Hidden Markov Model of Disease Progression and Control with Reference to COVID-19 Spread

Tirupathi Rao Padi*, V. Kanimozhi* and P. T. Sakkeel a
aDepartment of Statistics, Pondicherry University, India.

Author’s contributions
This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information
DOI: 10.9734/ARJOM/2022/v18i730387

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/87240

Received: 25 March 2022
Accepted: 29 May 2022
Published: 03 June 2022

Original Research Article

Abstract
Disease progression studies through stochastic modeling are the most effective approaches as different processes involved in the disease acquisition, growth, spread, and control are random. This study develops a stochastic model for studying the disease spread using Markov Processes (MP) and Hidden Markov Models (HMM). This study considered two states of illness under the categories of hidden and visible. Further hidden states, as well as visible states, are classified into two groups each. This study attempted to relate the spread of disease in Tamil Nadu and Puducherry and its neighboring states. Increment/Decrement in daily positive cases of Tamil Nadu and Puducherry influence the Increment/Decrement in neighboring states’ daily positive cases, assuming there are regular transitions of patients from one place to another. This study develops HMM for transitions among different states (Increment/Decrement) for understanding the dynamics of positivity for two consecutive days and three days. Probability distributions of the prevalence of positivity are derived from the developed transition probability matrices. The study further derived different statistical measures mathematical/functional relations through the parameters under consideration. This study will help to measure the severity of the disease spread. The development of an interactive user interface for healthcare management will be the scope of this study.

Keywords: Stochastic modelling; COVID-19; hidden markov model; disease progression; healthcare management.

*Corresponding author: vinkani7@gmail.com
1 Introduction

In late December 2019, China reported a new virus that affects humans, and it was later named COVID-19. Further, on 31\textsuperscript{st} January 2020 World Health Organization (WHO) declared this outbreak as a global pandemic. But despite the efforts, the spread of the infection worldwide was uncontrolled. To safeguard the people and avoid the further spread of COVID-19 government made some stringent control measures such as imposing a nationwide lockdown, making the use of face masks mandatory, and educating the people to maintain social distancing and proper sanitization. The precautionary measure of nationwide lockdown played a drastic role in people’s routine life. After the lockdown announcement, the most affected population were migrant workers, who lost their livelihood and were forced to move to their native places from workplaces. Once the worker started to migrate, there was a rapid increase in the virus spread and daily reported cases surged suddenly.

Yuan et al., used three machine learning models, the Hidden Markov chain model, the long-short-term memory model, and the Hierarchical Bayes model, for the prediction of COVID-19 cases for six countries, including the US, Italy, etc., for 5 days ahead [1]. Lynnette et al., used HMM to predict the people’s emotions on Twitter during the COVID-19 pandemic and constructed an emotion topic, HMM, to indicate the user’s repeated subject on Twitter[2]. Johannes et al., forecast the COVID-19 future spread between different countries by utilizing the recognized lead-lag structure and also suggested HMM can be used for future research work[3]. Abdelghofour et al., used HMM in their study to find out the future spread of the coronavirus from March 14, 2020, to October 5, 2020, in the Morocco context[4]. HMM has been used by Prabhu et al., to predict the future spread of the coronavirus. There are two types of prediction models Long-term prediction model and the short-term prediction model[5]. Hongwei et al., used Suspected-Exposed-Infectious-Recovered (SEIR) based short-term forecast model to predict the COVID-19 cases for two to three weeks in length[6].

To predict the survival and mortality rate of the COVID-19 infected patients, Aljameel et al., used some machine learning methods. They analyzed the data with the help of three classification algorithms such as logistic regression, random forest, and extreme gradient boosting[7]. Ahmed Bani et al., used a stochastic model called Lotka-Volterra coupled with an extended Kalman Filter algorithm for predicting the spread of COVID-19 infections[8]. Cooper et al., predicted the spread of infection within the hospitals and also for understanding the transmission between patient to patient (or) transmission between staff to the patient by using HMM[9]. Tirupathi Rao et al used the Markov model to find the future growth of the COVID-19 disease in three different states, and model behavior is studied with real-life data[10]. Fractional calculus can be used to study the dynamic behaviour of the Infectious disease[11, 12, 13]. Salah Boulaaras and Tao-Qian Tang used Fractional derivative for analysing the transmission of dengue fever and breast cancer respectively[14, 15].

2 Stochastic Model

This model intends to derive probability distribution functions of the number of emission states in a discrete distribution. Thus, the transition states are of two kinds: State 1: Decrement and State 2: Increment.

2.1 Notations and terminology

Let us assume,

\[ \pi_i \] - Initial probability for \( i^\text{th} \) hidden state. \( \pi_i \geq 0; \forall i = 1, 2; \sum_{i=1}^{2} \pi_i = 1 \)
X_n - Resulting value of hidden states at n^{th} trial
Y_n - Resulting value of visible states with the influence of hidden states at n^{th} trial

\( \alpha_{kl} \) denotes the transition probability within hidden states

\[
\alpha_{kl} : P\{X_n = l|X_{n-1} = k\} \geq 0 \\
0 \leq \alpha_{kl} \geq 1 \text{ and } \sum_{l=1}^{2} \alpha_{kl} = 1 \forall \, k = 1, 2
\]

\( \beta_{kl} \) denotes the emission probability in between hidden and visible states

\[
\beta_{kl} : P\{Y_n = l|X_{n-1} = k\} \geq 0 \\
0 \leq \beta_{kl} \geq 1 \text{ and } \sum_{l=1}^{2} \beta_{kl} = 1 \forall \, k = 1, 2
\]

State 1: Decrement is \( Z_{n+1} - Z_n < 0 \), State 2: Increment is \( Z_{n+1} - Z_n > 0 \)

\( Z_n \) is the number of positive cases identified on \( n^{th} \) day of study.

Fig. 1. Schematic diagram for two state Hidden Markov Model of COVID-19 spread

2.2 Assumptions

i. Hidden states have the initial probabilities \( \pi_i, \forall \, \pi_i \geq 0; \, i = 1, 2 \).

ii. Transition probabilities among hidden states are of intra and inter transits in nature.
iii. Visible/Emission states are the effects of hidden states. 
iv. The transition probabilities of visible states are initiated with hidden state. 

2.2.1 Transition probability matrix within hidden states 

\[ A = X_{n-1} \begin{bmatrix} \alpha_{kl} \end{bmatrix}; k, l = 1, 2 \]  

(2.1)

2.2.2 Emission/observed probability matrix in between hidden and visible states 

\[ B = X_{n-1} \begin{bmatrix} \beta_{kl} \end{bmatrix}; k, l = 1, 2 \]  

(2.2)

2.2.3 Initial probabilities with hidden States: 

\[ P(H_1) = \pi_1; P(H_2) = \pi_2; \sum_{i=1}^{2} n_i = n; \sum_{i=1}^{2} \pi_i = 1; \pi_i = n_i / n \]  

(2.3)

\( n_i \): Number of observations in \( i^{th} \) initial state.

