The bayesian model of Covid-19 case fatality rate proportion on provinces in Indonesia

D Devianto\textsuperscript{1,2}, A N Afifah\textsuperscript{2} and I K Febrianti\textsuperscript{3}

\textsuperscript{1}Department of Mathematics, Dharma Andalas University, Padang 2500, Indonesia
\textsuperscript{2}Department of Mathematics, Andalas University, Padang 25163, Indonesia
\textsuperscript{3}Department of Biomedics, Andalas University, Padang 2500, Indonesia

Corresponding author : ddevianto@sci.unand.ac.id

Abstract. The Covid-19 pandemic has spread to all parts of Indonesia with different case fatality rates (CFR) between regions. The estimating parameter of the proportion of people who die compared to the number of people who test positive for coronavirus (parameter of CFR) can be determined using the Bayesian method approach. The estimation parameter of CFR is performed by using prior beta distribution, and the results have good performance with a high degree of accuracy. The choice of Bayesian model that can be built is a fixed effect model where the proportion of case deaths in each province is assumed to be mutually independent. Still, the movement of people between regions continues to occur so that a random effect model is more rational to be applied where the proportion of case deaths for each province is assumed to be the same as estimating parameter of CFR which is smaller than the current condition of Indonesia. The estimation parameter results of the CFR parameters are expected to be achieved by the Indonesian government by implementing Covid-19 controls system for each province as a mitigation diseases strategy.

1. Introduction
In early March 2020, Indonesia confirmed the first case of coronavirus disease (Covid-19) in two patients living in Depok regency of West Java, where this disease was initially endemic in Wuhan, China, in December 2019. The Covid-19 is an infectious disease of an acute respiratory syndrome caused by SARS-CoV-2, which belongs to a large family of coronaviruses that cause SARS such as in 2003. Until June 12, 2020, the World Health Organization (WHO) had reported 7,410,510 positive cases spread in 215 infected countries with the number of deaths reaching 418,294. At the same time, in Indonesia, Covid-19 has spread to 34 provinces [1] with 36,406 cases and 2,048 deaths.

Various protocols and efforts to handle Covid-19 have been carried out throughout Indonesia, ranging from the establishment of referral hospitals, the establishment the way of employee by Work From Home (WFH) in various agencies and companies, large-scale social restrictions to the entry and exit permit an area. However, death from this disease cannot be avoided. The mortality rate for each region in Indonesia varies, depending on treatment efforts and various other factors. The death rate referred to here is the case fatality rate (CFR), which is calculated based on the proportion of people who die compared to the number of people who test positive for being infected with the virus. Proportion is a parameter that is not known as a whole, so we need to build a procedure to predict the parameter, which is commonly referred to as parameter estimation.
The parameter estimating process of the proportion of death cases in the pandemic is a challenging thing to do as the information to be known in taking policy. Researchers from various parts of the world have reported their research results in the form of reports or articles published in scientific journals concerning empirical research of Covid-19, this study can be useful as a consideration for policy making by governments in a country, one of which is a review from [2] about the model and control of Covid-19 in China. The spread of Covid-19 is higher than SARS [3], other hand the research by [4] compares CFRs from SARS, Covid-19 and seasonal influenza and concludes that the danger of Covid-19 cannot be underestimated as is the case with seasonal influenza. Furthermore, the estimation of CFR in real terms is made by [5,6] which compares the mortality rate with the infection rate 14 (fourteen) days before transmitted. The results of this estimation are in accordance with the CFR estimation model conducted by [7] using the Gaussian distribution. However, according to [8] the calculation of CFR per total case is the best estimate for expressing the fatality rate of Covid-19 disease although it is less effective if done early in the appearance of the case. In addition, [9] have estimated the CFR based on age and sex based on a history of positive case deaths in one of the Provinces in Canada.

Recent research on predicting CFR of Covid-19 disease involving various factors has also been carried out as in [10,11]. Estimation of the proportion of deaths using the Bayesian method was carried out by [12] to predict the number of deaths due to Covid-19 in Peru. In the Bayesian method, the parameter of the proportion of deaths (CFR) is seen as a random variable describing preliminary knowledge about the parameter before observations are made and expressed in a distribution that is the prior distribution [13]. Furthermore, the sample data will be combined with information in the prior distribution through the Bayesian theorem and the results of the parameter estimation are expressed in the form of a posterior distribution. Bayes [12] modeled the daily death case as a random variable with the Poisson distribution with the estimated death rate using non-informative priors. In this paper, it will be explored the estimation of the proportion of deaths in Covid-19 cases in 34 provinces in Indonesia, it is using the Bayesian method, where the estimation parameter is done by modeling the number of cases of death due to Covid-19 as a random variable with binomial distribution by using specific prior for fixed effect and random effect models.

