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COVID-19-Infected Cases in Thailand During the Omicron Wave Using the Capture-Recapture Method

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Abstract

Thailand is among many countries, severely affected by the COVID-19 pandemic. In December 2021, the Thai Ministry of Public Health announced the discovery of the first imported case of the Omicron variant, and the local transmission of the Omicron variant was confirmed. The Omicron variant spread rapidly but was less dangerous than the Delta. Some patients experienced mild or no symptoms and self-treated without requiring medical assistance. Lower fatality rates during the Omicron outbreak were reported compared with previous variants. Information concerning hidden COVID-19-infected patients is beneficial and will lead to a better understanding of the disease outbreak mechanism. This study proposed the lower bound estimator under the capture-recapture (CR) method to estimate the true value of COVID-19 infections in Thailand during the Omicron wave. The Chao lower bound estimator for the Poisson mixture model was created to take into account the fact that populations can be different based on how cases and deaths have been spread out over time. The approximate variance of the estimator was constructed for a confidence interval of 95%, focusing on the ratio of total estimated infected cases to observed cases in March 2022. The average ratio was 2.99 (95% CI: 2.96 to 3.01), suggesting that for every 100 observed patients, at least 199 infected patients were underreported.

Keywords: Capture-recapture, Poisson mixture model, Chao estimator, COVID-19.

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Introduction

COVID-19 is a respiratory infectious disease caused by the SARS-CoV-2 virus. Common symptoms are fever, chills, cough, and breathing difficulties. COVID-19 was first discovered in Wuhan, Hubei Province, China in December 2019. The virus spread rapidly around the world, and the World Health Organization (WHO) declared COVID-19 a global pandemic on March 11, 2020.[1] Thailand was indexed as the top country handling COVID-19 in 2020 but has been facing an uncontrolled outbreak since April 2021, with both protective behavior and mass vaccination applied as control measures. The Thai Government implemented the new normal D-M-H-T-T measures as 1). Distancing, 2). Mask wearing, 3). Hand washing, 4). Temperature testing, and 5). Check-in application Thai-Cha-Na.[2] Thailand has attempted to find the optimal strategy to solve the COVID-19 epidemic. In April 2021, a vaccination policy was initiated among medical personnel. Getting vaccinated boosts immunity by creating an antibody, thereby reducing the risk of disease spread, severe illness and death, and ultimately reconnecting with society. The Thai Government targeted 50 million people, or 70% of the population, to receive the first vaccination dose to create "herd immunity" or "population immunity" as protection from an infectious disease that occurs when enough individuals develop immunity through vaccination or previous infection.[3] The WHO also recommended increasing the COVID-19 vaccine rate in Thailand to significantly reduce levels of severe illness and deaths caused by circulating COVID-19 strains. High vaccination rates also help reduce the transmission of COVID-19.

As represents cumulative numbers of people receiving at least one dose of the COVID-19 vaccine, the graph shows the increasing percentage of Thai people vaccinated from March 2021 to March 2022. By 1 March 2022, 76.9% of the population had been vaccinated with the primary series for COVID-19 protection, and 71.2% has received at least one booster dose as shown in Figure 1

However, herd immunity did not occur in reality, with the virus strain changing from Delta to the Omicron

Figure 1 Cumulative numbers of people receiving at least one dose of the COVID-19 vaccine[2]

variant. Thailand reported the first Omicron cluster on 24 December 2021.[2] The Omicron variant broke Thailand's record for the highest number of daily confirmed cases but the fatality rate during the Omicron wave was lower than during the previous outbreak.[4-5] The omicron variant spread rapidly but was less dangerous than the Delta. Some patients experienced mild or no symptoms and self-treated without requiring medical assistance. The efficiency of vaccines and the new Omicron variant of COVID-19 also led to an increase in the number of asymptomatic patients.

