In this section, we explained the data source and the Bayesian Safe-Infected-Dead-Recovered (SIDR) multi-wave model that we used to forecast the situation of the COVID-19 pandemic in Jakarta. The fitting process to get posterior distributions of model parameters was also going to be explained.

3.1. Data source

We downloaded daily COVID-19 official data in form of a spreadsheet from Jakarta's government, downloaded from https://tiny.cc/Datacovidjakarta on 26 November 2021 at 5.30 PM (Jakarta time). We used the first sheet that contains 635 rows of data starting from 1 March 2020 until 25 November 2021. The first day with cases occurred on 3 March 2020 with one death and two patients being hospitalized. At the end of the study period, there were 863687 cumulative cases with 13576 deaths, 849638 recoveries, 274 patients were in self-isolation, and 199 patients were in hospitalization.

Empirically, **Figure 1** shows that there are three local peaks in the plot of daily new COVID-19 cases with the third peak as the global peak. According to the data, most daily new cases occurred on 12 July 2021 with 14619 cases, most active cases occurred on 16 July 2021 with 113138 cases, most daily new deaths occurred on 20 July 2021 with 265 cases, and most daily recoveries occurred on 11 July 2021 with 20570 cases. **Figure 2** suggests that there are at least two waves already occurred with the first wave starting to be significant around July to October 2020 and flattening around February to May 2021, while when the second wave started to be significant around June 2021 to August 2021 and flattened around September 2021.

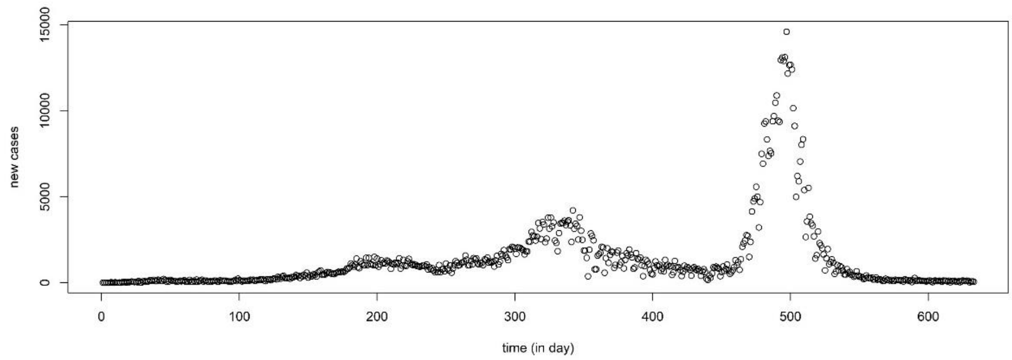

Figure 1. Daily new COVID-19 cases in Jakarta.

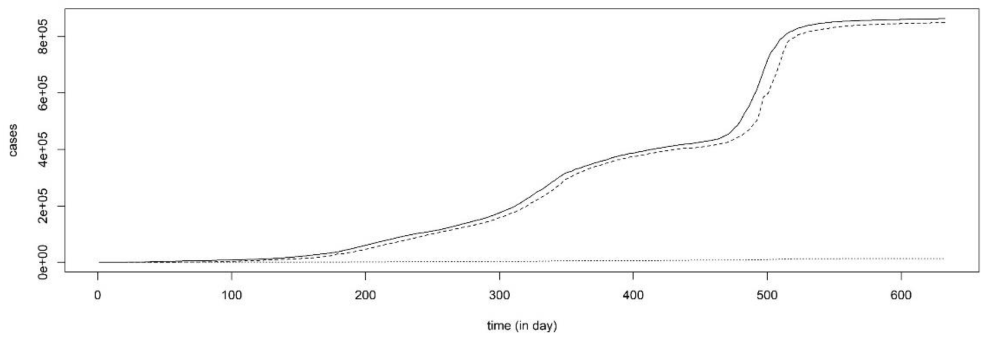

Figure 2. Cumulative number of cases (solid line), recoveries (dashed line), and deaths (dotted line).