2. Methodology

2.1. Data source
The data in this study are secondary data downloaded from the website covid-19.go.id which contains data on the development of Covid-19 disease in Indonesia from the beginning of the first case until June 12, 2020. The data are extracted for ranking the proportion of case deaths, cumulative data from 34 (thirty four) provinces in Indonesia such as in Table 1.

2.2. Stage of research analysis
Based on these data of Covid-19 disease in Indonesia, the parameters were estimated for the proportion of case fatalities in 34 provinces in Indonesia by using Bayesian method both theoretically and its application through the suitable software. The steps for applying the methods to the data is perform as follows:
1) Assume that the number of deaths in each of the provinces has binomial distribution with the proportion considered as a parameter of the case fatality rate (CFR),
2) Determine the prior distribution of parameter by using prior Beta(a,b) distribution.
3) Determine the posterior distribution and then determine the posterior mean as a point estimation.
4) Evaluate the Mean Square Error (MSE) value from the results of the point estimation.
5) Determine the estimated interval for parameter.

The estimation of the proportion parameter value is done by the Bayesian Markov Chain Monte Carlo (MCMC) approach, which is a numerical approach to obtain the posterior distribution especially if the posterior distribution of the parameter is suspected to have a nonstandard and complicated form. The steps included as follows:
1) Determine the model that relates to the data and parameters to be expected. In this case, a fixed effect model and a random effect model are used.

2) Determine the prior distribution for presumed parameters i.e. the prior Beta(\(a,b\)) distribution for the fixed effect model and the logit function is used for the random effect model.

3) Making the interpretation of the results estimation obtained based on the prior distribution and display in several forms such as tables and ranking plots.

| Provincial Number | Province          | Number of Positive Cases | Number of Deaths | Number of Recovery | CFR (Case Fatality Rate) |
|-------------------|-------------------|--------------------------|------------------|--------------------|--------------------------|
| 01                | Aceh              | 22                       | 1                | 18                 | 4.55%                    |
| 02                | Bali              | 695                      | 5                | 448                | 0.72%                    |
| 03                | Banten            | 1157                     | 76               | 417                | 6.57%                    |
| 04                | Bangka Belitung   | 132                      | 1                | 48                 | 0.76%                    |
| 05                | Bengkulu          | 95                       | 4                | 49                 | 4.21%                    |
| 06                | DI Yogyakarta     | 262                      | 8                | 196                | 3.05%                    |
| 07                | DKI Jakarta       | 8740                     | 540              | 3781               | 6.18%                    |
| 08                | Jambi             | 106                      | 0                | 27                 | 0.00%                    |
| 09                | Jawa Barat        | 2572                     | 161              | 1057               | 6.26%                    |
| 10                | Jawa Tengah       | 1876                     | 103              | 681                | 5.49%                    |
| 11                | Jawa Timur        | 7421                     | 575              | 1865               | 7.75%                    |
| 12                | Kalimantan Barat  | 267                      | 4                | 146                | 1.50%                    |
| 13                | Kalimantan Timur  | 373                      | 4                | 239                | 1.07%                    |
| 14                | Kalimantan Tengah | 565                      | 29               | 215                | 5.13%                    |
| 15                | Kalimantan Selatan| 1694                     | 116              | 179                | 6.85%                    |
| 16                | Kalimantan Utara  | 170                      | 2                | 135                | 1.18%                    |
| 17                | Kepulauan Riau    | 238                      | 16               | 128                | 6.72%                    |
| 18                | Nusa Tenggara Barat| 891                      | 31               | 520                | 3.48%                    |
| 19                | Sumatera Selatan  | 1304                     | 47               | 543                | 3.60%                    |
| 20                | Sumatera Barat    | 671                      | 29               | 407                | 4.32%                    |
| 21                | Sulawesi Utara    | 644                      | 52               | 97                 | 8.07%                    |
| 22                | Sumatera Utara    | 768                      | 57               | 205                | 7.42%                    |
| 23                | Sulawesi Tenggara | 277                      | 5                | 180                | 1.81%                    |
| 24                | Sulawesi Selatan  | 2582                     | 110              | 830                | 4.26%                    |
| 25                | Sulawesi Tengah   | 159                      | 4                | 95                 | 2.52%                    |
| 26                | Lampung           | 153                      | 11               | 109                | 7.19%                    |
| 27                | Riau              | 120                      | 6                | 108                | 5.00%                    |
| 28                | Maluku Utara      | 285                      | 22               | 40                 | 7.72%                    |
| 29                | Maluku            | 387                      | 10               | 104                | 2.58%                    |
| 30                | Papua Barat       | 200                      | 2                | 86                 | 1.00%                    |
| 31                | Papua             | 1197                     | 7                | 78                 | 0.58%                    |
| 32                | Sulawesi Barat    | 97                       | 2                | 66                 | 2.06%                    |
| 33                | Nusa Tenggara Timur| 105                      | 1                | 37                 | 0.95%                    |
| 34                | Gorontalo         | 181                      | 7                | 79                 | 3.87%                    |