The number of confirmed COVID-19 infections is widely available but might be underreported in official statistics and the available data provide part of the story. Several studies also stated that numbers of undiagnosed cases of COVID-19 were much higher than those official reported.[6-7] For example, reports estimate the number of infected in the USA to be around 1.9 times higher than reported.[8] For Italy, likely more than 200% of infections have been undocumented.[9] since there focuses on only testing in hospital with symptoms. Another study points out that probably less than 25% cases were identified by March 31, 2020 in Wuhan, China.[10] Therefore, the total number of infections is unknown and requires to be estimated. Many approaches have been suggested to estimate undetected and total cases for COVID-19 such as a time-dependent transmission model,[10] an application of probability model for estimating the proportion of undetected COVID-19 infected cases,[11] and an agent-based model by considering the ratio between detected and undetected cases of COVID-19.[12]

This research proposed an estimator based on a simple and effective capture-recapture (CR) method to achieve sensible lower bound point and confidence interval estimates of the total number of COVID-19 infected cases in Thailand. CR approaches are widely used in ecology for estimating elusive target population size and they have also been used in epidemiology and health science applications.[13-15] The concept behind the capture-recapture (CR) approach is to use the history of individuals who have been captured to estimate the unobserved part. In the analysis of COVID-19 data, the population is considered open due to deaths and heterogeneity in the probability of being detected. To address the heterogeneous occurrence in CR data, an applied version of the original Chao's estimator that is based on the Poisson mixture model is used.[16]

This is a foundational method that typically provides the lower bound population size when heterogeneity is present based on the Poisson model.[17-18] The lower bound result is important as it provides policymakers with reasonable information about the undetected cases and the potential impact it may have on national health systems during Omicron wave. This will allow them to be aware of the minimum number of cases that may require healthcare services. The Chao estimator based on the Poisson mixture model method uses only the frequencies of individuals caught once and caught twice. In the context of COVID-19, those caught once are the ones newly identified on a given day, and those caught twice are the ones newly identified the day before, subtracted by the number of deaths on the given day. Here, the modified estimator was used to answer the question: "What was the true scale of COVID-19 infection in Thailand during the Omicron wave?". Information concerning hidden COVID-19 infected patients is beneficial and will lead to a better understanding of the disease outbreak mechanism.

Methods

Basic notation and data

The cumulative count of infractions at day t, and D(t) defines the cumulative count of deaths at day t_m where $t = t_0, \ldots, t_m$. Therefore, the number of new infections at days t is $\Delta N(t) = N(t) - N(t-1)$, and the count of new deaths at day *t* is $\Delta D(t) = D(t) - D(t-1)$, where $t = t_0 + 1, \ldots, t_m$ and $t_m > t_0$. The time series of cumulative infection cases and deaths between 1 March 2022 and 31 March 2022 to estimate the lower bound of the true number are shown in Table 1 and 2.

Table 1 Cumulative COVID-19 infections during March 2022

t	1/03	2/03	3/03	4/03	5/03	6/03	7/03	8/03	9/03	10/03	
N(t)	2,912,347	2,934,544	2,958,162	2,981,996	3,004,814	3,026,695	3,047,857	3,066,800	3,088,873	3,111,857	
t	11/03	12/03	13/03	14/03	15/03	16/03	17/03	18/03	19/03	20/03	
N(t)	3,136,649	3,161,241	3,184,825	3,206,955	3,226,697	3,250,642	3,276,098	3,303,169	3,328,973	3,353,969	
t	21/03	22/03	23/03	24/03	25/03	26/03	27/03	28/03	29/03	30/03	31/03
N(t)	3,377,410	3,398,792	3,423,956	3,450,980	3,477,030	3,503,264	3,529,085	3,553,720	3,575,398	3,600,787	3,628,347

Table 2 Cumulative COVID-19 deaths during March 2022

t	1/03	2/03	3/03	4/03	5/03	6/03	7/03	8/03	9/03	10/03	
D(t)	22,976	23,021	23,070	23,124	23,176	23,235	23,300	23,369	23,438	23,512	
t	11/03	12/03	13/03	14/03	15/03	16/03	17/03	18/03	19/03	20/03	
D(t)	23,575	23,643	23,709	23,778	23,848	23,918	23,995	24,075	24,162	24,246	
t	21/03	22/03	23/03	24/03	25/03	26/03	27/03	28/03	29/03	30/03	31/03
D(t)	24,334	24,417	24,497	24,579	24,648	24,715	24,799	24,880	24,958	25,045	25,130

These data sets are taken from https://covid19.ddc.moph.go.th/api which is an official annulment from the Department of Disease Control of Thailand and is openly available for all developers. Cumulative counts of infected patients and deaths were selected to achieve the goal. The number of recoveries was ignored, with the focus on the true number of infected cases at day t. The identified day t and the day before were assumed to be infections, adjusted by the number of deaths on an interesting day.

