Modelling COVID-19 Pandemic with Asymptomatic Patients for the State Andhra Pradesh, India

Munukutla Srinivasa Lakshmana Bala Subrahmanyam[1*], Vajjha Hem Kumar[2]
[1]*Head-Imaging & Algorithm Practices, Srikari Impetus Solutions Pvt. Ltd., Hyderabad, India*
[2]*Founder and Chief Architect, Srikari Impetus Solutions Pvt. Ltd., Hyderabad, India*

***Abstract*: Andhra Pradesh is one of most covid affected state during first and second waves in India. This state contains 13 districts. This paper proposes Susceptible, Asymptomatic, Infected and Recovered – Regression and Grid Search (SAIR-RGS) model for analyzing COVID-19 pandemic with asymptomatic patients for the state Andhra Pradesh during second wave from 1-2-2021 to 30-09-2021. SAIR-RGS initially collects daily covid cases information from Department of Health, medical and family welfare, AP and estimates the model parameters using regression and grid search methods. To calculate recovery rate (γ) the proposed model uses least square method between daily active cases and recoveries. This method estimates remaining two parameters i.e., contact rate (β) and symptomatic rate (δ) using grid search method in two phases. After that the proposed method estimates the average total number of asymptomatic cases during second wave for all 13 districts of AP. Also, the proposed SAIR-RGS model calculates infectious period and basic reproduction number (R_0) for all districts. Finally proposed model predicts the chances of third wave in each district.**

***Keywords*: Asymptomatic, Andhra Pradesh, SAIR, regression, grid search, infectious period, basic reproduction number.**

1. Introduction

Currently more than two hundred and thirty-four million people infected with Covid–19 globally and more than 4 million people lost their life [33]. Unlike Influenza (flu), covid spread more easily and can infect some people very seriously. The major problem with Covid -19 is the asymptomatic nature of the huge number of patients even after infection. They can infect others like symptomatic patients. Initial asymptomatic person either turn into sever symptomatic person after some days or can recover from the virus with antibodies in their body. Also, there are chances to carry this asymptomatic nature for a long time. India is one of the biggest democratic countries with huge number of populations more than 134 crores. India is homeland for different cultures, different religions, different casts, and different languages. Because of this diversity India witnessed most covid affected country in the world in both first and second waves. India recorded second highest number of infections after USA and third highest number of deaths after USA and Brazil [33]. Compared to first wave, virus transmitted very fast in second wave. New mutations or variants and shorter incubation period could be the major reason behind this.

In first wave government of India imposed country wide lock down and implemented strict covid protocols i.e., face masking, social distancing, ban on international transport etc. to reduce covid transmission rate. But in second wave government of India allowed states to take their own decisions for controlling covid transmission in their respective states and encouraged micro cantonment zones. This decision resulted difference in both waves. The first wave was national whereas second wave purely regional. Because of this reason states started taking individual decisions to control virus in their respective area. This could be the major reason for increasing number of cases in second wave in the rest of India. For example, due to huge number of covid cases and lack of sufficient hospital beds, oxygen cylinders, Delhi government announced full state lock down in the month of April. Then migrated people from different states prefer to return to their native places and transmitted virus even remote areas too. Also, local body elections in some states would be major reason for the transmission of virus in rural areas. In first wave more cases registered in Urban areas for first five months while in second wave more cases stared in rural areas within two months. Out of more than 50 most affected districts 26 districts from rural areas. Maharashtra, Andhra Pradesh, Kerala, Tamil Nādu and Karnataka were most top five most affected states in India. Second wave initially started from Maharashtra, then went to North after that transmitted to south and east part of India.

Andhra Pradesh is one of the most Covid affected states in India. This state contains 13 districts. Coastal Andhra and Rayalaseema are two regions in this state. Nine districts come under coastal region and remaining four districts comes under Rayalaseema region. In this state on an average 70 daily cases were registered in the month of February but this number reached to more than 24 thousand daily cases in the month of May. Because of this sudden surge effected the shortage of oxygen and ICU beds. Also, in second wave younger generation less than 45 years affected more especially in rural areas and

*Corresponding author: subbu@impetus-solutions.com

most of the cases were asymptomatic. Lack of proper infrastructure, testing mechanism, awareness over the virus resulted high transmission of infection in this state and leads to community spread in both rural and urban areas. Nearly more than 39 lakhs rural people suffered from this pandemic during second wave. In second wave initially 80 days taken to reach one lakh cases on 22-4-2021[31] but reached to two lakh cases within seven days and reached to three lakh cases in eight days interval. Next four lakhs and five lakhs touched within 5 days intervals respectively. More than ten lakhs cases touched on 20th July 2021. After that reached to eleven lakhs in 44 days i.e., on 14-08-2021[31].

In this paper we are proposing Susceptible, Asymptomatic, Infected and Recovered – Regression and Grid Search (SAIR-RGS) model for analyzing covid trends with asymptomatic patients. The proposed model considers from 1-2-2-21 to 30-09-2021 i.e., 242 days as second wave and collects daily covid information from department of Health, medical and family welfare daily bulletin [31]. The proposed method estimates model parameters using regression and grid search mechanisms. From these parameters we can estimate Infectious period, average total number of asymptomatic cases and average basic reproduction(R_0) of each district in this state.