3. Results and Discussion
The CFR value due to Covid-19 in Indonesia is in general at 5.63%. This CFR value is equivalent to the estimation results from the first wave Covid-19 pandemic in China studied by [13]. Based on this
evidence, it is very important for Indonesia to deal with the modeling of estimating CFR parameters as mitigation of coronavirus disease.

**Tabel 2.** Results of estimating parameter of the proportion of death of Covid-19 cases by using the Bayesian method with prior Beta(1.1) distribution for Fixed Effect.

| Provincial Code Number | Mean     | Standard Deviation | MC Error | Lower Bound 2.50% | Median   | Upper Bound 97.50% |
|------------------------|----------|--------------------|----------|-------------------|----------|-------------------|
| p[01]                  | 0.08329  | 0.05524            | 1.213E-04| 0.01072           | 0.07182  | 0.21960           |
| p[21]                  | 0.08205  | 0.01080            | 2.283E-05| 0.06214           | 0.08160  | 0.10430           |
| p[28]                  | 0.08014  | 0.01600            | 3.582E-05| 0.05171           | 0.07917  | 0.11410           |
| p[11]                  | 0.07760  | 0.00310            | 6.966E-06| 0.07164           | 0.07755  | 0.08381           |
| p[26]                  | 0.07750  | 0.02144            | 4.853E-05| 0.04096           | 0.07571  | 0.12450           |
| p[22]                  | 0.07533  | 0.00951            | 2.112E-05| 0.05784           | 0.07493  | 0.09505           |
| p[17]                  | 0.07091  | 0.01655            | 3.561E-05| 0.04195           | 0.06971  | 0.10660           |
| p[15]                  | 0.06902  | 0.00616            | 1.424E-05| 0.05742           | 0.06885  | 0.08158           |
| p[03]                  | 0.06645  | 0.00732            | 1.633E-05| 0.05281           | 0.06621  | 0.08150           |
| p[09]                  | 0.06292  | 0.00478            | 1.098E-05| 0.05388           | 0.06281  | 0.07265           |
| p[07]                  | 0.06188  | 0.00257            | 5.623E-06| 0.05695           | 0.06185  | 0.06700           |
| p[27]                  | 0.05737  | 0.02092            | 4.850E-05| 0.02363           | 0.05496  | 0.10460           |
| p[10]                  | 0.05539  | 0.00528            | 1.202E-05| 0.04550           | 0.05523  | 0.06624           |
| p[14]                  | 0.05292  | 0.00938            | 1.982E-05| 0.03607           | 0.05238  | 0.07274           |
| p[05]                  | 0.05147  | 0.02227            | 4.962E-05| 0.01722           | 0.04835  | 0.10300           |
| p[20]                  | 0.04456  | 0.00795            | 1.796E-05| 0.03034           | 0.04410  | 0.06132           |
| p[34]                  | 0.04383  | 0.01507            | 3.407E-05| 0.01921           | 0.04219  | 0.07756           |
| p[24]                  | 0.04296  | 0.00398            | 8.964E-06| 0.03546           | 0.04284  | 0.05111           |
| p[19]                  | 0.03675  | 0.00521            | 1.185E-05| 0.02725           | 0.03650  | 0.04764           |
| p[18]                  | 0.03581  | 0.00621            | 1.438E-05| 0.02462           | 0.03547  | 0.04889           |
| p[06]                  | 0.03412  | 0.01116            | 2.497E-05| 0.01573           | 0.03295  | 0.05910           |
| p[25]                  | 0.03100  | 0.01366            | 2.905E-05| 0.01017           | 0.02903  | 0.06286           |
| p[32]                  | 0.03036  | 0.01721            | 3.796E-05| 0.00633           | 0.02723  | 0.07204           |
| p[29]                  | 0.02828  | 0.00840            | 1.767E-05| 0.01427           | 0.02745  | 0.04685           |
| p[23]                  | 0.02152  | 0.00867            | 1.999E-05| 0.00796           | 0.02039  | 0.04147           |
| p[33]                  | 0.01864  | 0.01299            | 2.863E-05| 0.00232           | 0.01573  | 0.05125           |
| p[12]                  | 0.01858  | 0.00822            | 1.813E-05| 0.00610           | 0.01742  | 0.03787           |
| p[16]                  | 0.01744  | 0.00997            | 2.227E-05| 0.00365           | 0.01559  | 0.04173           |
| p[04]                  | 0.01494  | 0.01045            | 2.411E-05| 0.00183           | 0.01261  | 0.04125           |
| p[30]                  | 0.01484  | 0.00848            | 1.899E-05| 0.00307           | 0.01326  | 0.03546           |
| p[13]                  | 0.01335  | 0.00593            | 1.335E-05| 0.00434           | 0.01250  | 0.02720           |
| p[08]                  | 0.00926  | 0.00915            | 2.112E-05| 0.02405           | 0.00647  | 0.03383           |
| p[02]                  | 0.00862  | 0.00349            | 7.767E-06| 0.00317           | 0.00816  | 0.01663           |
| p[31]                  | 0.00667  | 0.00234            | 4.963E-06| 0.00289           | 0.00640  | 0.01197           |
| **Pop. Mean**          | 0.04399  | 0.01117            | 2.487E-05| 0.03352           | 0.04257  | 0.06591           |