Statistical methods

The CR approach was modified to estimate the size of underreported COVID-19 cases. Let X_i denote the number of identifications for each infected individual i, and p_x represent the probability of identifying each patient exactly x times where x = 0, 1, 2,... A modification of the Chao lower bound estimator under the Poisson mixture model was proposed as the alternative estimator for unobserved population heterogeneity[16]. The repeated count probability was considered as a mixed Poisson with arbitrarv mixing density h(λ) as

$$p_x = \int_0^\infty \frac{\exp(-\lambda)\lambda^x}{x!} h(\lambda)d\lambda \quad (1)$$

Then, using the Cauchy-Schwarz inequality of any two random variables X and Y, this becomes

$$[E(XY)]^2 \le E(X^2)E(Y^2) \quad (2)$$

Suppose that h(λ) denotes arbitrary densities on parameter λ, and let the variables $X = \sqrt{e^{-\lambda}\lambda}$ and $Y = \sqrt{e^{-\lambda}}$. Then, $E(XY) = \int_0^\infty e^{-\lambda}\lambda h(\lambda)d\lambda$, $E(X^2) = \int_0^\infty e^{-\lambda}\lambda^2 h(\lambda)d\lambda$, $E(Y^2) = \int_0^\infty e^{-\lambda} h(\lambda)d\lambda$. Thus, any Poisson mixture probability can be represented as

$$\left(\int_0^\infty e^{-\lambda}\lambda h(\lambda)d\lambda\right)^2 \le \left(\int_0^\infty e^{-\lambda} h(\lambda)d\lambda\right)\left(\int_0^\infty e^{-\lambda}\lambda^2 h(\lambda)d\lambda\right). \quad (3)$$

Since , $p_0 = \int_0^\infty e^{-\lambda} h(\lambda)d\lambda$, $p_1 = \int_0^\infty e^{-\lambda}\lambda h(\lambda)d\lambda$, and $p_2 = \int_0^\infty \frac{e^{-\lambda}\lambda^2}{2!} h(\lambda)d\lambda$, a lower bound for the hidden probability p_0 can be represented as $\frac{p_1^2}{2p_2} \le p_0$. Multiplying the probabilities by the population size (*N*) leads to $\frac{(Np_1)^2}{2(Np_2)} \le Np_0$ and replacing Np_1 and Np_2 by the observed frequencies f_1 and f_2 results in the lower bound estimator $\frac{f_1^2}{2f_2}$, giving $\hat{f}_0 = \frac{f_1^2}{2f_2}$, where $\hat{f}_0$ is the number of unobserved members of the target population with x = 0. This idea was applied to estimate the underreported patients in COVID-19 by substituting f_1 and f_2 with $\Delta N(t)$ and $\Delta N(t-1) - \Delta D(t)$, respectively. Then, the number of underreported infections at day t is given by

$$\hat{f}_0(t) = \frac{[\Delta N(t)]^2}{2[\Delta N(t-1) - \Delta D(t)]}, \quad (4)$$

where $f_1 = \Delta N(t)$ represents the infected people identified just one or the new infections, and $f_2 = \Delta N(t-1) - \Delta D(t)$ represents the infected people detected at time (t-1) and still infected at time t.

The lower bound estimator for estimating the true number of COVID-19 infections at day t, $\hat{N}_t$ is the combination of the confirmed cases and underreported cases. Thus,

$$\hat{N}_t = n_t + \hat{f}_0(t), \quad (5)$$

Where n_t is the confirmed cases at day t (daily new cases at day t). To account for the uncertainty of the lower bound estimator, a variance of $\hat{N}_t$ was applied from the Chao estimator under the Poisson mixture model. This version of the conditional technique, together with the Delta method, was modified to construct the variance formula[19]. $\hat{N}$ is the original Chao estimator based on the Poisson mixture model which is fixed but an unknown quantity, and n is the observed unit. The variance of the population size estimator can be represented as

$$Var(\hat{N}) = E_n\left\{Var(\hat{N}|n)\right\} + Var_n\left\{E(\hat{N}|n)\right\}$$

where $E_n(.)$ and $Var_n(.)$ refer to the first and the second central moment with respect to the distribution of n. For the estimator $\hat{N} = n + \frac{f_1^2}{2f_2}$,

$$Var(\hat{N}) = \left(\frac{1}{4}\right)\frac{f_1^4}{f_2^3} + \frac{f_1^3}{f_2^2} + \left(\frac{1}{2}\right)\frac{f_1^2}{f_2} - \left(\frac{1}{4}\right)\frac{f_1^4}{(f_2^2 n)} - \left(\frac{1}{2}\right)\frac{f_1^4}{f_2(2f_2 n + f_1^2)} \quad (7)$$