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3.2. Bayesian PIRD multi-wave model

A lot of models have been created to understand the COVID-19 pandemic, including the Richards model, generalized growth model, classical logistic growth model, generalized logistic model, suspected-infected-recovered (SIR) model (Zreiq *et al.*, 2020), Verhulst model (Abusam *et al.*, 2020), Bertalanffy-Putter model (Brunner & Kühleitner, 2021), suspected-infected-recovered-dead (SIRD) model (Lounis & Raeei, 2021), suspected-exposed-infected-recovered (SEIR) model (Yang *et al.*, 2021), susceptible-exposed-infected-quarantined-recovered-dead (SEIQRD) model, susceptible-exposed-infected-asymptotic undetected-asymptotic detected-recovered ($SEIA_uA_dR$) model (Aldila *et al.*, 2020), and susceptible-exposed-infected-hospitalized-critical-recovered-dead (SEIHCRD) model (Mbogo & Orwa, 2021) model. Later models tried to assess more states and details but we are not going to have similar features in our model due to lack of data and even though we have many self-isolation and hospitalizations, we chose not to model them because both health conditions of the cases and bed availability in hospitals play a significant part to determine the number of hospitalizations. Those models also do not have the adequate ability to capture multi-wave dynamics as suggested by empirical analysis in **Figure 1** and **Figure 2**, multi-wave model is significantly needed and should be preferred over the single-wave model.

The multiple wave forced-SIR models (Kaxiras & Neofotistos, 2020) are introduced to leave the single wave assumption. It can capture several pandemic waves that occurred, but the result is deterministic instead of considering the possibility of having more or fewer waves than expected. Complex epidemic Renormalisation Group model (CeRG) multi-wave model (Cot *et al*., 2021), Bayesian structural time series model (Xie, 2021), and modified protected-susceptible-exposed-infected-recovered-deaths (PSEIRD(S)) model (Beira & Sebastião, 2021), also served deterministic results with a harder model form to understand than multiple wave forced-SIR model. Stochastic results are given through Bayesian inference and implemented multi-wave model consists of single waves assumed to have lognormal distribution (Blonigan *et al*., 2021), but determining the number of cases needs a stepwise model with a different number of waves.

Another important thing to understand is the adequate duration of COVID-19 case isolation to determine travel quarantine and hospitalization to prepare enough capacity beds. With an average incubation period of 8.29 days and a latent period is 2.9 days, it is suggested that testing on exit (or entry and exit) can reduce travel quarantine duration from fourteen days to seven days, and testing only on entry shortens fourteen days of quarantine by at most one day. The median of symptom onset to death in hospitalized patients in the United Kingdom varies between six to fifteen days for cases before 1 August 2020 based on age group, while after 1 August 2020 it decreased to a range of two to eight days (https://www.gov.uk/government/publications/co-cin-covid-19-time-from-symptom-onset-until-death-in-uk-hospitalised-patients-7-october-2020).

Learning from previous works, we designed and implemented a protected-infected-recovered-dead (PIRD) model to be learned by Bayesian inference. The number of cumulative infections is constructed by the compounding of the reparameterized Richards curve and in this study, we assumed that Jakarta has no more than five pandemic waves. The mathematical model form of every single wave is inspired by Lee *et al.* (2020) and shown as (1).

$$f(t;\theta_1,\theta_2,\theta_3,\xi) = \theta_1 \times [1+\xi \cdot \exp\{-\theta_2 \times (t-\theta_3)\}]^{-\frac{1}{\xi}} \tag{1}$$

Comparing to model form in Roosa *et al.* (2020) and Nuraini *et al.* (2020), we learned that θ_1 represents the final epidemic size, ξ represents scaling of growth parameter, θ_2 represents

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the growth rate, and θ_3 represents the lag phase. Learning from parameter estimates by [38], later we set domain for ξ and θ_2 in interval of [0, 1]. To be able to detect the possibility of more waves in the future, we set a domain for θ_3 in an interval of (0, ∞). When we were mixing several Richards curves to have our multi-wave model, we had to ensure that sum of each wave's θ_1 value does not exceed the population size in Jakarta which is around 11 million (https://www.macrotrends.net/cities/21454/jakarta/population). Therefore, we decided to split this 11 million population size into groups to be infected in every single wave and protected to be safe from the COVID-19 infection.