The parameter of CFR in this study will be estimated by the Bayesian method, it is followed by ranking the proportion of case deaths for each province and its interpretation according to the current conditions. At the initial stage of this modeling, the proportion of case fatalities in each province is assumed to be mutually independent so that the resulting model is a fixed effect model using prior
Beta($a, b$) distribution. Furthermore, the posterior distribution is determined for the data of 34 provinces with their likelihood and prior multiplications which also follow the Beta($x+a, n-x+b$) distribution for $n$ as the number of positive cases and $x$ as the number of deaths. From the resulting posterior distribution, the posterior mean can be obtained as a result of point estimation by the Bayesian method for fixed effect.

To determine the best estimator value for CFR parameter can be done by evaluating the point estimation of the performed method. This evaluation can be done by utilizing the nature of unbiased property and Mean Square Error (MSE) values. The property of unbiased estimator is determined by comparing the posterior mean values while the MSE is determined by utilizing the precision (variance) and accuracy (bias) of the estimator values. In [12], it is using the prior Beta($a, b$) distribution to have MSE based on parameters in the binomial distribution of the beta distribution. The estimation parameters of the Bayesian model by using WinBugs is done as many iterations as to produce a more precise, convergent estimation in an interval confident and close to the actual parameter values. For the fixed effect model, it is assumed that the parameters of CFR is independent of each province which means it is proportional to assuming the non-informative prior distribution for estimation is Beta(1,1) distribution. Furthermore, posterior variance and simulation error (MC error) can be calculated so that the interval estimation that is obtained from the upper bound and lower bound presented in Table 2.

In the Table 2, it can be seen that MC error is relatively small, it is meaning that the Bayesian method with prior Beta($a, b$) distribution results in a pretty good estimation of parameters. It can be seen that the posterior mean representing the Bayesian proportion estimator from the first province (Aceh) is the highest posterior mean, which is 8.33%. After Aceh, the provinces with the highest proportion of case fatalities were Sulawesi Utara (8.21%) followed by Maluku Utara (8.01%) and Jawa Timur (7.76%) to the last being Papua with the lowest proportion of case deaths 0.67%. DKI Jakarta Province which had the highest positive case turned out to have a reasonably low proportion of deaths estimated at 11th place with 6.19%. This could be because they are doing more testing so it is closer to counting the actual number of cases that have been mentioned.