3 Probability distributions for one day length of sequence 

Let \( X(\omega) = n \), be the random variable that denotes the occurrence of the specific state. \( \omega \) represents two different states, namely Decrement and Increment (i.e.) \( \omega = D \) (or) I. \( 'n' \) be the number of times the events happen in that specific state, \( 'n' \) can be 0, 1, 2, 3, .... Where 0 will be non-happening, 1 will be an event occur once, 2 will be an occurrence of the event twice, 3 will be an occurrence of the event thrice, and so on.

3.1 Probability mass function for "Decrement State" distribution 

\[ P[X(D)] = \begin{cases} \sum_{i=1}^{2} \pi_i \beta_{i2}; & X(D) = 0 \\ \sum_{i=1}^{2} \pi_i \beta_{i1}; & X(D) = 1 \end{cases} \]  

(3.1)

3.2 Statistical characteristics of decrement state’s probability distribution: 

Some statistical characteristics are derived in this section for the probability distribution given in the equation (3.1).

 Mean, \( E[X(D)] = \sum_{i=1}^{2} \pi_i \beta_{i1} \)  

(3.2)

 Variance, \( V[X(D)] = \sum_{i=1}^{2} \pi_i \beta_{i1} \left( 1 - \sum_{i=1}^{2} \pi_i \beta_{i1} \right) \)  

(3.3)

 Third and fourth central moments: 

\[ \mu_3[X(D)] = \sum_{i=1}^{2} \pi_i \beta_{i1} \left( 1 - 2 \sum_{i=1}^{2} \pi_i \beta_{i1} \right) \left( 1 - \sum_{i=1}^{2} \pi_i \beta_{i1} \right) \]  

(3.4)
Characteristic Function

Coefficient of kurtosis for Increment state

\[ \mu_4[X(D)] = \sum_{i=1}^{2} \pi_i \beta_{11} \left( \sum_{i=1}^{2} \pi_i \beta_{11} - 1 \right) \left[ -3 \left( \sum_{i=1}^{2} \pi_i \beta_{11} \right)^2 + 3 \sum_{i=1}^{2} \pi_i \beta_{11} - 1 \right] \]  
\[ (3.5) \]

\[ S_4[X(D)] = \left( 1 - 2 \sum_{i=1}^{2} \pi_i \beta_{11} \right)^2 \left[ \sum_{i=1}^{2} \pi_i \beta_{11} \left( 1 - \sum_{i=1}^{2} \pi_i \beta_{11} \right) \right]^{-1} \]  
\[ (3.6) \]

Coefficient of kurtosis for Decrement state

\[ \left[ 3 \left( \sum_{i=1}^{2} \pi_i \beta_{11} \right)^2 - 3 \sum_{i=1}^{2} \pi_i \beta_{11} + 1 \right] \left[ \sum_{i=1}^{2} \sum_{i=1}^{2} \pi_i \beta_{11} \left( 1 - \sum_{i=1}^{2} \pi_i \beta_{11} \right) \right]^{-1} \]  
\[ (3.7) \]

Characteristic Function, \( \phi_s[X(D)] = 1 - \sum_{i=1}^{2} \pi_i \beta_{11} (1 - e^{it}) \)  
\[ (3.8) \]

3.3 Probability mass function for "Increment State" distribution

\[ P[X(I)] = \begin{cases} \sum_{i=1}^{2} \pi_i \beta_{11} & \text{for } X(I) = 0 \\ \sum_{i=1}^{2} \pi_i \beta_{22} & \text{for } X(I) = 1 \end{cases} \]  
\[ (3.9) \]

3.4 Statistical characteristics of Increment state’s probability distribution:

Some statistical characteristics are derived in this section for the probability distribution given in the equation (3.9)

Mean, \( E[X(I)] = \sum_{i=1}^{2} \pi_i \beta_{12} \)  
\[ (3.10) \]

Variance, \( V[X(I)] = \sum_{i=1}^{2} \pi_i \beta_{12} \left( 1 - \sum_{i=1}^{2} \pi_i \beta_{12} \right) \)  
\[ (3.11) \]

Third and fourth central moments:

\[ \mu_3[X(I)] = \sum_{i=1}^{2} \pi_i \beta_{12} \left( 1 - 2 \sum_{i=1}^{2} \pi_i \beta_{12} \right) \left( 1 - \sum_{i=1}^{2} \pi_i \beta_{12} \right) \]  
\[ (3.12) \]

\[ \mu_4[X(I)] = \sum_{i=1}^{2} \pi_i \beta_{12} \left( \sum_{i=1}^{2} \pi_i \beta_{12} - 1 \right) \left( -3 \left( \sum_{i=1}^{2} \pi_i \beta_{12} \right)^2 + 3 \sum_{i=1}^{2} \pi_i \beta_{12} - 1 \right) \]  
\[ (3.13) \]

\[ S_4[X(I)] = \left( 1 - 2 \sum_{i=1}^{2} \pi_i \beta_{12} \right)^2 \left[ \sum_{i=1}^{2} \pi_i \beta_{12} \left( 1 - \sum_{i=1}^{2} \pi_i \beta_{12} \right) \right]^{-1} \]  
\[ (3.14) \]

Coefficient of kurtosis for Increment state

\[ \left[ 3 \left( \sum_{i=1}^{2} \pi_i \beta_{12} \right)^2 - 3 \sum_{i=1}^{2} \pi_i \beta_{12} + 1 \right] \left[ \sum_{i=1}^{2} \sum_{i=1}^{2} \pi_i \beta_{12} \left( 1 - \sum_{i=1}^{2} \pi_i \beta_{12} \right) \right]^{-1} \]  
\[ (3.15) \]

Characteristic Function, \( \phi_s[X(I)] = 1 - \sum_{i=1}^{2} \pi_i \beta_{12} (1 - e^{it}) \)  
\[ (3.16) \]
4 Probability distributions for two days length of sequence:

4.1 Probability mass function for “Decrement State” distribution

\[ P[X(D)] = \begin{cases} 
\sum_{i,j=1}^{2} \pi_{i} \alpha_{ij} \beta_{i2}^2; & X(D) = 0 \\
2 \sum_{i,j=1}^{2} \pi_{i} \alpha_{ij} \beta_{j1} \beta_{i2}^2; & X(D) = 1 \\
\sum_{i,j=1}^{2} \pi_{i} \alpha_{ij} \beta_{j1}^2; & X(D) = 2 
\end{cases} \tag{4.1} \]