2. Literature Review

So many papers available for modeling epidemics in the literature. In [4, 9-15, 20-23] authors predicted and estimated virus trends using SEIR model. In [16, 18, 21] authors used latest technologies like artificial intelligence, machine learning and deep learning techniques. Authors in [24]-[27] used SIR model for predicting parameters and authors in [1 3 8 28 29 34 - 44] presented models with asymptomatic patients. Herbert W. Hethcote et al. presented mathematics of infectious disease in [6]. In [7] authors contributed mathematical theory on epidemics. Gemma Massonis et al in [37] presented 36 epidemiological models. Kenji Mizumoto et al [34] presented asymptomatic portion of covid 19 cases. In [35] authors addressed asymptomatic role of ongoing pandemics. Sang Woo Park et al [36] provided time scale of asymptomatic transmission effects. In [38] Xiaoqi Bi et al. presented group and networked versions-based model for capturing dynamics of asymptomatic infections. SUTRA model for addressing asymptomatic patients presented in [1]. Impact of Covid on different sectors addressed in [46], [47]. IoT based health monitoring addressed in [48]. In [39] Paolo Di Giamberardino et al. presented ordinary differential equation-based model for Italy covid 19 trends. SEIR model improved with asymptomatic patients in [40]. Using wirelesses network functions in [41] Alaa A. R. Alsaeedy et al. detected COVID – 19 risk regions. SAIR model which includes mobility data presented in [42]. SAIR model which includes mobility data presented in [42]. A review on asymptomatic infections assessment and management addressed in [43]. SEIAR model presented in [44] to assess the virus intervention measures.

3. Methodology

Initial epidemiological model SIR divides the population into three categories i.e., Susceptible (S), Infected (I) and Removed (R) and its dynamics given by

$$\frac{dS(t)}{dt} = -\beta * S(t) * I(t) \quad (1)$$
$$\frac{dI(t)}{dt} = \beta * S(t) * I(t) - \gamma * I(t) \quad (2)$$
$$\frac{dR(t)}{dt} = \gamma * I(t) \quad (3)$$

where β represents contact rate and γ represents recovery rate respectively.

In this model the susceptible people directly enter Infected group. More realistic model SEIR which consists intermediate compartment exposed (E) in between S and I and its dynamic given by

$$\frac{dS(t)}{dt} = -\beta * S(t) * I(t) \quad (4)$$
$$\frac{dE(t)}{dt} = \beta * S(t) * I(t) - \varepsilon * E \quad (5)$$
$$\frac{dI(t)}{dt} = \varepsilon * E - \gamma * I(t) \quad (6)$$
$$\frac{dR(t)}{dt} = \gamma * I(t) \quad (7)$$

where parameter ε represents the incubation rate.

In this model contact with infected person in I with any one in S group leads to probability of new infection. But such people first enter intermediate compartment E rather than directly into I group. In this model there is no SE term i.e., no chance of new infections with contact between S and E group of people. But from characteristics of COVID-19 there are chances of asymptomatic infections in between S and I instead of E. To differentiate symptomatic and asymptomatic cases the present paper proposes SAIR model and estimates the model parameters using regression and grid search methods.

The proposed model divides the considered population into four compartment namely susceptible, asymptomatic, infectious, and removed. The first compartment i.e., susceptible represents the fraction of people who can be able to transmit the disease. The second compartment i.e., asymptomatic represents the fraction of people who does not show any symptoms but able to transmit to others. The third compartment i.e., Infectious represents the fraction of people who are infected with the disease. The fourth compartment contains the fraction of people who recovered from the disease.

Let t be the time variable and N be the size of population Let S(t), A(t), I(t) and R(t) represents the susceptible, asymptomatic, Infected and recovered respectively at time t as shown in Fig 1. Suppose all component values divided by N then these values lie between 0 and 1.

So S(t) + A(t) + I(t) + R(t) = 1

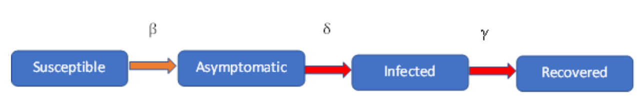


Fig. 1. SAIR model

The following four differential equations represents migration of people from one compartment to another compartment with time variable t. in this equation β, δ, and γ represents contact rate, symptomatic rate and infection rate respectively. These parameters relate the model differential equations.

$$\frac{dS(t)}{dt} = -\beta * S(t) * I(t) - \beta * S(t) * A(t) \quad (8)$$
$$\frac{dA(t)}{dt} = \beta * S(t) * A(t) + \beta * S(t) * I(t) - (\gamma + \delta) * A(t) \quad (9)$$
$$\frac{dI(t)}{dt} = \delta * A(t) - \gamma * I(t) \quad (10)$$
$$\frac{dR(t)}{dt} = \gamma * I(t) \quad (11)$$

The proposed method uses the following initial conditions,

$$S(0) = 1 - A(0) - I(0) - R(0) \quad (12)$$

where I(0) = 0 , R(0) = 0 and A(0) << 1

Let M = A+I then,

$$\frac{dS(t)}{dt} = -\beta * S(t) * M(t) \quad (13)$$
$$\frac{dM(t)}{dt} = \beta * S(t) * M(t) - (\gamma) * M(t) \quad (14)$$
$$\frac{dI(t)}{dt} = \delta * M(t) - (\gamma + \delta) * I(t) \quad (15)$$