Denoting K_i as a proportion of the infected population in i^{th} pandemic wave for i = 1, 2, 3, 4, and 5, or K_6 as a proportion of the protected population to be not infected in any pandemic wave, we have to ensure that the total of them must be one. Setting total population size as n variable, the occurrence of the i^{th} pandemic wave as β_i (zero if not occurs or one if occurs), time variable (in a unit of days) as t, reparameterizing ξ as α, θ_2 as g, and θ_3 as p, also letting each pandemic wave have independent values of α, g, and p, we can define $y_{i,t}|\beta_i = 1$ as the number of cumulative cases in i^{th} pandemic wave at day t (since the start of the first pandemic wave) given the wave occurs as (2).

$$\left(y_{i,t}|\beta_i = 1\right) = \frac{K_i \times n}{\left(1+\alpha_i \times e^{-g_i \times (t-p_i)}\right)^{\frac{1}{\alpha_i}}} \tag{2}$$

Therefore, the total of cumulative cases infected in every wave as of day t could be defined as (3).

$$y_t = \sum_{i=1}^{5}\{\left(y_{i,t}|\beta_i = 1\right) \times \beta_i\} \tag{3}$$

Another feature that we would like to add to this model is its capability to project the number of deaths and recoveries. By assuming that a case infected in day t will be dead exactly in a day ($t + t_d$) with the probability of p_d or recovered in a day ($t + t_r$) with the probability of ($1 - p_d$), then we could define cumulative deaths in day t as d_t and cumulative recoveries in day t as r_t with mathematical form in (4) and (5). Until this step, a high-level understanding of this model is explained in **Figure 3**.

$$d_t = y_{t-t_d} \times p_d \tag{4}$$
$$r_t = y_{t-t_r} \times (1 - p_d) \tag{5}$$

Later when we fitted the model, we did not estimate p_i directly instead of estimating duration between lag phases denoted as s_i. In other words, s_1 is the lag phase for wave 1 and s_i is the duration between the lag phase for wave (i-1) with wave i. Therefore, for each i, p_i could be defined as (6).

$$p_i = \sum_{j=1}^{i} s_i, i = 1,2,3,4,5 \tag{6}$$

In fact, the duration between infection and death, also the duration between infection and recovery are not exact. Due to the condition that the number of infections, deaths, and recoveries are only recorded once a day, we simplify our assumption that t_d and t_r are discrete binomial random variables with prior distributions defined as (7), (8), (9), and (10).

$$t_d \sim binomial\left(n = 30, p_{t_d}\right) \tag{7}$$
$$t_r \sim binomial\left(n = 30, p_{t_r}\right) \tag{8}$$
$$p_{t_d} \sim U(0,1) \tag{9}$$
$$p_{t_r} \sim U(0,1) \tag{10}$$

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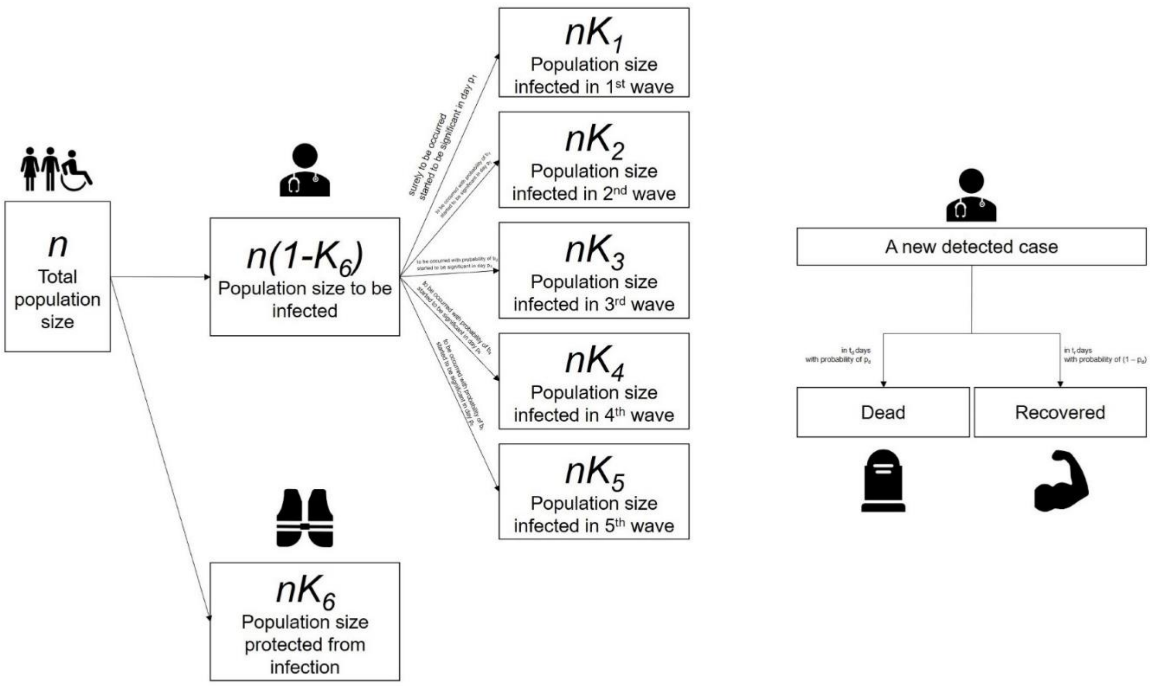