4.2 Statistical characteristics of Decrement state’s probability distribution:

In this section, some statistical characteristics are explored for the probability distribution given in the equation (4.1) by assuming, \( \theta_1 = \sum_{i,j=1}^{2} \pi_{i} \alpha_{ij} \beta_{i2}^2; \theta_2 = \sum_{i,j=1}^{2} \pi_{i} \alpha_{ij} \beta_{j1} \beta_{i2}^2; \theta_3 = \sum_{i,j=1}^{2} \pi_{i} \alpha_{ij} \beta_{j1}^2 \)

Mean, \( E[X(D)] = 2(\theta_2 + \theta_3) \tag{4.2} \)

Variance, \( V[X(D)] = 2(\theta_2 + 2\theta_3) - [2(\theta_2 + \theta_3)]^2 \tag{4.3} \)

Third and fourth central moments

\( \mu_3[X(D)] = 2(\theta_2 + 4\theta_3) - 4(\theta_2 + \theta_3)^2 \tag{4.4} \)

\( \mu_4[X(D)] = 2(\theta_2 + 8\theta_3) - 8(\theta_2 + \theta_3)^3 \tag{4.5} \)

\( S_6[X(D)] = \left( \frac{\theta_2 + 4\theta_3}{(\theta_2 + 2\theta_3)^3} \right)^{-1} \tag{4.6} \)

Coefficient of kurtosis for Decrement state

\( (\theta_2 + 8\theta_3 - 4(\theta_2 + \theta_3)^2) \left( \frac{2(\theta_2 + 2\theta_3)}{(\theta_2 + 2\theta_3)} - 2(\theta_2 + \theta_3)^2 \right) \]

\( \left[ 2(\theta_2 + 2\theta_3 - 2(\theta_2 + \theta_3)^2) \right]^{-1} \tag{4.7} \)

Characteristic Function, \( \phi[X(D)] = e^{\theta_1} \phi_2 + e^{2\theta_1} \phi_3 \tag{4.8} \)

4.3 Probability mass function for “Increment State” distribution

\[ P[X(I)] = \begin{cases} 
\sum_{i,j=1}^{2} \pi_{i} \alpha_{ij} \beta_{j1}^2; & X(I) = 0 \\
2 \sum_{i,j=1}^{2} \pi_{i} \alpha_{ij} \beta_{j1} \beta_{j2}^2; & X(I) = 1 \\
\sum_{i,j=1}^{2} \pi_{i} \alpha_{ij} \beta_{j2}^2; & X(I) = 2 
\end{cases} \tag{4.9} \]
4.4 Statistical characteristics of Increment state’s probability distribution:

In this section, some statistical characteristics are explored for the probability distribution given in the equation (4.9) by considering,

\[ \tau_1 = \sum_{i,j=1}^{2} \pi_i \alpha_{ij} \beta_{ik}^2; \quad \tau_2 = \sum_{i,j=1}^{2} \pi_i \alpha_{ij} \beta_{ik}^2; \quad \tau_3 = \sum_{i,j=1}^{2} \pi_i \alpha_{ij} \beta_{ik}^2 \]

Mean, \( E[X(I)] = 2(\tau_2 + \tau_3) \)  \hspace{1cm} (4.10)

Variance, \( V[X(I)] = 2(\tau_2 + 2\tau_4) - (2(\tau_2 + \tau_4))^2 \)  \hspace{1cm} (4.11)

Third and fourth central moments

\[ \mu_3[X(I)] = 2(\tau_2 + 4\tau_3) - 4(\tau_2 + 4\tau_3)(3(\tau_2 + 2\tau_4) - 4(\tau_2 + \tau_4)^2) \]  \hspace{1cm} (4.12)

\[ \mu_4[X(I)] = 2(\tau_2 + 8\tau_3) - 8(\tau_2 + \tau_3)(2(\tau_2 + 4\tau_3) - 6(\tau_2 + \tau_3)(\tau_2 + 2\tau_3)^3) \]  \hspace{1cm} (4.13)

\[ S_4[X(I)] = \left[ (\tau_2 + 4\tau_3) - 2(\tau_2 + \tau_4)(3(\tau_2 + 2\tau_4) - 4(\tau_2 + \tau_4)^2) \right]^2 \left[ 2(\tau_2 + 2\tau_4) - 2(\tau_2 + \tau_4)^2 \right]^{-1} \]  \hspace{1cm} (4.14)

Coefficient of kurtosis for Increment State

\[ (\tau_2 + 8\tau_3) - 4(\tau_2 + \tau_4) \left[ 2(\tau_2 + 4\tau_3) - 6(\tau_2 + \tau_3)(\tau_2 + 2\tau_3)^3 \right] \left[ 2(\tau_2 + 2\tau_4) - 2(\tau_2 + \tau_4)^2 \right]^{-1} \]  \hspace{1cm} (4.15)

Characteristic Function, \( \phi_{X(I)} = \tau_1 + e^{it\tau_2} + e^{2it\tau_3} \)  \hspace{1cm} (4.16)

5 Probability distributions for three days length of sequence:

5.1 Probability mass function for ”Decrement State” distribution

\[
P[X(D)] = \begin{cases} 
\sum_{i,j,k=1}^{2} \pi_i \alpha_{ij} \alpha_{jk} \beta_{ik}^2; & X(D) = 0 \\
3 \sum_{i,j,k=1}^{2} \pi_i \alpha_{ij} \alpha_{jk} \beta_{ik}^2; & X(D) = 1 \\
3 \sum_{i,j,k=1}^{2} \pi_i \alpha_{ij} \alpha_{jk} \beta_{ik}^2; & X(D) = 2 \\
\sum_{i,j,k=1}^{2} \pi_i \alpha_{ij} \alpha_{jk} \beta_{ik}^2; & X(D) = 3
\end{cases}
\]  \hspace{1cm} (5.1)