Initially S(t) ~ 1 when t very small So we can write 14 equations as follows,

$$\frac{dM(t)}{dt} \sim (\beta - \gamma)\, M(t)$$

So $M(t) = M(0) \exp[(\beta - \gamma)t]$ (16)

Substituting 16 in 15 we get,

$$\frac{dI(t)}{dt} = \delta * M(0) * \exp[(\beta - \gamma)t] - (\gamma + \delta) * I(t),$$
$$I(0) = 0 \quad (17)$$

the solution of (17) as

$$I(t) = \frac{\delta}{\beta + \delta}[\exp[(\beta - \gamma)t] - \exp[-(\gamma + \delta)t)]] \quad (18)$$

Let $C = \frac{\delta}{\beta + \delta}$

The equation (18) can be written as

$$I(t) = C \exp[(\beta - \gamma)t]\{1 - \exp[(\beta + \delta)t]\} \quad (19)$$

Take log on both in equation 19 we get

$$\ln I(t) = \ln C + (\beta - \gamma)\, t + \ln\{1 - \exp[(\beta + \delta)t]\} \quad (20)$$

From these equations we can estimate all three parameters.

The block diagram of proposed SAIR-RGS model given in Fig. 2.

Step 1: the proposed method initially collects daily covid cases from the Department of Health, medical and family welfare daily bulletin [31] from 1-2-2021 to 18-09-2021. This data contains the cumulative daily infections, active infections, cumulative recoveries, and deaths respectively.

Step 2: Calculate seven days average value for each active infection. Let us say I_{avg}

Step 3: To calculate model parameters i.e. β, δ and γ the proposed method uses following procedure

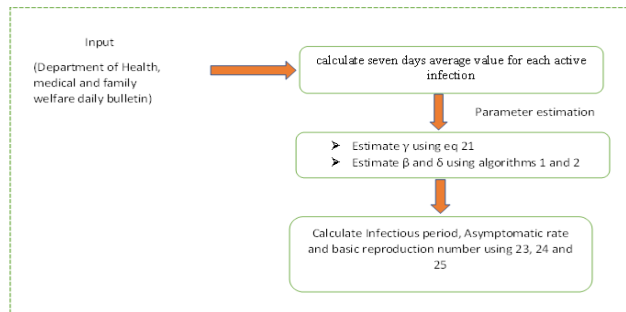


Fig. 2. Proposed SAIR-RGS model

Estimating γ:

The proposed method estimates the γ value from the two time series data i.e., daily active cases and cumulative recoveries provided by Department of Health, medical and family welfare daily bulletin, AP.

From equation 5 we have

$$\frac{dR(t)}{dt} = \gamma * I(t)$$

It can be written as

$$R(t+T) - R(t) = \gamma * \int_t^T I(s)ds \quad (21)$$

where T is fixed time width.

Now generate two vectors { $R(t+T) - R(t)$} and {I(t)} for various values of t using two time series data i.e., daily active infections and cumulative recoveries respectively provided by Department of Health, medical and family welfare AP [31].

Finally, this paper estimates gamma value by fitting best line [45] passing through origin and through these vectors using equation 21. The slope of this line gives the gamma value. This paper considers T as 7 days.

Estimating β and δ:

From equation 20 we can observe that I(.) is combination of growing and decaying exponentials. We can easily estimate $\beta - \gamma$ by ignoring initial part. From the result we can estimate β with calculated γ using equation 21. We can estimate $\beta + \delta$ using residual term $\{1 - \exp[(\beta + \delta)t]\}$.

When infection at maximum we have $\frac{dI(t)}{dt} = 0$

So, from equation (11) we can conclude that

$$A(t) = \frac{\gamma}{\delta} I(t) \quad (22)$$

Since β >> δ estimating error in β + δ may leads to error in calculating δ and ultimately leads to poor calculation of number of asymptomatic cases.

The proposed method uses grid search method for estimating these parameters.

The proposed algorithm uses the following range of values for each parameter

β in the range between 0.1 and 0.5 with 0.001 increment.

δ in the range between 0.001 and 0.009 with 0.001 increment.

The proposed model estimates these parameters in two phases. In first phase the proposed estimates the parameters in two digits after decimal using Algorithm 1. After that the proposed model estimates the third digit after decimal by extending calculated parameters in the first phase by 0.05 with increment 0.001 and by 0.0009 with increment 0.0001 respectively for β and δ. (Algorithm – 2).

Algorithm 1: Estimating each parameter two digits after decimal using proposed SAIR-RGS method

Let β, δ and γ be transmission rate, symptomatic rate and infection rate respectively. Let β ∈ [0.1 0.5], δ ∈ [0.001 0.009] and γ be slope of the equation 2 using least square technique.