Figure 3. High-level understanding of Bayesian PIRD multi-wave model

Prior distributions for other parameters are defined as (11), (12), (13), (14), (15), (16), (17), and (18). Value for β_1 should be 1 as we know already that the COVID-19 pandemic happens, so at least one wave occurs.

$$\alpha_i \sim U(0,1), i = 1,2,3,4,5 \tag{11}$$
$$g_i \sim U(0,1), i = 1,2,3,4,5 \tag{12}$$
$$s_i \sim \exp(\lambda = 0.01), i = 1,2,3,4,5 \tag{13}$$
$$K \sim dirichlet(1,1,1,1,1,1) \tag{14}$$
$$\beta_1 = 1 \tag{15}$$
$$\beta_i \sim binomial(1, b_i), i = 2,3,4,5 \tag{16}$$
$$b_i \sim U(0,1), i = 2,3,4,5 \tag{17}$$
$$p_d \sim U(0,1) \tag{18}$$

The random variables of cumulative infections, deaths, and recoveries in day t are denoted as Y_t, D_t, and R_t, respectively. The sampling model for those variables is defined as (19), (20), and (21).

$$Y_t \sim Poisson(y_t) \tag{19}$$
$$D_t \sim Poisson(d_t) \tag{20}$$
$$R_t \sim Poisson(r_t) \tag{21}$$

3.3. Model fitting process

To estimate model parameters, we fit the data into our model by using OpenBUGS 3.2.3 (https://www.mrc-bsu.cam.ac.uk/software/bugs/openbugs). We fit all data for cumulative cases when we discarded the first thirty days of data for cumulative deaths and recoveries. Two Markov chains with 500 burned iterations and 2500 kept iterations per chain and the thinning rate at 1 are fitted with quad-cores Intel® Core™ i7 11th generation processor and 32GB RAM. Two cores are used in parallel to speed up fitting duration with help of the pbugs package (https://github.com/fisabio/pbugs) in R version 4.1.1 (https://r-project.org).

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4. RESULTS AND DISCUSSION

4.1. Model fitting performance

We assessed how well our model fits the data of cumulative infection cases with graphical and numerical assessments. **Figure 4** shows that the expected number of cumulative cases as a result of the first chain (represented by dashed line) and second chain (represented by dotted line) fit well with the actual number of cumulative cases (represented by solid line). **Table 1** shows the Mean Absolute Error (MAE) and Root Mean Squared Error (RMSE) of both two chains. They are still below 5% of the unweighted mean calculated from daily cumulative cases in the data source. Then, together with a high R-squared (R^2) score, it shows that the model can explain variation in data source well.