5.2 Statistical characteristics of Decrement state’s probability distribution:

Statistical characteristics are explored for the probability distribution given in the equation (5.1) by considering,

\[ \lambda_1 = \sum_{i,j,k=1}^{2} \pi_i \alpha_{ij} \alpha_{jk} \beta_{ik}^2; \quad \lambda_2 = \sum_{i,j,k=1}^{2} \pi_i \alpha_{ij} \alpha_{jk} \beta_{ik}^2; \quad \lambda_3 = \sum_{i,j,k=1}^{2} \pi_i \alpha_{ij} \alpha_{jk} \beta_{ik}^2; \quad \lambda_4 = \sum_{i,j,k=1}^{2} \pi_i \alpha_{ij} \alpha_{jk} \beta_{ik}^2; \]

\[ = \sum_{i,j,k=1}^{2} \pi_i \alpha_{ij} \alpha_{jk} \beta_{ik}^2; \quad \lambda_5 = \sum_{i,j,k=1}^{2} \pi_i \alpha_{ij} \alpha_{jk} \beta_{ik}^2; \]

\[ = \sum_{i,j,k=1}^{2} \pi_i \alpha_{ij} \alpha_{jk} \beta_{ik}^2; \quad \lambda_6 = \sum_{i,j,k=1}^{2} \pi_i \alpha_{ij} \alpha_{jk} \beta_{ik}^2; \]

\[ = \sum_{i,j,k=1}^{2} \pi_i \alpha_{ij} \alpha_{jk} \beta_{ik}^2; \quad \lambda_7 = \sum_{i,j,k=1}^{2} \pi_i \alpha_{ij} \alpha_{jk} \beta_{ik}^2; \]

\[ = \sum_{i,j,k=1}^{2} \pi_i \alpha_{ij} \alpha_{jk} \beta_{ik}^2; \quad \lambda_8 = \sum_{i,j,k=1}^{2} \pi_i \alpha_{ij} \alpha_{jk} \beta_{ik}^2; \]

\[ = \sum_{i,j,k=1}^{2} \pi_i \alpha_{ij} \alpha_{jk} \beta_{ik}^2; \]
Mean, $E[X(D)] = 3(\lambda_2 + 2\lambda_3 + \lambda_4)$ \hspace{1cm} (5.2)

Variance, $V[X(D)] = 3(\lambda_2 + 4\lambda_3 + 3\lambda_4) - \left[3(\lambda_2 + 2\lambda_3 + \lambda_4)\right]^2$ \hspace{1cm} (5.3)

Third and fourth central moments

$\mu_3[X(D)] = 3(\lambda_2 + 8\lambda_3 + 9\lambda_4) - 27(\lambda_2 + 2\lambda_3 + \lambda_4)\left((\lambda_2 + 4\lambda_3 + 3\lambda_4) - 2(\lambda_2 + 2\lambda_3 + \lambda_4)^2\right)$ \hspace{1cm} (5.4)

$\mu_4[X(D)] = 3(\lambda_2 + 16\lambda_3 + 27\lambda_4) - 9(\lambda_2 + 2\lambda_3 + \lambda_4)\left[4(\lambda_2 + 8\lambda_3 + 9\lambda_4) - 9(\lambda_2 + 2\lambda_3 + \lambda_4)\right] - 27(\lambda_2 + 2\lambda_3 + \lambda_4)\left((\lambda_2 + 4\lambda_3 + 3\lambda_4) - 2(\lambda_2 + 2\lambda_3 + \lambda_4)^2\right)$ \hspace{1cm} (5.5)

$S_6[X(D)] = \left[(\lambda_2 + 8\lambda_3 + 9\lambda_4) - 9(\lambda_2 + 2\lambda_3 + \lambda_4)\left((\lambda_2 + 4\lambda_3 + 3\lambda_4) - 2(\lambda_2 + 2\lambda_3 + \lambda_4)^2\right)\right]^2 \left[3\left((\lambda_2 + 4\lambda_3 + 3\lambda_4) - 3(\lambda_2 + 2\lambda_3 + \lambda_4)^2\right)\right]^{-1}$ \hspace{1cm} (5.6)

Coefficient of kurtosis for Decrement State

$(\lambda_2 + 16\lambda_3 + 27\lambda_4) - 3(\lambda_2 + 2\lambda_3 + \lambda_4)\left[4(\lambda_2 + 8\lambda_3 + 9\lambda_4) - 9(\lambda_2 + 2\lambda_3 + \lambda_4)\right] - 27(\lambda_2 + 2\lambda_3 + \lambda_4)\left((\lambda_2 + 4\lambda_3 + 3\lambda_4) - 2(\lambda_2 + 2\lambda_3 + \lambda_4)^2\right)$ \hspace{1cm} (5.7)

Characteristic Function, $\psi_{X(D)} = \lambda_1 + e^{it\lambda_2} + e^{2it\lambda_3} + e^{3it\lambda_4}$ \hspace{1cm} (5.8)

5.3 Probability mass function for ”Increment State” distribution

$$P[X(I)] = \begin{cases} 
\frac{2}{\mu} \sum_{i,j,k=1} \pi_{ij} \beta_{ij}^2 \beta_{jk}^2; & X(I) = 0 \\
3 \sum_{i,j,k=1} \pi_{ij} \beta_{ij}^2 \beta_{jk}^2; & X(I) = 1 \\
3 \sum_{i,j,k=1} \pi_{ij} \beta_{ij}^2 \beta_{jk}^2; & X(I) = 2 \\
\frac{2}{\mu} \sum_{i,j,k=1} \pi_{ij} \beta_{ij}^2 \beta_{jk}^2; & X(I) = 3
\end{cases}$$ \hspace{1cm} (5.9)

5.4 Statistical characteristics of Increment State’s probability distribution

Statistical characteristics are explored for the probability distribution given in the equation (5.9), by considering, $\psi_1 = \frac{2}{\mu} \sum_{i,j,k=1} \pi_{ij} \beta_{ij}^3 \beta_{jk}^1; \psi_2 = \sum_{i,j,k=1} \pi_{ij} \beta_{ij}^2 \beta_{jk}^2 \beta_{ik}^1; \psi_3 = \sum_{i,j,k=1} \pi_{ij} \beta_{ij} \beta_{jk}^3 \beta_{ik}^2; \psi_4 = \sum_{i,j,k=1} \pi_{ij} \beta_{ij} \beta_{jk} \beta_{ik}^3$

Mean, $E[X(I)] = 3(\psi_2 + 2\psi_3 + \psi_4)$ \hspace{1cm} (5.10)

Variance, $V[X(I)] = 3(\psi_2 + 4\psi_3 + 3\psi_4) - \left[3(\psi_2 + 2\psi_3 + \psi_4)\right]^2$ \hspace{1cm} (5.11)
Third and fourth central moments

\[ \mu_3[X(I)] = 3(\psi_2 + 8\psi_3 + 9\psi_4) - 27(\psi_2 + 2\psi_3 + \psi_4)\left((\psi_2 + 4\psi_3 + 3\psi_4) - 2(\psi_2 + 2\psi_3 + \psi_4)^2\right) \]  