Furthermore, it is assumed that the proportion of case deaths in each province is interrelated because the transmission of Covid-19 is still occurring, so the resulting model is a random effects model. The model used is binomial($n,p$) distributed data with $n$ as the number of positive cases and $p$ as the probability of death cases, where logit function for the proportion of deaths that are normally distributed with mean $\mu$ and variance $\tau$. In this logit function, the parameter for the normal distribution $\mu$ is considered a random variable with a normal distribution $N(0,10^{-6})$ and parameter $\tau$ is considered a random variable with Gamma($10^{-3},10^{-3}$) distribution by its specific property of infinitely divisible exponential distribution [14] and Levy measure of gamma distribution [15]. The results of the prediction can be seen in Table 3 as the random effect model.

Table 3 shows the estimated proportion of deaths in 34 provinces in Indonesia with the assumption that in the future one day the proportion of deaths will be the same as 3.35%. There is a significant difference in the proportion of deaths in each province compared to the estimation results with the fixed effects model in Table 1. The highest proportion of case fatalities was occupied by Sulawesi Utara with 7.82% and the lowest proportion in Papua with an estimated value of 0.82%. The proportion of Covid-19 deaths in Papua is the lowest because it is influenced by the age distribution factor of positive Covid-19 patients as discussed by [16]. Besides, Bali Province which is one of the 5 (five) provinces with the highest cure rates as explained by [17] has the result of estimating a low proportion of case fatalities, which is ranked second from bottom. It can be said that the Province of Bali is a province with good enough and consistent handling in controlling Covid-19.
Tabel 3. Results of estimating parameter of the proportion of death of Covid-19 cases by using Bayesian method with prior Beta(1,1) distribution for Random Effect.

| Provincial Code Number | Mean      | Standard Deviation | MC Error | Lower Bound 2.50% | Median   | Upper Bound 97.50% |
|------------------------|-----------|--------------------|----------|-------------------|----------|-------------------|
| p[21]                  | 0.07816   | 0.01042            | 2.389E-05| 0.05904           | 0.07772  | 0.09970           |
| p[11]                  | 0.07725   | 0.00311            | 7.138E-06| 0.07130           | 0.07722  | 0.08341           |
| p[22]                  | 0.07226   | 0.00922            | 2.037E-05| 0.05533           | 0.07189  | 0.09126           |
| p[28]                  | 0.07201   | 0.01467            | 3.144E-05| 0.04620           | 0.07101  | 0.10350           |
| p[15]                  | 0.06765   | 0.00608            | 1.314E-05| 0.05624           | 0.06749  | 0.07999           |
| p[03]                  | 0.06459   | 0.00716            | 1.557E-05| 0.05134           | 0.06434  | 0.07927           |
| p[26]                  | 0.06414   | 0.01821            | 4.034E-05| 0.03384           | 0.06238  | 0.10460           |
| p[17]                  | 0.06232   | 0.01476            | 3.523E-05| 0.03681           | 0.06117  | 0.09431           |
| p[09]                  | 0.06211   | 0.00476            | 1.103E-05| 0.05314           | 0.06200  | 0.07169           |
| p[07]                  | 0.06164   | 0.00258            | 5.909E-06| 0.05673           | 0.06160  | 0.06678           |
| p[10]                  | 0.05441   | 0.00523            | 1.161E-05| 0.04470           | 0.05425  | 0.06501           |
| p[14]                  | 0.04998   | 0.00890            | 1.971E-05| 0.03414           | 0.04946  | 0.06876           |
| p[27]                  | 0.04593   | 0.01650            | 3.817E-05| 0.01988           | 0.04384  | 0.08368           |
| p[20]                  | 0.04258   | 0.00761            | 1.743E-05| 0.02904           | 0.04214  | 0.05862           |
| p[24]                  | 0.04242   | 0.00397            | 8.862E-06| 0.03504           | 0.04230  | 0.05049           |
| p[01]                  | 0.04127   | 0.02515            | 6.134E-05| 0.00962           | 0.03566  | 0.10490           |
| p[05]                  | 0.04015   | 0.01665            | 3.637E-05| 0.01509           | 0.03764  | 0.07918           |
| p[34]                  | 0.03791   | 0.01264            | 2.824E-05| 0.01764           | 0.03640  | 0.06670           |
| p[19]                  | 0.03595   | 0.00510            | 1.144E-05| 0.02675           | 0.03571  | 0.04648           |
| p[18]                  | 0.03477   | 0.00602            | 1.309E-05| 0.02406           | 0.03444  | 0.04736           |
| p[06]                  | 0.03129   | 0.00977            | 2.154E-05| 0.01536           | 0.03024  | 0.05320           |
| p[25]                  | 0.02811   | 0.01118            | 2.514E-05| 0.01103           | 0.02657  | 0.05405           |
| p[29]                  | 0.02706   | 0.00765            | 1.628E-05| 0.01432           | 0.02634  | 0.04393           |
| p[32]                  | 0.02687   | 0.01275            | 2.948E-05| 0.00854           | 0.02474  | 0.05742           |
| p[23]                  | 0.02145   | 0.00774            | 1.828E-05| 0.00928           | 0.02051  | 0.03898           |
| p[33]                  | 0.02037   | 0.01043            | 2.535E-05| 0.00570           | 0.01849  | 0.04568           |
| p[12]                  | 0.01933   | 0.00740            | 1.797E-05| 0.00783           | 0.01838  | 0.03625           |
| p[16]                  | 0.01903   | 0.00864            | 1.942E-05| 0.00629           | 0.01767  | 0.03932           |
| p[04]                  | 0.01798   | 0.00905            | 2.261E-05| 0.00514           | 0.01639  | 0.03968           |
| p[30]                  | 0.01714   | 0.00769            | 1.906E-05| 0.00574           | 0.01597  | 0.03518           |
| p[08]                  | 0.01566   | 0.00883            | 2.160E-08| 0.00370           | 0.01398  | 0.03722           |
| p[13]                  | 0.01508   | 0.00570            | 1.353E-05| 0.00621           | 0.01439  | 0.02794           |
| p[02]                  | 0.01050   | 0.00369            | 9.695E-06| 0.00471           | 0.01009  | 0.01863           |
| p[31]                  | 0.00817   | 0.00261            | 6.372E-06| 0.00403           | 0.00791  | 0.01369           |
| Pop. Mean              | 0.03354   | 0.00502            | 1.430E-05| 0.02462           | 0.03335  | 0.04362           |