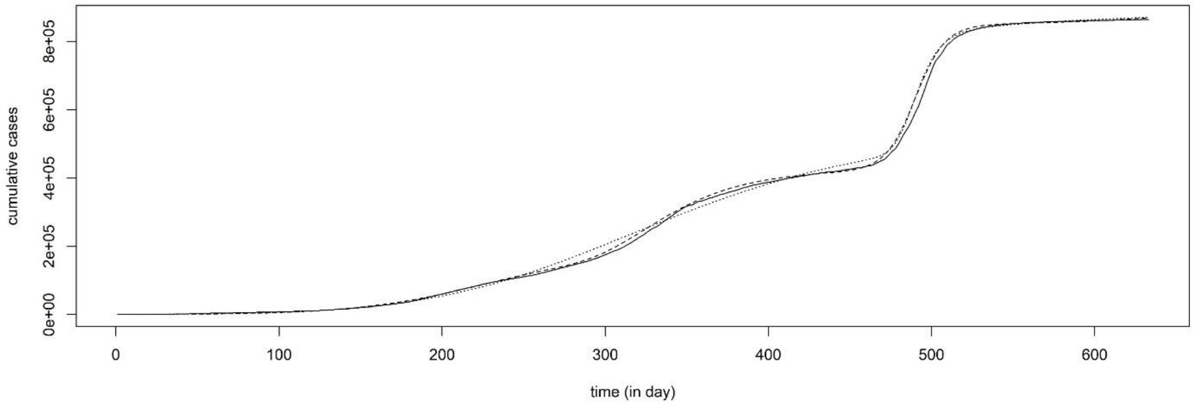

Figure 4. The actual number of cumulative infections versus the expected number fitted.

Table 1. RMSE, MAE, and R^2 scores of fitted cumulative infections from the two chains.

Chain	Unweighted mean of daily cumulative cases	MAE	RMSE	R^2
1	320062	5149.32	8880.44	99.92%
2		8161.22	12646.76	99.84%

We also assessed how well our model fits the data on cumulative deaths and recoveries. **Figure 5** shows that fit for recoveries is well and the number of cumulative deaths is quite overestimated. **Table 2** shows that MAE and RMSE of recoveries are under 5% of their unweighted mean, while MAE and RMSE of deaths are higher than 5% but under 15% of their unweighted mean. However, the R^2 score shows that variation in both cumulative numbers of deaths and recoveries is still well explained by the model.

Combining parameter estimates from these two chains, we obtained that b_2 = 50%, b_3 = 100%, b_4 = 32%, b_5 = 69%. The numbers show that the COVID-19 pandemic in Jakarta should have at least two waves, with possibilities of another wave occurrence being significant under the 5% significance level. As shown in **Table 3**, it is expected that the protected population in Jakarta is only between 24.36% to 38.89% of the total population size under a 95% confidence level which indicates that they still have to put high awareness on pandemic handling since it means that more population are ever infected than never infected. Even if they survive later, it was reported that they have to face a continuous impact on the cognitive and functional decline even if they only had mild symptoms (Baker *et al*., 2021).

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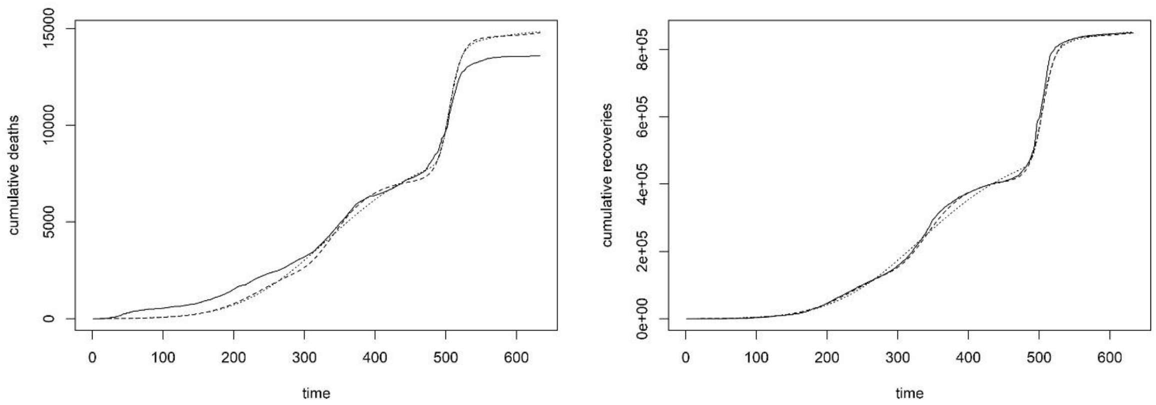

Figure 5. The actual number of cumulative deaths (left) and recoveries (right) versus the expected number fitted by the model.