(5.12)

\[ \mu_4[X(I)] = 3(\psi_2 + 16\psi_3 + 27\psi_4) - 9(\psi_2 + 2\psi_3 + \psi_4)\left[4(\psi_2 + 8\psi_3 + 9\psi_4) \right. \\
\left. - 9(\psi_2 + 2\psi_3 + \psi_4)\left(2(\psi_2 + 4\psi_3 + 3\psi_4) + (\psi_2 + 2\psi_3 + \psi_4)^2\right)\right] \]  

(5.13)

\[ S_k[X(I)] = \left[(\psi_2 + 8\psi_3 + 9\psi_4) - 9(\psi_2 + 2\psi_3 + \psi_4)\left((\psi_2 + 4\psi_3 + 3\psi_4) - 2(\psi_2 + 2\psi_3 + \psi_4)^2\right)\right]^2 \]

\[ \left[3\left((\psi_2 + 4\psi_3 + 3\psi_4) - 3(\psi_2 + 2\psi_3 + \psi_4)^2\right)^3\right]^{-1} \]  

(5.14)

Coefficient of kurtosis for Decrement State

\[ (\psi_2 + 16\psi_3 + 27\psi_4) - 3(\psi_2 + 2\psi_3 + \psi_4)\left[4(\psi_2 + 8\psi_3 + 9\psi_4) - 9(\psi_2 + 2\psi_3 + \psi_4) \right. \\
\left. \left(2(\psi_2 + 4\psi_3 + 3\psi_4) + (\psi_2 + 2\psi_3 + \psi_4)^2\right)\right]\left[3\left((\psi_2 + 4\psi_3 + 3\psi_4) - 3(\psi_2 + 2\psi_3 + \psi_4)^2\right)^3\right]^{-1} \]  

(5.15)

Characteristic Function, \( \phi_{X(t)} = \psi_1 + e^{it}\psi_2 + e^{2it}\psi_3 + e^{3it}\psi_4 \)  

(5.16)

### 6 Results and Discussion

By using the collected COVID-19 dataset (placed in the annexure), the derived model behavior is studied[16]. The data consist of the number of reported positive cases state-wise in India from 24th March 2020 to 25th August 2020. This model is focused on the dynamic behavior of two states. The total number of cases per day is divided into two transition states, "Decrement" and "Increment." This study primarily focuses on the southern states of India, and it aims to predict the COVID-19 positive cases in Tamilnadu and Puducherry that are influenced by its adjacent states, namely Kerala, Karnataka, and Andhra Pradesh. If the previous day’s cases are more than the current day, then that state is considered a "Decrement State." At the same time, the state is mentioned as an "Increment State" when the previous day’s cases are less than the current day. The number of positive cases identified each day in Kerala, Karnataka, Telangana, and Andhra Pradesh is considered to identify Hidden states. The daily positive cases of Tamilnadu and Puducherry are supposed to identify visible states. Transition frequency tables and transition probability matrices are obtained for the hidden and visible states.

#### 6.1 Initial probability matrix for hidden states.

\[ \pi = \begin{bmatrix} 0.4183 & 0.5817 \end{bmatrix} \]

#### 6.2 Transition probability matrix among hidden states:

Thorouh processing of identified daily positive cases in the total neighboring states of Tamil Nadu, the number of initial states, Decrement (D) and Increment (I), was carried out with the collected data. The joint states (HD, HD), (HD, HI), (HI, HD) and (HI, HI) are identified as
(HD, HD) : (X_{n+1} < X_n) \cap (X_n < X_{n-1})
(HD, HI) : (X_{n+1} < X_n) \cap (X_n > X_{n-1})
(HI, HD) : (X_{n+1} > X_n) \cap (X_n < X_{n-1})
(HI, HI) : (X_{n+1} > X_n) \cap (X_n > X_{n-1})

Transition Frequency Table:

| X_n | X_{n-1} | n(D) | n(I) |
|-----|---------|------|------|
|     | n(D)    | 16   | 47   |
|     | n(I)    | 46   | 43   |

Transition Probability Matrix:

| X_n | X_{n-1} | n(D) | n(I) |
|-----|---------|------|------|
|     | n(D)    | 0.2540 | 0.7460 |
|     | n(I)    | 0.5169 | 0.4831 |

\[ A = \begin{bmatrix} 0.2540 & 0.7460 \\ 0.5169 & 0.4831 \end{bmatrix} \]

6.3 Transition probability matrix between hidden and visible states:

The emission probability matrix is obtained after processing the emission frequency matrix. The joint states (HD, VD), (HD, VI), (HI, VD) and (HI, VI) are identified as

(HD, VD) : (X_{n+1} < X_n) \cap (Y_{n+1} < Y_n)
(HD, VI) : (X_{n+1} < X_n) \cap (Y_{n+1} > Y_n)
(HI, VD) : (X_{n+1} > X_n) \cap (Y_{n+1} < Y_n)
(HI, VI) : (X_{n+1} > X_n) \cap (Y_{n+1} > Y_n)

Transition Frequency Table:

| X_n | Y_n | n(D) | n(I) |
|-----|-----|------|------|
|     | n(D)    | 28   | 36   |
|     | n(I)    | 35   | 54   |

Transition Probability Matrix:

| X_n | Y_n | n(D) | n(I) |
|-----|-----|------|------|
|     | n(D)    | 0.4375 | 0.5625 |
|     | n(I)    | 0.3933 | 0.6067 |

\[ B = \begin{bmatrix} 0.4375 & 0.5625 \\ 0.3933 & 0.6067 \end{bmatrix} \]

Table 1. Probability distribution for Decrement state

| X(D) | 0 | 1 | 2 | 3 |
|------|---|---|---|---|
| P[X(D)|1 day sequence] | 0.5882 | 0.4118 | - | - |
| P[X(D)|2 day sequence] | 0.3471 | 0.4833 | 0.1697 | - |
| P[X(D)|3 day sequence] | 0.2048 | 0.4265 | 0.2985 | 0.0702 |

From Table 1 it is observed that non-occurrence of decrement state in one-day length is having more chance. The chance of happening of decrement state once in a two days sequence is more. In three-day sequence occurrence of decrement state once having more chance when compared to other. And the graph is plotted for the above probability.
Based on the results obtained for “Decrement State” it is observed that the average happening of decrement state is less than 1 in one day study, nearly one in two day’s study and there is a chance of occurrence of the state is more than 1 in three day’s calculation. And also observed that the decrement state is positively skewed. The kurtosis measure is less than 3, which means it is platy kurtic.

It is observed from the “Decrement State” that the average happening of decrement state is less than 1 in one day study, nearly one in two day’s study, and more than 1 in three day’s calculation. It is observed from the result that the decrement state is positively skewed. The kurtosis measure is less than 3, which means it is platy kurtic.