Function CalculateTwoDigistAfterDecimal(β, δ, γ)
Begin:
For each value β in the range between 0.1 and 0.5 with increment value 0.01
Begin:
For each value δ in the range between 0.001 and 0.009 with increment value 0.001
Solve differential equations 1 with parameter values (β, δ, γ) and using initial condition 1
Let (S, A, I, R) be the solution.
Calculate sum of squared distance between estimated I and I_{avg}
End For
End For
Let (β', δ') be the final set of values which having the minimum sum of squared distance with I_{avg}
return (β', δ')
End Function

Algorithm-2: Estimating each parameter third digit after decimal using proposed SAIR-GS method

Let β'and δ' be estimated transmission rate and symptomatic rate respectively from the Algorithm 1 and γ be slope of the equation 2 using least square technique

Function CalculateThirdDigitAfterDecimal(β, δ, γ)
Begin:
For each value β in the range between β' – 0.05 and β' + 0.05 with increment value as 0.001
Begin:
For each value ε in the range between δ' – 0.0009 and δ' + 0.0009 with increment value as 0.0001
Begin:
Solve differential equations 1 with parameter values (β, δ, γ) and using initial condition 1
Let (S , A , I, R) be the solution.
Calculate sum of squared distance between estimated I and I_{avg}
End For
End For
Let (β'', δ'') be the final set of values which having the minimum sum of squared distance with I_{avg}
return (β'', δ'')
End Function

Step 4: To estimate infectious period, number of asymptomatic infections and basic reproduction number the present model uses following formulas from the estimated model parameters β, ε and γ.

$$\text{Infectious period} = 1/\gamma \quad (23)$$

$$\text{Asymptomatic infections} = (\gamma/\delta) * I \quad (24)$$

$$\text{Basic reproduction number } (R_0) = \beta/\gamma \quad (25)$$

4. Results

The present paper considered the daily covid information of all thirteen districts from 1-2-2-2021 to 30-9-2021[31]. Table 1 shows the total number population [30], total infections, total recoveries and total deaths during this period and Table 2 shows the infected population percentage, total infected percentage, total recovery percentage all thirteen districts in AP and Fig 3 shows the comparison of all districts.

Table 1
Total number of populations, infections, recoveries, and deaths of each 13 districts of Andhra Pradesh

District Name	Population	Infections	Recoveries	Deaths
Anantapur	4424781	89970	89434	493
Chittoor	4525520	157208	154566	1073
East Godavari	5588288	167369	164727	646
Guntur	5299367	100659	99389	545
YSR Kadapa	2882469	59785	59389	176
Krishna	4897763	68934	67285	707
Kurnool	4394765	63204	62865	363
Nellore	3213088	82807	80858	534
Prakasam	3683513	75287	73324	517
Srikakulam	2930716	76597	76061	437
Visakhapatnam	4651857	96948	96280	558
Vizianagaram	2541879	41645	41158	431
West Godavari	4268459	83685	82389	561
Total AP	91702478	1161203	1144830	7041

The present SAIR-RGS model estimated that β as 0.207, δ as 0.0028 and γ as 0.098 for the entire state AP. So average duration of infectious period as 10.16 days and average basic reproduction (R_0) as 2.1 for total Andhra Pradesh during second wave i.e., from 1-2-2021 to 30-10-2021[31]. The proposed model estimated that ration between asymptomatic and symptomatic cases is 35.15. So totally 4,08,16,285 people were asymptomatic in this state. Table 3 and fig shows details of the proposed SAIR-RGS model.

Table 2
Infected population percentage, infection percentage, recovery percentage and death percentage of all districts in AP

District Name	Infected Population %	Infection % of total State	Recovery % of total State	Death % of total state
Anantapur	2.03	7.75	7.81	7.0
Chittoor	3.47	13.54	13.5	15.24
East Godavari	2.99	14.41	14.39	9.17
Guntur	1.9	8.67	8.68	7.74
YSR Kadapa	2.07	5.15	5.19	2.5
Krishna	1.41	5.94	5.88	10.04
Kurnool	1.44	5.44	5.49	5.16
Nellore	2.58	7.13	7.06	7.58
Prakasam	2.04	6.48	6.4	7.34
Srikakulam	2.66	6.6	6.64	6.21
Visakhapatnam	2.08	8.35	8.41	7.93
Vizianagaram	1.64	3.59	3.6	6.12
West Godavari	1.96	7.21	7.2	7.97
Total AP Cases	1.27	100	100	100

Table 3
Parameters table for Andhra Pradesh using SAIR-RGS model

Parameter	Value
Contact rate(β)	0.207
Infectious period (1/ γ)	10.16 days
Asymptomatic rate (γ/ δ)	35.15
Basic reproduction (R_0)	2.1

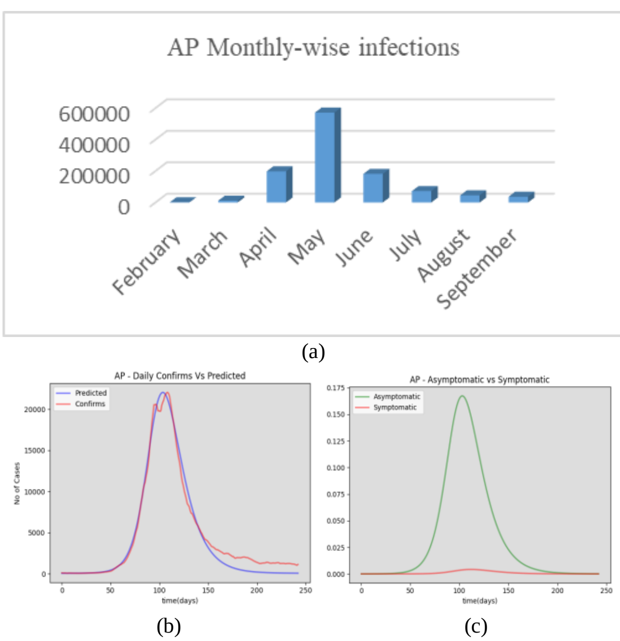


Fig. 3. Andhra Pradesh (a) Monthly wise cases, (b) daily confirms vs predicted by proposed SAIR-RGS model, (c) Asymptomatic vs. Symptomatic cases