The graphics of the proportion of deaths due to Covid-19 in 34 provinces can be seen in Figure 1 for their rank probabilities and Figure 2 for their rank scatter plots. It can be seen that Province of Sulawesi Utara still has the highest proportion rate as the first rank in Indonesia, this result is inline with the random effect model. In addition, the Province of Papua is ranked 34th, which means the lowest predictive value is in accordance with the previous discussion where the estimated value of Papua province is not inline with the estimated value from other provinces, which means the probability of the estimated value of the proportion of case fatalities in Papua is quite low (close to 1).
Figure 1. The rank of histogram of the proportion of deaths in 34 provinces in Indonesia.

Figure 2. Scatter plot ranking versus the estimating parameter of the proportion of death of Covid-19 cases of 34 provinces in Indonesia

The final result of estimating CFR according to the random effect model with population mean 3.35% tends to be small when compared to the CFR reported by the Ministry of Health of the Republic of Indonesia [1] which is around 5.60%. From the various data processing series above, ranking can be done but some regions have the same opportunity to be in a certain rank. Consistent control and handling of Covid-19 is expected to be carried out evenly and comprehensively for each province in Indonesia, so that the current CFR value can later fall to the estimate in the random effects model.
4. Conclusion
The estimating parameters of the proportion of Covid-19 case deaths in 34 provinces in Indonesia can be determined by using the Bayesian method. The estimation parameter of the proportion of case fatalities rate using prior beta distribution gives better results in terms of MSE values and the length of the confidence interval. The estimating parameters by using Bayesian method gives quite different results for the fixed effect model and the random effect model. However, there are similarities in the two models applied, namely the lowest proportion of case fatalities occupied by selected province where very small estimated CFR of <1% was obtained. In the random effect model where the proportion of case fatalities in each province is assumed to be the same with CFR target value is 3.35%. It is hoped that the results of this estimation can be achieved by the Indonesian government as the mitigation diseases strategy by applying Covid-19 controls and handling that is consistent evenly and thoroughly for each province.

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