An application of asymptotic variance estimation of the Chao estimator based on the Poisson mixture model for times series data was constructed by

$$\begin{aligned}\mathrm{Var}[\hat{N}_t] = &\left(\frac{1}{4}\right)^2\left(\frac{[\Delta N(t)]^4}{[\Delta N(t-1)-\Delta D(t)]^3}\right)+\left(\frac{[\Delta N(t)]^3}{[\Delta N(t-1)-\Delta D(t)]^2}\right)\\&+\left(\frac{1}{2}\right)\left(\frac{[\Delta N(t)]^2}{[\Delta N(t-1)-\Delta D(t)]}\right)-\left(\frac{1}{4}\right)\frac{[\Delta N(t)]^4}{[\{\Delta N(t-1)-\Delta D(t)\}\{n^*_{obs}(t)\}]}\\&-\left(\frac{1}{2}\right)\frac{[\Delta N(t)]^4}{[\Delta N(t-1)-\Delta D(t)][2\{f\Delta N(t-1)-\Delta D(t)\}\{n^*_{obs}(t)\}]+[\Delta N(t)]^2)},\end{aligned} \quad (8)$$

where $n^*_{obs}(t)$ is the number of currently infected individuals observed at the time t. To avoid the high risk of overlapping cases of COVID-19 patient cases, the number of observations were considered for three days at day t, at day t and the day before, and at day t and two days before. A 95% confidence interval of $\hat{N}_t$ was then constructed as

$$\hat{N}_t \pm 1.96\sqrt{\mathrm{Var}(\hat{N}_t)} \quad (9)$$

Ethical approval

The study was approved by the Human Research Ethics Committee of Thaksin University No. 0061 on 8 March 2023.

Results

Numbers of estimated daily reported cases are presented in Figures 2 and 3. The pattern of estimating the true number of COVID-19 infected cases followed reported deaths and confirmed cases. The average true number of infected cases on March, 2022 was 35,842 per day (95% CI: 35,516 to 36,168) consisting of 12,086 reported cases and 23,755 underreported cases.

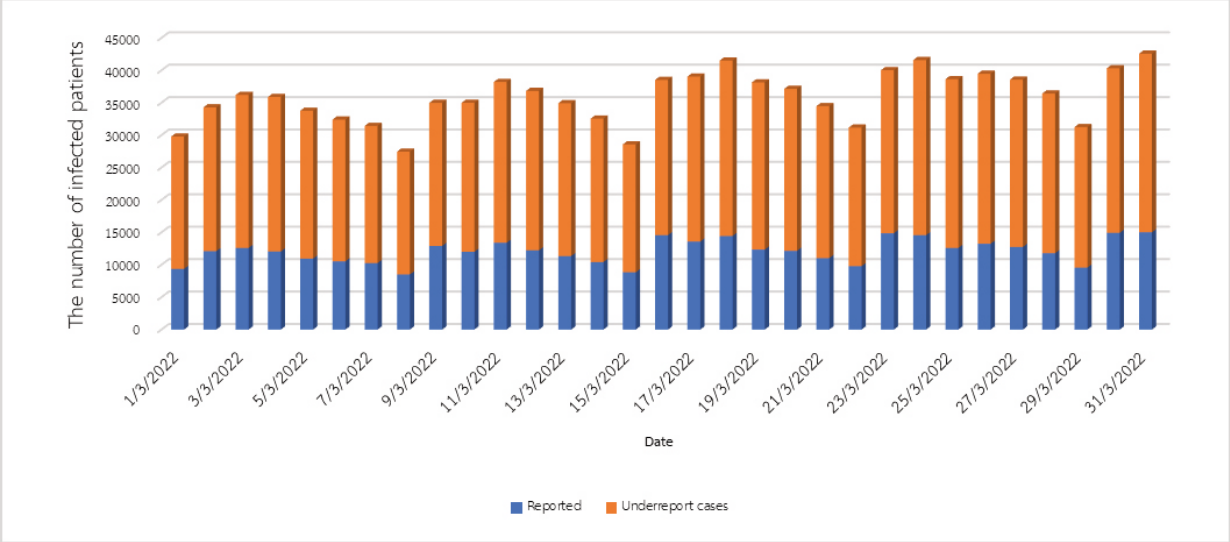

Figure 2 COVID-19 confirmed and underreported cases.