Anantapur: Anantapur comes under Rayalaseema region in AP. As per [30] 89,970 (eighty-nine thousand nine hundred and seventy) people infected, 89434 (eighty-nine thousand four hundred and thirty-four) people recovered and 493 (four hundred and ninety-three) people died during second wave in this district respectively, nearly 2.03% people effected with the pandemic out of total population. The present SAIR-RGS method estimated that β as 0.302, δ as 0.008 and γ as 0.158. So average duration of infectious period as 6.34 days and average basic reproduction (R_0) as 1.91. The proposed model estimated that ration between asymptomatic and symptomatic cases is 19.73. So totally 1775108 people were asymptomatic in this district. Table 3 and fig shows details of the proposed SAIR-RGS model.

Chittoor: Chittoor is bordering district with Tamil Nādu state. Its population around 45 lacs [30]. In second wave 1,57,208 (one lac fifty-seven thousand two hundred and eight) people infected with covid – 19 but 1,54,566 (one lac fifty-four thousand five hundred and sixty-six) (98.02%) people recovered as on 31st September. This district recorded highest number of deaths i.e., 1073 (one thousand and seventy-three) (15.24%) out of total deaths in AP.

As per proposed model, 0.202, and 0.101 are contact rate and recovery rate respectively of this district during second wave. The infectious period of this district as 9.9 days and basic reproduction as 2.0. The proposed model estimated that ration between asymptomatic and symptomatic cases is 12.62. So totally 1775108 people were asymptomatic in this district. Table 5 and fig 5 shows details of the proposed SAIR-RGS model.

Table 4
Parameters table for Anantapur district using SAIR-RGS model

Parameter	Value
Contact rate(β)	0.302
Infectious period (1/ γ)	6.34 days
Asymptomatic rate (γ/ δ)	19.73
Basic reproduction (R_0)	1.91

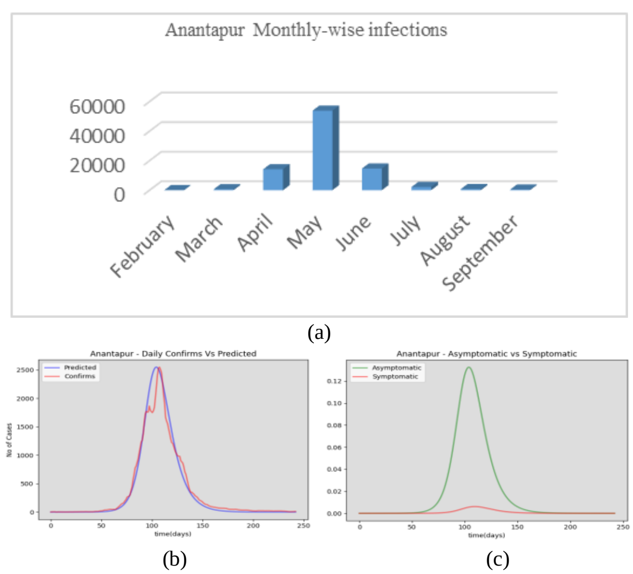
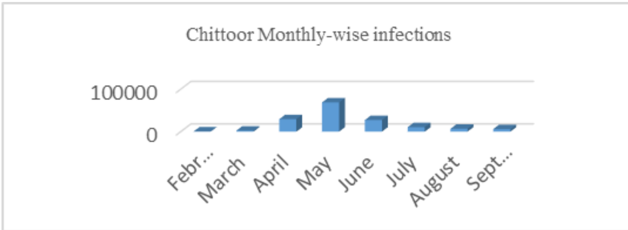


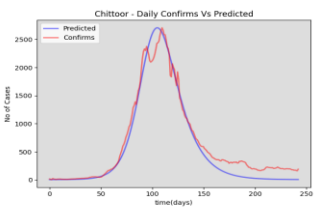
Fig. 4. Anantapur (a) Monthly wise cases (b) daily confirms vs. predicted by proposed SAIR-RGS model, (c) Asymptomatic vs. Symptomatic cases.

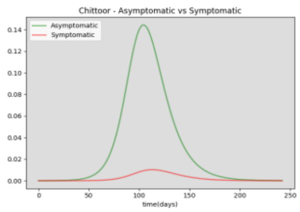
Table 5
Parameters table for Chittoor district using SAIR-RGS model

Parameter	Value
Contact rate(β)	0.202
Infectious period (1/ γ)	9.91 days
Asymptomatic rate (γ/ δ)	12.62
Basic reproduction (R_0)	2.0



(a)





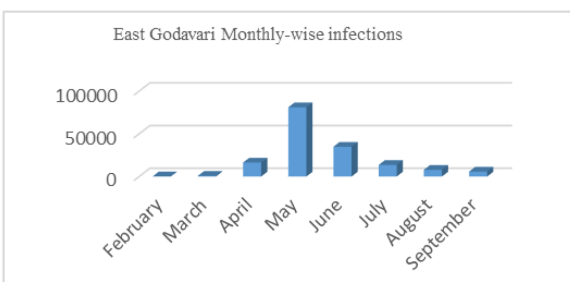
(b) (c)