From table 3 it is observed that happening of increment state is having more chance when compared to the non-happening of increment state. In two days sequence chance of happening of increment state once is more. The occurrence of increment state twice is having more chance in three days sequence. Graphical representation is given below.
Fig. 3. Probability of Increment State for 1 day sequence, 2 days sequence, 3 days sequence.

Table 4. Statistical results for Increment state for different (one day, two days run and three days run) lengths of consecutive day's

| Statistical measures | 1 day’s  | 2 day’s  | 3 day’s  |
|----------------------|---------|---------|---------|
| Mean                 | 0.5882  | 1.1774  | 1.7658  |
| Variance             | 0.2422  | 0.4852  | 0.7293  |
| 3rd central moment   | -0.04274| -0.0865 | -0.1302 |
| 4th central moment   | 0.0662  | 0.4854  | 1.2617  |
| Skewness             | 0.1286  | 0.0654  | 0.0438  |
| Kurtosis             | 1.1286  | 2.0618  | 2.3722  |

From table 4, it is observed that the average happening of Increment state is less than 1 in one-day length, more than 1 in two, three day’s study. It is noticed that the Increment state is positively skewed. The kurtosis measure is less than 3 which means it is platy kurtic.

7 Summary and Conclusion

This research study mainly focused on developing the Hidden Markov Model based on the transitions among states. The primary intent of the study is to examine whether the total number of positive cases registered in Tamil Nadu and Puducherry has an association with the total number of positive cases reported in its adjacent southern states like Andhra Pradesh, Telangana, Kerala, and Karnataka. A transition frequency table has been obtained by considering discrete Markov processes. Transition probability matrices are also derived based on transition frequency tables. As an extended activity for understanding the model behavior, the classical formulae for probability distributions of one-day occurrence, two-day successive occurrences, and three-day successive occurrences of a single state and two states are derived. Probability distribution’s mass function for the states of increment and decrement are derived. Explicit functions of various statistical characteristics to the said probability distributions are also derived. A numerical analysis was also carried out based on the derived mathematical relations. The statistical measures based on pearson’s coefficients are obtained for the derived probability mass functions of the hidden Markov models and related discrete distributions. Model behavior is studied with the help of the COVID-19 dataset, which was collected from internet sources. This data is about the occurrences of positive cases identified in Tamil Nadu, Puducherry, Telangana, Andhra Pradesh, Kerala, and Karnataka. Study reports on statistical measures are obtained for the said numerical data sets. The intensity of the prevalence, trends of increments, or decrement fluctuations is studied. This study will provide indicators of disease prevalence and will be helpful to the government in developing suitable health care management strategies. The indicators that explored the mobilities of the population have revealed the necessary course of action for the governing agencies. The controlling measures on the spread of disease may be implemented with the observed indicators.
Competing Interests

Authors have declared that no competing interests exist.

References

[1] Yuan Tian, Ishika Luthra and Xi Zhang. Forecasting COVID-19 cases using Machine Learning Models, medRxiv; 2020.

[2] Hui Xian Lynnette Ng, Roy Ka-Wei Lee and Md Rabiul Awal. I miss you babe: Analyzing emotion dynamics during COVID-19 Pandemic, Proceedings of the Fourth Workshop on Natural Language Processing and Computational Social Science. 2020:41-49.

[3] Johannes stubinger and Lucas Schneider. Epidemiology of coronavirus covid-19: Forecasting the future incidence in different countries, Healthcare. 2020;8(2):99.

[4] Abdelghafour Marfak, Doha Achak, Asmaa Azizi and Chakib Nejjari,, Khalid Aboudi, , Elmadani Saad and , Abderranaouf Hilali and Ibtissam Youlyouz-Marfak. The Hidden Markov chain modelling of the COVID-19 spreading using Moroccan dataset, Data in Brief. 2020;32:106067.

[5] Prabhu SM, Subramaniam, N. Surveillance of COVID-19 Pandemic using Hidden Markov Model. arXiv preprint arXiv:2008.07609; 2020.

[6] Hongwei Zhao, Merchant NN, McNulty A, Radcliff TA, Cote MJ, Fischer RS, Ory MG. COVID-19: Short term prediction model using daily incidence data. PloS One. 2021;16(4).

[7] Aljameel SS, Khan IU, Aslam N, Aljabri M, Alsuymi ES. Machine learning-based model to predict the disease severity and outcome in COVID-19 patients. Scientific programming; 2021.

[8] Bani Younes A, Hasan Z. COVID-19: modeling, prediction, and control. Applied Sciences. 2020;10(11):3666.

[9] Cooper B, Lipsitch M. The analysis of hospital infection data using hidden Markov models. Biostatistics. 2004;5(2):223-237.

[10] Tirupathi Rao P, Kanimozhi V, Sakkeel PT. Markov model of COVID-19 disease progression, Stochastic Modeling and Applications. 2021;25(1):101-114.

[11] Rashid Jan, Amin Khan, Salah Boulaaras, Sulima Ahmed Zubair. Dynamical Behaviour and Chaotic Phenomena of HIV Infection through Fractional Calculus. Discrete Dynamics in Nature and Society; 2022.

[12] Rashid Jan, Salah Boulaaras. Analysis of fractional-order dynamics of dengue infection with non-linear incidence functions. Transactions of the Institute of Measurement and Control; 2022.

[13] Rashid Jan, Zahir Shah,Wejdan Deebani, Ebraheem Alzahrani. Analysis and dynamical behavior of a novel dengue model via fractional calculus. International Journal of Biomathematics; 2022.

[14] Tao-Qian Tang, Zahir Shah, Ebenezer Bonyah, Rashid Jan, Eshal Shutaywi, Nasser Alreshidi. Modeling and Analysis of Breast Cancer with Adverse Reactions of Chemotherapy Treatment through Fractional Derivative. Computational and Mathematical Methods in Medicine; 2022.

[15] Salah Boulaaras, Rashid Jan, Amin Khan, Muhammad Ahsan. Dynamical analysis of the transmission of dengue fever via Caputo-Fabrizio fractional derivative, Chaos, Solitons Fractals: X, 2022;8:100072.