Table 2. RMSE, MAE, and R^2 score of fitted cumulative recoveries and deaths from the two chains.

Chain	The unweighted mean of daily cumulative cases		MAE		RMSE		R^2	
	Recovery	Death	Recovery	Death	Recovery	Death	Recovery	Death
1	302617	5263	4780.48	513.96	9270.22	619.77	99.91%	98.29%
2			8824.94	504.78	13445.82	621.96	99.81%	98.27%

Table 3. Summary statistics from posterior distributions of K_i.

x	$\overline{x}$	σ_x	Median	95% CI
K_1	3.29%	1.63%	3.10%	(1.59%, 5.41%)
K_2	14.97%	12.96%	7.25%	(2.03%, 32.04%)
K_3	3.48%	0.37%	3.36%	(2.83%, 3.90%)
K_4	23.26%	5.13%	24.90%	(16.72%, 30.28%)
K_5	23.68%	11.20%	23.29%	(11.78%, 35.70%)
K_6	31.32%	3.93%	30.04%	(24.36%, 38.89%)

Table 4 shows that Jakarta could be already in its third wave at the end of our study period. They have to be aware of the possibility of the next wave which is expected to start from mid-May to mid-July 2022. We do not suggest their government switch the status from pandemic to endemic until February 2023.

Table 5 shows that the projected mortality rate due to COVID-19 in Jakarta is 1.71% with both infection-death and infection-recovery duration projected to be in the range of 10 to 20 days under 95% confidence level. It will be better if Jakarta could maintain bed availability in hospitals and isolation centers to be able to accommodate patients in 20 days, so their health condition could be monitored adequately with a quick medical response in emergencies and the government could ensure that they do not join together with a healthy society.

4.2. Daily cases forecast and COVID-19 handling recommendation

The next factor that we would like to discuss in this section is our forecast. As our data source provided numbers for 633 days, we had our forecast also for the next 633 days. Our forecast is served in base 10 logarithm of daily new infections as depicted in **Figure 6** with a

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regular dashed line, dotted line, dot-dash line, solid line, long-dashed line, and two-dashes line, all are black colored, represent 2.5-percentile, 25-percentile, median, mean, 75-percentile, and 97.5-percentile of our forecast, respectively. The red solid line means that there is only one new infection and indicates the end of the pandemic.

Table 4. Summary statistics from posterior distributions of p_i.

x	$\overline{x}$	σ_x	Median	95% CI
p_1	2.71 x 10^2	4.43 x 10^1	2.72 x 10^2	(2.24 x 10^2, 3.23 x 10^2)
p_2	3.64 x 10^2	3.72 x 10^1	3.68 x 10^2	(3.26 x 10^2, 4.02 x 10^2)
p_3	4.90 x 10^2	5.34 x 10^{-1}	4.90 x 10^2	(4.89 x 10^2, 4.90 x 10^2)
p_4	8.07 x 10^2	2.09 x 10^2	7.99 x 10^2	(4.97 x 10^2, 1.05 x 10^3)
p_5	8.73 x 10^2	1.81 x 10^2	8.94 x 10^2	(5.38 x 10^2, 1.07 x 10^3)

Table 5. Summary statistics from posterior distributions of p_d, p_{t_d}, and p_{t_r}.

x	$\overline{x}$	σ_x	Median	95% CI
p_d	1.71 x 10^{-2}	9.48 x 10^{-6}	1.71 x 10^{-2}	1.71 x 10^{-2}
p_{t_d}	5.00 x 10^{-1}	8.78 x 10^{-2}	5.00 x 10^{-1}	(3.30 x 10^{-1}, 6.69 x 10^{-1})
p_{t_r}	4.99 x 10^{-1}	8.77 x 10^{-2}	5.00 x 10^{-1}	(3.30 x 10^{-1}, 6.68 x 10^{-1})