Fig. 5. Chittoor (a) Monthly wise cases, (b) daily confirms vs predicted by proposed SAIR-RGS model, (c) Asymptomatic vs Symptomatic cases

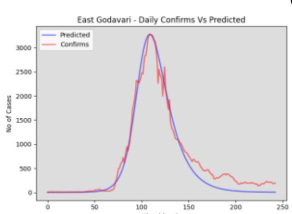
East Godavari: East Godavari is one of highest number of populations out of 13 districts in AP. As per [30] its population nearly 55 lacs. From Andhra Pradesh official daily covid bulletin [31], 1,67,369 (one lac sixty-seven thousand three hundred and sixty-nine) people infected from Covid – 19 during second wave i.e., 2.99% people infected from this pandemic and 1,64,727 (one lac sixty-four thousand seven hundred and twenty-seven) people recovered from this as on 31st September.

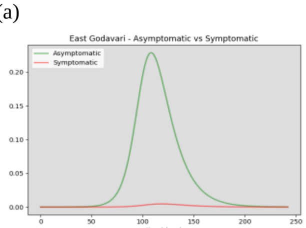
Table 6
Parameters table for East Godavari district using SAIR-RGS model

Parameter	Value
Contact rate(β)	0.21
Infectious period (1/ γ)	11.9 days
Asymptomatic rate (γ/ δ)	42.09
Basic reproduction (R_0)	2.49



(a)





(b) (c)

Fig. 6. East Godavari (a) Monthly wise cases, (b) daily confirms vs. predicted by proposed SAIR-RGS model, (c) Asymptomatic vs. Symptomatic cases

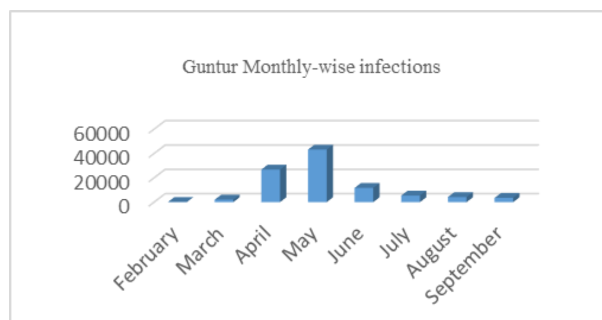
The proposed SAIR-RGS method estimated that β and γ as 0.21 and 0.084 respectively. The average duration of infectious period (1/ γ) of this district as 11.9 days and average basic reproduction(R_0) as 2.49. The proposed model estimated that ration between asymptomatic and symptomatic cases is 42.09. So totally 7044561 people were asymptomatic in this district. Table 6 and fig. 6 shows details of the proposed SAIR-RGS model.

Guntur: Guntur is one of center located district in AP and bordering with Telangana state. According to [30] its population around 53 lacs. In this district totally 1,00,659 (one lakh six hundred and fifty-nine) people infected from covid during second wave. Nearly 8.67% people infected in this district out of total infections in the state of Andhra Pradesh. Out of total infections 99389 (ninety-nine thousand three hundred and eighty-nine) people recovered from covid. Only 1.9% people infected out of total population in this district.

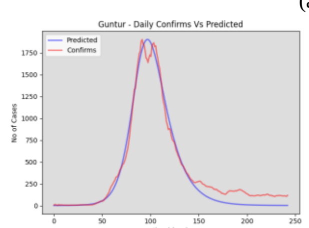
The present model estimated that β as 0.203, δ as 0.002 and γ as 0.096. The average duration of infectious period (1/ γ) of this district as 10.38 days and average basic reproduction(R_0) as 2.18. The proposed model estimated that ration between asymptomatic and symptomatic cases is 48.16. So totally 4847737 people were asymptomatic in this district. Table 7 and fig. 7 shows details of the proposed SAIR-RGS model.

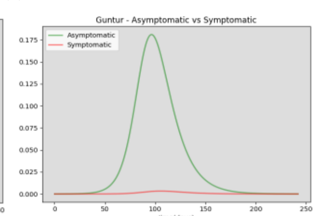
Table 7
Parameters table for Guntur district using SAIR-RGS model

Parameter	Value
Contact rate (β)	0.203
Infectious period (1/ γ)	10.38 days
Asymptomatic rate (γ/ δ)	48.16
Basic reproduction (R_0)	2.18



(a)





(b) (c)

Fig. 7. Guntur (a) Monthly wise cases, (b) daily confirms vs. predicted by proposed SAIR-RGS model, (c) Asymptomatic vs. Symptomatic cases

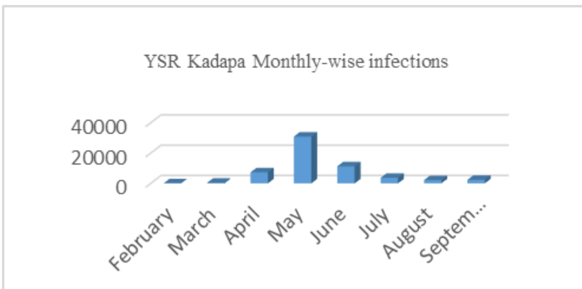
YSR Kadapa: Kadapa is one of Rayalaseema district in AP. Its population nearly 29 lacs [30]. 59785 (fifty-nine thousand seven hundred and eighty-five), 59389 (fifty-nine thousand three hundred and eighty-nine) and 176(one hundred and seventy-six) are total number of infected, recovered and deaths people respectively in this district during second wave.