[16] COVID-19 pandemic data/India medical cases by state and union territory. Available: https://en.wikipedia.org/wiki/COVID-19_pandemic_data/India_medical_cases_by_state_and_union_territory
## Annexure

| Date  | Tamil Nadu | Puducherry | Andhra Pradesh | Telangana | Karnataka | Kerala |
|-------|------------|------------|----------------|-----------|-----------|--------|
| Mar-24 | 6          | 0          | 1              | 3         | 7         | 28     |
| Mar-25 | 3          | 0          | 1              | 0         | 4         | 14     |
| Mar-26 | 8          | 0          | 2              | 9         | 14        | 9      |
| Mar-27 | 12         | 0          | 3              | 4         | 0         | 43     |
| Mar-28 | 2          | 0          | 0              | 8         | 9         | 15     |
| Mar-29 | 9          | 0          | 5              | 10        | 12        | 6      |
| Mar-30 | 18         | 0          | 4              | 5         | 7         | 37     |
| Mar-31 | 7          | 0          | 17             | 8         | 0         | 15     |
| Apr-01 | 160        | 2          | 43             | 17        | 18        | 7      |
| Apr-02 | 0          | 0          | 3              | 11        | 9         | 24     |
| Apr-03 | 75         | 2          | 46             | 51        | 14        | 21     |
| Apr-04 | 102        | 0          | 29             | 1         | 4         | 9      |
| Apr-05 | 71         | 0          | 29             | 110       | 16        | 11     |
| Apr-06 | 86         | 0          | 36             | 52        | 7         | 8      |
| Apr-07 | 50         | 0          | 49             | 43        | 24        | 13     |
| Apr-08 | 69         | 0          | 39             | 63        | 0         | 9      |
| Apr-09 | 48         | 0          | 43             | 15        | 6         | 9      |
| Apr-10 | 96         | 0          | 15             | 31        | 16        | 12     |
| Apr-11 | 77         | 2          | 18             | 31        | 17        | 7      |
| Apr-12 | 58         | 0          | 0              | 0         | 0         | 12     |
| Apr-13 | 106        | 0          | 51             | 58        | 21        | 2      |
| Apr-14 | 98         | 0          | 41             | 62        | 11        | 3      |
| Apr-15 | 31         | 0          | 30             | 23        | 19        | 8      |
| Apr-16 | 38         | 0          | 31             | 51        | 38        | 1      |
| Apr-17 | 25         | 0          | 38             | 45        | 38        | 7      |
| Apr-18 | 56         | 0          | 31             | 48        | 18        | 1      |
| Apr-19 | 49         | 0          | 0              | 53        | 13        | 4      |
| Apr-20 | 105        | 0          | 119            | 20        | 11        | 2      |
| Apr-21 | 43         | 0          | 37             | 46        | 20        | 6      |
| Apr-22 | 76         | 0          | 56             | 26        | 10        | 19     |
| Apr-23 | 33         | 0          | 82             | 15        | 18        | 11     |
| Apr-24 | 54         | 0          | 69             | 24        | 20        | 10     |
| Apr-25 | 72         | 0          | 106            | 0         | 26        | 3      |
| Apr-26 | 66         | 0          | 36             | 7         | 12        | 7      |
| Apr-27 | 64         | 1          | 80             | 11        | 10        | 11     |
| Apr-28 | 52         | 0          | 82             | 2         | 9         | 13     |
| Apr-29 | 121        | 0          | 73             | 8         | 12        | 4      |
| Apr-30 | 104        | 0          | 71             | 0         | 25        | 10     |
| Date  | Tamil Nadu | Puducherry | Andhra Pradesh | Telangana | Karnataka | Kerala |
|-------|------------|------------|----------------|-----------|-----------|--------|
| May-01| 261        | 0          | 60             | 27        | 19        | 1      |
| May-02| 203        | 0          | 62             | 18        | 22        | 1      |
| May-03| 281        | 0          | 58             | 6         | 8         | 2      |
| May-04| 266        | 0          | 67             | 19        | 36        | 0      |
| May-05| 527        | 1          | 67             | 3         | 17        | 0      |
| May-06| 508        | 0          | 0              | 11        | 12        | 2      |
| May-07| 771        | 0          | 60             | 11        | 22        | 1      |
| May-08| 580        | 0          | 70             | 16        | 12        | 0      |
| May-09| 526        | 0          | 43             | 30        | 41        | 2      |
| May-10| 669        | 0          | 59             | 33        | 54        | 7      |
| May-11| 798        | 3          | 38             | 79        | 14        | 7      |
| May-12| 716        | 1          | 72             | 51        | 63        | 5      |
| May-13| 569        | 0          | 47             | 41        | 34        | 10     |
| May-14| 447        | 0          | 68             | 47        | 28        | 25     |
| May-15| 434        | 0          | 102            | 40        | 69        | 16     |
| May-16| 477        | 0          | 48             | 55        | 36        | 11     |
| May-17| 689        | 0          | 52             | 42        | 55        | 14     |
| May-18| 556        | 5          | 67             | 46        | 99        | 29     |
| May-19| 688        | 0          | 58             | 37        | 151       | 12     |
| May-20| 743        | 0          | 70             | 27        | 65        | 24     |
| May-21| 776        | 2          | 45             | 38        | 143       | 24     |
| May-22| 786        | 6          | 62             | 62        | 138       | 42     |
| May-23| 759        | 0          | 48             | 52        | 216       | 63     |
| May-24| 765        | 15         | 66             | 41        | 130       | 52     |
| May-25| 805        | 0          | 287            | 66        | 93        | 49     |
| May-26| 646        | 5          | 61             | 71        | 101       | 67     |
| May-27| 817        | 0          | 0              | 107       | 135       | 41     |
| May-28| 827        | 5          | 80             | 158       | 115       | 84     |
| May-29| 874        | 0          | 185            | 169       | 248       | 62     |
| May-30| 638        | 0          | 133            | 74        | 141       | 38     |
| Jun-01| 1149       | 19         | 110            | 199       | 299       | 61     |
| Jun-02| 1162       | 4          | 104            | 94        | 187       | 57     |
| Jun-03| 1091       | 8          | 115            | 99        | 388       | 86     |
| Jun-04| 1296       | 0          | 182            | 129       | 267       | 82     |
| Jun-05| 1384       | 0          | 143            | 127       | 257       | 94     |
| Jun-06| 1438       | 17         | 80             | 143       | 515       | 111    |
| Jun-07| 1458       | 0          | 207            | 206       | 378       | 108    |
| Jun-08| 1545       | 0          | 198            | 154       | 239       | 107    |
| Jun-09| 1562       | 28         | 143            | 92        | 308       | 91     |