Therefore, we are going to interpret **Figure 6** as the following. If Jakarta let pre-COVID normal lifestyle sooner be reimplemented, we worry that a 75-percentile case with its fourth pandemic wave could occur. Especially if some societies violate the rules, the pandemic situation could be as worse as the expected case and even Jakarta could have its fifth pandemic wave as seen in **Figure 7**. In both situations, new daily infection cases could go between ten to thirty thousand during peak season. The worst scenario in our calculation, represented by a 97.5-percentile case, could occur with new daily infection cases could surpass 380000 at the peak. For those three scenarios, we expect that the COVID-19 pandemic will still be there as of 20 August 2023.

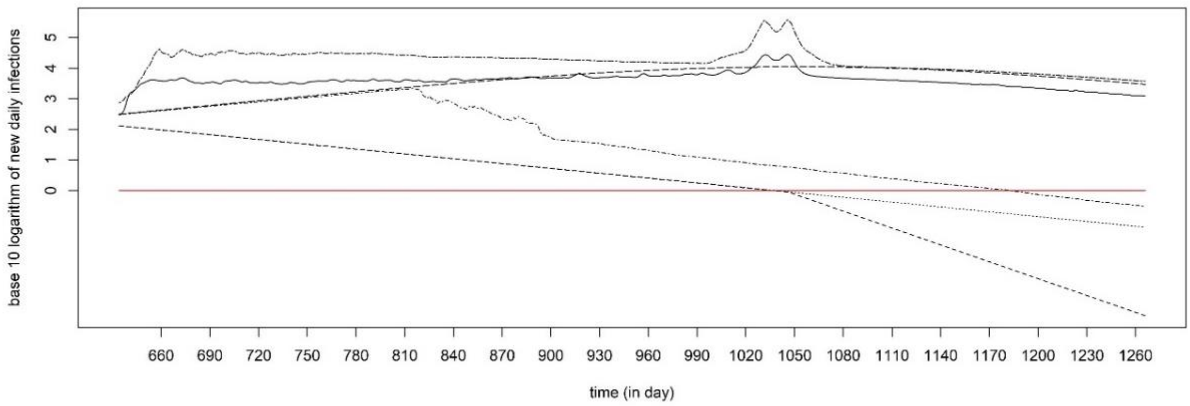

Figure 6. Daily new infections forecast for day 634 (26 November 2021) to 1266 (20 August 2023).

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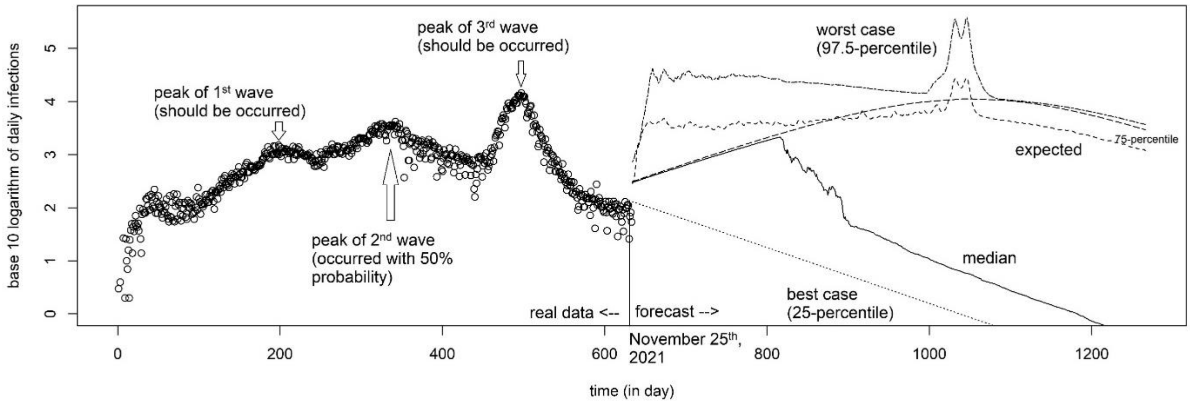

Figure 7. Occurred cases from the beginning of COVID-19 infection in Indonesia to 25 November 2021 combined with forecast up to 20 August 2023.