The present model estimated that β as 0.281, δ as 0.0088 and

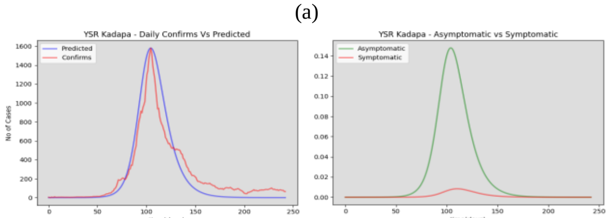
γ as 0.139 The average duration of infectious period ($1/\gamma$) of this district as 7.19 days and average basic reproduction(R_0) as 2.01. The proposed model details are shown in Table 8 and Fig 9. The proposed model estimated that ration between asymptomatic and symptomatic cases is 15.88. So totally 949385 people were asymptomatic in this district.

Table 7
Parameters table for YSR Kadapa district using SAIR-RGS model

Parameter	Value
Contact rate (β)	0.281
Infectious period ($1/\gamma$)	7.19 days
Asymptomatic rate (γ/δ)	15.88
Basic reproduction (R_0)	2.01



(a)



(b) (c)

Fig. 7. YSR Kadapa district (a) Monthly wise cases, (b) daily confirms vs. predicted by proposed SAIR-RGS model, (c) Asymptomatic vs. Symptomatic cases

Krishna: Krishna is one of border district with state of Telangana. Its population nearly about 49 lacs [30]. In this district 68934 (sixty-eight thousand nine hundred thirty-four) population effected with covid second wave. Totally 707 (seven hundred and seven) people lost their life during second wave.

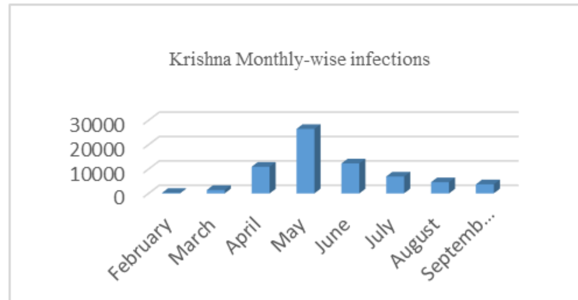
The present model estimated that β as 0.182, δ as 0.002 and γ as 0.076. The average duration of infectious period ($1/\gamma$) of this district as 13.15 days and average basic reproduction(R_0) as 2.39. Table 8 and Fig 8 shows the details of the proposed SAIR-RGS model. The proposed model estimated that ration between asymptomatic and symptomatic cases is 38.01. So totally 2620181 people were asymptomatic in this district.

Table 8
Parameters table for Krishna district using SAIR-RGS model

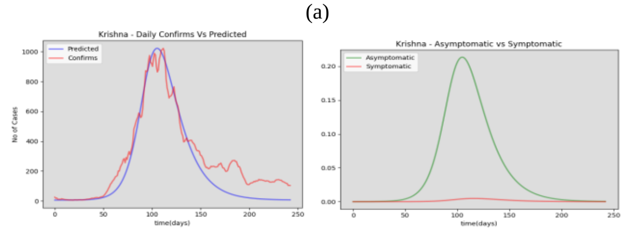
Parameter	Value
Contact rate (β)	0.182
Infectious period ($1/\gamma$)	13.15 days
Asymptomatic rate (γ/δ)	38.01
Basic reproduction (R_0)	2.39

Kurnool: Kurnool comes under Rayalaseema district in AP. Its population around 44 lacs according to estimated population [30]. In this district 5.44% (63,204) effected with covid second wave out of total infections in the state of Andhra Pradesh. 5.49% (62,865) people recovered out of total recoveries in AP.

The present model estimated that β as 0.275, δ ε as 0.0088 and γ as 0.134. The average duration of infectious period ($1/\gamma$) of this district as 7.48 days and average basic reproduction(R_0) as 2.06. Table 10 and Fig. 11 shows the details of the proposed SAIR-RGS of this district. The proposed model estimated that ration between asymptomatic and symptomatic cases is 15.2. So totally 960700 people were asymptomatic in this district.



(a)

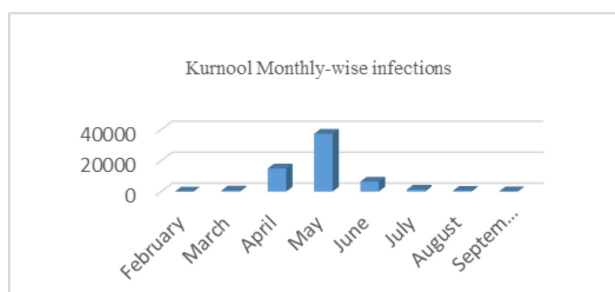


(b) (c)