The maximum and minimum values of the estimated true numbers were 27,450 and 42,569, respectively. The true scale of cumulative daily COVID-19 confirmed cases was estimated from the proposed estimator and compared with the cumulative reported values, as shown in Figure 3 (b).

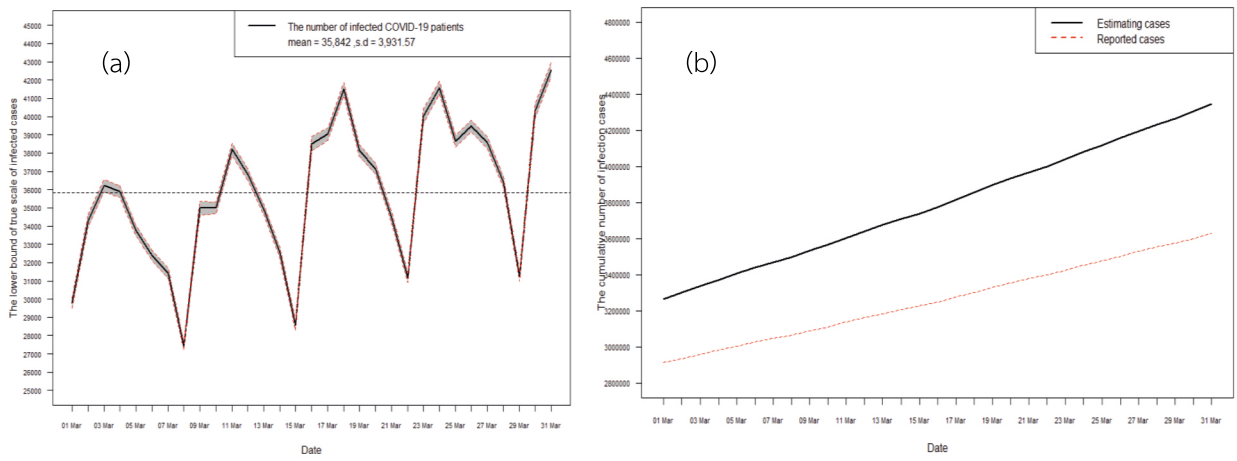

Figure 3 (a) Estimated true numbers of COVID-19 infected cases during March 2022 by confidence interval. (b) Cumulative numbers of reported confirmed COVID-19 cases and estimated true values.

The graph shows that the reporting of COVID-19 cases significantly underestimated the true scale of the pandemic throughout the study period. The cumulative number of infected patients was estimated at 4,347,371 cases at the end of March 2022. The results also estimated the number of underreported COVID-19 infected cases using the ratio of total estimated cases (in the optimistic scenario) to the reported cases. Figure 4 illustrates an average ratio of 2.99 (95% CI: 2.96 to 3.01). This would mean that for every 100 reported infections, there were 199 hidden infected persons. The reasons for this are varied, as underreported cases may show no symptoms or very mild signs of infection that do not require treatment. The main finding of this work is the small proportion of underreported COVID-19 infections in Thailand during the Omicron wave. These results are not surprising, prior study suggest that on 31 March, 2022 the estimated cases was 402,519.81 (95% of CI: 235,229.6 – 604,614.41)[20] greater than this research. To control the pandemic, it is important to know the true numbers of patients, with asymptomatic patients having the same infectivity as symptomatic patients. The Chao estimator based on the Poisson mixture model was applied to compute the lower bound of infected patients as a daily time series.