Otherwise, we could expect that the pandemic ends before 20 August 2023 if we give extra effort to handle COVID-19. We recommend two scenarios below and do not expect any stricter social restrictions since we expect that they will harm economics without giving a significant impact on the pandemic wave.

(i) In the median case, Jakarta could enter the endemic phase at the end of August 2022 and finally has zero COVID-19 new infection in mid-January 2023. We could reach this situation by:
   (i) Permitting a maximum of 40% back officers and 70% front officers in essential sectors to work from the office,
   (ii) Permitting shopping centers, traditional markets, supermarkets, and groceries store to operate with a maximum of 50% capacity, eight hours duration, and two hours visits per person,
   (iii) Permitting restaurants to have dine-in customers with a maximum of 25% capacity and one-hour duration,
   (iv) Permitting wedding reception to have maximum guests at 85% of room capacity without any onsite meal,
   (v) Permitting public transport to have maximum passengers at 80% of its capacity,
   (vi) Other activities such as worshipping, watching films in the cinema, and doing exercise in fitness centers are being permitted to have 50% maximum capacity and 95 minutes of maximum duration,
   (vii) Asking international flight passengers to show covid-19 negative results at least by antigen test (maximum d-1), no matter how many vaccination shots that they got already,
   (viii) Obliging plane passengers who are just coming from other countries to have their 14-days travel quarantine,
   (ix) Prohibiting physical learning activities at school,
   (x) Letting as many as a possible population to get their booster vaccination shot.

(ii) In the 25-percentile case, Jakarta could enter the endemic phase at the beginning of February 2023 and finally has zero COVID-19 new infection in mid-June 2023. We could reach this situation by:
   (i) Permitting a maximum of 20% back officers and 60% front officers in essential sectors to work from the office,

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(ii) Permitting shopping centers, traditional markets, supermarkets, and groceries store to operate with a maximum of 40% capacity, eleven hours duration, and 100 minutes visit per person,
(iii) Permitting wedding reception to have maximum guests at 75% of room capacity without any onsite meal,
(iv) Permitting public transport to have maximum passengers at 50% of its capacity,
(v) Other activities such as worshipping, watching films in the cinema, and doing exercise in fitness centers are being permitted to have 25% maximum capacity and 70 minutes of maximum duration,
(vi) Asking international flight passengers to show covid-19 negative results by pcr test (maximum d-1) or two times antigen test (the first should occur between d-4 to d-3 and the second should occur maximum d-1), no matter how many vaccination shots that they got already,
(vii) Obliging plane passengers who are just coming from other countries to have their 14-days travel quarantine,
(viii) Prohibiting dine-in activities at a restaurant and physical learning activities at school,
(ix) And letting as much as a possible population get their booster vaccination shot.

4.3. Comparison between the forecast and the actual result

Later we compared our projection results with updated data up to 23 April 2022. Actual daily cases are better than the expectation of our PIRD model in 106 of 149 days (71.14%) and it is worse for the rest. Compared to the prediction interval of our PIRD model result, 34 days (22.82%) are better than 2.5-percentile, 48 days (32.21%) are between 25-percentile and median, 63 days (42.28%) are worse than 97.5-percentile, and the rest are between 50-percentile to 75-percentile.

5. CONCLUSION

This study proposes a protected-infected-recovered-dead (PIRD) model to understand if the COVID-19 pandemic in an area consists of single wave or multi-wave, together with dynamics in each wave and how infected cases turn into recoveries or deaths. Bayesian inference is implemented to understand possible scenarios behind realization numbers that are presented in the data source. Model parameters are fitted with OpenBUGS to forecast numbers of cumulative infections, deaths, and recoveries in Jakarta by assuming that they have at most five pandemic waves.

If Jakarta decides to reimplement the pre-COVID normal lifestyle sooner, they could face a fourth and even fifth pandemic wave that starts around mid-May to mid-July 2022 and reaches its peak around January to February 2023. Otherwise, a stricter social restriction policy could avoid the fourth pandemic wave and let Jakarta enter the endemic phase around the end of August 2022 until the beginning of February 2023, and finally have zero COVID-19 new infection around mid-January until mid-June 2023.

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7. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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