| Jun-10| 1685       | 0          | 219            | 178       | 161       | 91     |
| Jun-11| 1927       | 0          | 199            | 191       | 120       | 64     |
| Jun-12| 1875       | 30         | 160            | 209       | 204       | 83     |
| Jun-13| 1982       | 0          | 251            | 164       | 271       | 78     |
| Jun-14| 1989       | 19         | 285            | 253       | 308       | 85     |
| Date  | Tamil Nadu | Puducherry | Andhra Pradesh | Telangana | Karnataka | Kerala |
|-------|------------|------------|----------------|-----------|-----------|--------|
| Jun-15| 1974       | 18         | 198            | 216       | 176       | 54     |
| Jun-16| 1843       | 8          | 203            | 219       | 213       | 82     |
| Jun-17| 1515       | 14         | 385            | 213       | 317       | 79     |
| Jun-18| 2174       | 29         | 239            | 209       | 264       | 75     |
| Jun-19| 2141       | 26         | 447            | 352       | 210       | 97     |
| Jun-20| 2115       | 15         | 443            | 499       | 337       | 118    |
| Jun-21| 2396       | 0          | 491            | 546       | 416       | 127    |
| Jun-22| 2532       | 80         | 517            | 730       | 453       | 133    |
| Jun-23| 2710       | 17         | 373            | 872       | 239       | 138    |
| Jun-24| 2516       | 19         | 630            | 879       | 322       | 141    |
| Jun-25| 2865       | 59         | 329            | 891       | 397       | 152    |
| Jun-26| 3509       | 41         | 553            | 920       | 442       | 123    |
| Jun-27| 3645       | 0          | 605            | 985       | 445       | 150    |
| Jun-28| 3713       | 117        | 796            | 1087      | 918       | 195    |
| Jun-29| 3940       | 0          | 906            | 983       | 1267      | 118    |
| Jun-30| 3949       | 0          | 650            | 975       | 1105      | 0      |
| Jul-01| 3943       | 95         | 704            | 945       | 937       | 253    |
| Jul-02| 3882       | 0          | 657            | 1018      | 1272      | 151    |
| Jul-03| 4343       | 88         | 815            | 1213      | 1362      | 160    |
| Jul-04| 4329       | 0          | 837            | 1892      | 1694      | 211    |
| Jul-05| 4230       | 0          | 705            | 1850      | 1839      | 250    |
| Jul-06| 4150       | 0          | 908            | 1500      | 1925      | 225    |
| Jul-07| 3827       | 0          | 1322           | 1831      | 1843      | 193    |
| Jul-08| 3616       | 128        | 1178           | 1879      | 1408      | 272    |
| Jul-09| 3756       | 78         | 1062           | 1924      | 2062      | 301    |
| Jul-10| 4231       | 143        | 1555           | 1410      | 2228      | 339    |
| Jul-11| 3680       | 121        | 1608           | 1278      | 2313      | 416    |
| Jul-12| 3065       | 65         | 1813           | 1178      | 2798      | 488    |
| Jul-13| 4244       | 81         | 1933           | 1269      | 2627      | 435    |
| Jul-14| 4328       | 50         | 1935           | 1550      | 2738      | 449    |
| Jul-15| 4526       | 63         | 1916           | 1524      | 2496      | 608    |
| Jul-16| 4496       | 65         | 2432           | 1507      | 3176      | 623    |
| Jul-17| 4549       | 147        | 2533           | 1676      | 4169      | 722    |
| Jul-18| 4538       | 89         | 2602           | 1478      | 3693      | 791    |
| Jul-19| 4807       | 62         | 3963           | 1284      | 4537      | 593    |
| Jul-20| 4079       | 105        | 5041           | 1286      | 4120      | 821    |
| Jul-21| 4085       | 93         | 4074           | 1198      | 3648      | 794    |
| Jul-22| 4965       | 87         | 4944           | 1431      | 3649      | 720    |
| Jul-23| 5849       | 121        | 6045           | 1554      | 4764      | 1038   |
| Jul-24| 6472       | 120        | 7998           | 1567      | 5030      | 1078   |
| Jul-25| 6785       | 95         | 8147           | 1649      | 5007      | 885    |
| Jul-26| 6088       | 139        | 7813           | 0         | 5072      | 1103   |
| Jul-27| 6986       | 132        | 7627           | 1593      | 5199      | 927    |
| Jul-28| 6993       | 86         | 6051           | 3083      | 5324      | 702    |
| Jul-29| 6972       | 139        | 7948           | 0         | 5536      | 1167   |
| Jul-30| 6426       | 166        | 10093          | 1764      | 5563      | 903    |
| Date  | Tamil Nadu | Puducherry | Andhra Pradesh | Telangana | Karnataka | Kerala |
|-------|------------|------------|----------------|-----------|-----------|--------|
| Jul-31 | 5864       | 121        | 10147          | 1811      | 6128      | 506    |
| Aug-01 | 5881       | 174        | 10376          | 1986      | 5483      | 1310   |
| Aug-02 | 5870       | 134        | 9276           | 2083      | 5172      | 1129   |
| Aug-03 | 5875       | 200        | 8555           | 1891      | 5532      | 1169   |
| Aug-04 | 5860       | 176        | 7822           | 2289      | 4752      | 962    |
| Aug-05 | 5063       | 165        | 9747           | 2012      | 6259      | 1083   |
| Aug-06 | 5175       | 286        | 10128          | 2092      | 5619      | 1195   |
| Aug-07 | 5684       | 188        | 10328          | 2307      | 6805      | 1298   |
| Aug-08 | 5880       | 241        | 10171          | 2256      | 6670      | 1251   |
| Aug-09 | 5883       | 261        | 10080          | 1982      | 7178      | 1420   |
| Aug-10 | 5994       | 259        | 10820          | 1256      | 5985      | 1211   |
| Aug-11 | 5914       | 242        | 7665           | 1896      | 4267      | 1184   |
| Aug-12 | 5834       | 276        | 9024           | 1897      | 6257      | 1417   |
| Aug-13 | 5871       | 481        | 9597           | 1931      | 7883      | 1212   |
| Aug-14 | 5835       | 299        | 9996           | 1921      | 6706      | 1504   |
| Aug-15 | 5990       | 315        | 8943           | 1863      | 7908      | 1569   |
| Aug-16 | 5860       | 359        | 8732           | 1302      | 8818      | 1608   |
| Aug-17 | 5950       | 378        | 8912           | 894       | 7040      | 1530   |
| Aug-18 | 5990       | 297        | 8780           | 1682      | 6217      | 1735   |
| Aug-19 | 5709       | 367        | 9652           | 1763      | 7665      | 1758   |
| Aug-20 | 5795       | 354        | 9742           | 1724      | 8642      | 2333   |
| Aug-21 | 5986       | 542        | 9393           | 1967      | 7385      | 1968   |
| Aug-22 | 5995       | 302        | 9544           | 2474      | 7571      | 1983   |
| Aug-23 | 5980       | 518        | 10276          | 2384      | 7330      | 2172   |
| Aug-24 | 5975       | 410        | 7895           | 1842      | 5938      | 1908   |
| Aug-25 | 5967       | 337        | 8601           | 2579      | 5851      | 1242   |

© 2022 Padi et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here (Please copy paste the total link in your browser address bar)
https://www.sdiarticle5.com/review-history/87240