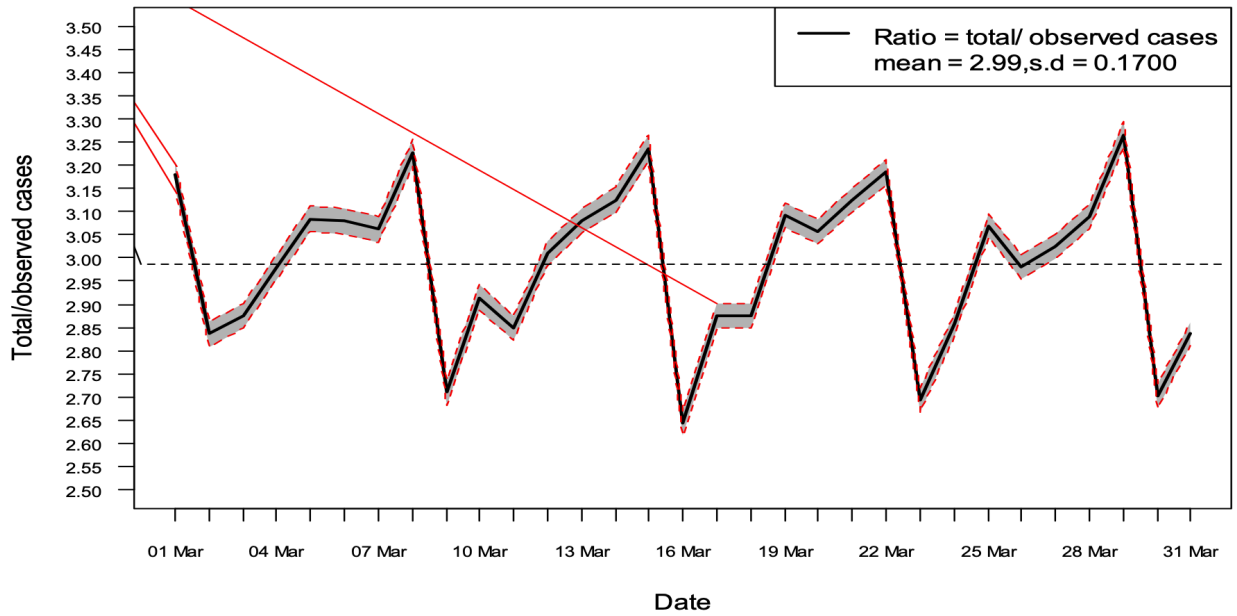

Figure 4 Ratio between the number of cases using the proposed method and reported cases.

Discussion

The proposed estimator provides an estimate of the actual number of COVID-19 cases during the Omicron wave in Thailand. We introduced an alternative choice of a lower bound estimator under cumulative time series data distribution in open population by using the CR method. As official COVID-19 data is available at the aggregate level but not at the individual level for academic use. It is impossible to obtain the exact distribution of infected individuals for each day. Many distributions may incorporate a heterogeneous population, which affects the probability of being detected. The geometric distribution or the Poisson-exponential distribution is the wildly known and used to crop the heterogeneity. An application of CR method using the Chao estimator under the geometric distribution was introduced for estimation for estimating the number of infected COVID-19 in Europe [21-22]. Other parametric mixing distributions, such as Poisson-Gamma, Poisson-Shanker[23], and Poisson-Prakaamy[24], may be adapted to estimate hidden population size.

In this study, we employed the Chao lower bound estimator, which is based on the Poisson mixture distribution. This was done to illustrate a positive scenario for COVID-19 during the Omicron wave in Thailand. This method can also be used to demonstrate regional variations. In other words, it has the potential to be applied to other countries or smaller geographical units in Thailand such as province or region.

There is a question about the COVID-19 testing process in Thailand. The Polymerase Chain Reaction (PCR) tests are highly accurate in detecting the genetic material of the SARS-COV-2 virus. However, the confirmed and death cases may be delayed due to the limited availability of testing facilities, which are usually overwhelmed with service on business days and can be found only at designated hospitals, clinics, and testing centers across Thailand. The official confirmed death cases are announced by the Department of Disease Control on the following day. For our observational period, we have used a sample size of 4 weeks, which is reasonable enough to cover the infection period with COVID-19 and its announcement.

Conclusions

The proposed estimator was utilized to determine the actual scale of COVID-19 infection in Thailand during the Omicron wave. A lower bound estimator was provided under the cumulative time-series data distribution for the optimistic scenario in terms of vaccination or herd immunity. The CR technique was used to provide a practical solution for underreported cases, and it was easy to calculate. The Chao estimator, based on underreported population heterogeneity, was used to determine the true value of infection. Future research should extend to the maximum number of undetected COVID-19 cases using the Poisson Mixture model. This information might be valuable for local policymakers evaluating the epidemic's situation in worse cases.

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