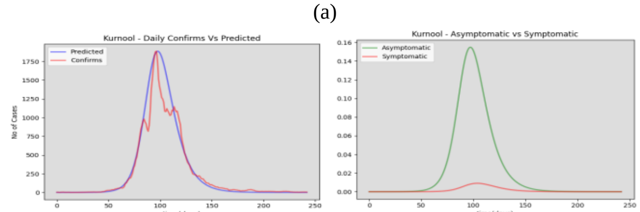
Fig. 8. Krishna district (a) Monthly wise cases, (b) daily confirms vs. predicted by proposed SAIR-RGS model, (c) Asymptomatic vs. Symptomatic cases

Table 9
Parameters table for Kurnool district using SAIR-RGS model

Parameter	Value
Contact rate (β)	0.275
Infectious period ($1/\gamma$)	7.48 days
Asymptomatic rate (γ/δ)	15.2
Basic reproduction (R_0)	2.06



(a)



(b) (c)

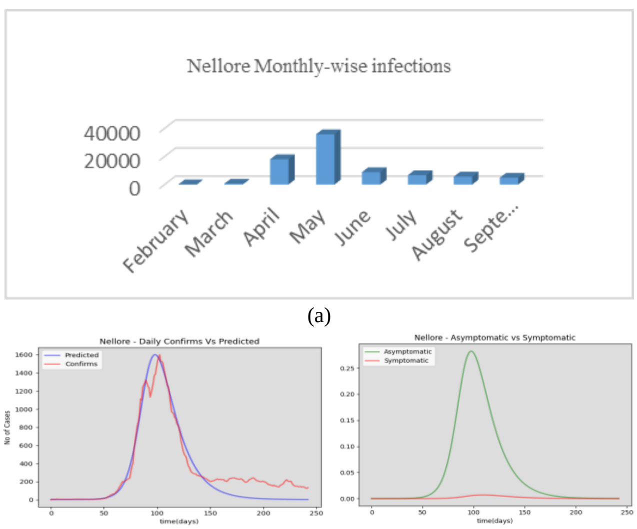
Fig. 9. Kurnool district (a) Monthly wise cases, (b) daily confirms vs. predicted by proposed SAIR-RGS model, (c) Asymptomatic vs. Symptomatic cases

Nellore: Nellore is one of southeastern coastal district of AP. Its population around 32 lacs. Totally 81,098(eighty-one thousand ninety-eight) people effected with covid during second wave and 82807 (eighty-two thousand eight hundred and seven) people recovered with percentage of 7.06 out of total recoveries in AP. But 534 people lost their life.

The present model estimated that β as 0.209, δ as 0.0022 and γ as 0.072. The average duration of infectious period (1/ γ) of this district as 13.89 days and average basic reproduction(R_0) as 2.9. The proposed model estimated that ration between asymptomatic and symptomatic cases is 32.74. So totally 2711101 people were asymptomatic in this district. Table 10 and fig 10 shows details of the proposed SAIR-RGS model.

Table 10
Parameters table for Nellore district using SAIR-RGS model

Parameter	Value
Contact rate (β)	0.209
Infectious period (1/ γ)	13.89 days
Asymptomatic rate (γ/ δ)	32.74
Basic reproduction (R_0)	2.9



(a)

(b) (c)

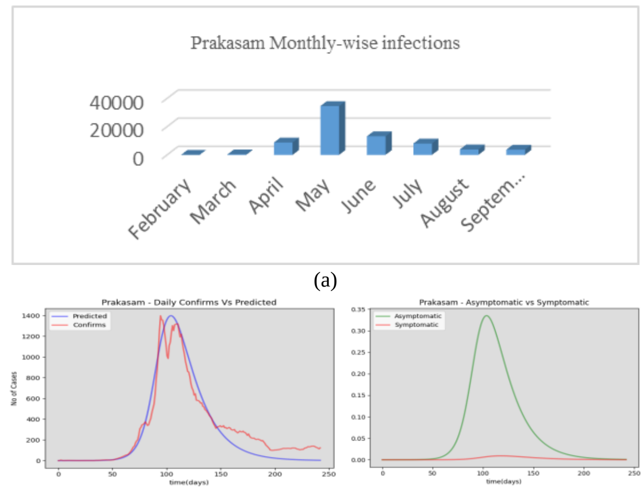
Fig. 10. Nellore district (a) Monthly wise cases, (b) daily confirms vs. predicted by proposed SAIR-RGS model, (c) Asymptomatic vs. Symptomatic cases

Prakasam: Prakasam is third largest district in the state of AP. The estimated population in this district around nearly 37 lacs [30] (according to 2021 estimation). During second wave 75287 (seventy-five thousand two hundred and eighty-seven) people in this district effected with covid with percentage of 6.48 out of total infections in AP. Only 2.04% people effected out of total population in this district.

The present model estimated that β as 0.189, δ as 0.002 and γ as 0.056. The average duration of infectious period (1/ γ) of this district as 17.85 days and average basic reproduction(R_0) as 3.37. More details shown in Table 12 and Fig 13. The proposed model estimated that ration between asymptomatic and symptomatic cases is 28.07. So totally 2113306 people were asymptomatic in this district. Table 11 and fig. 11 shows details of the proposed SAIR-RGS model.

Table 11
Parameters table for Prakasam district using SAIR-RGS model

Parameter	Value
Contact rate (β)	0.189
Infectious period (1/ γ)	17.85 days
Asymptomatic rate (γ/ δ)	28.07
Basic reproduction (R_0)	3.37



(a)

(b) (c)

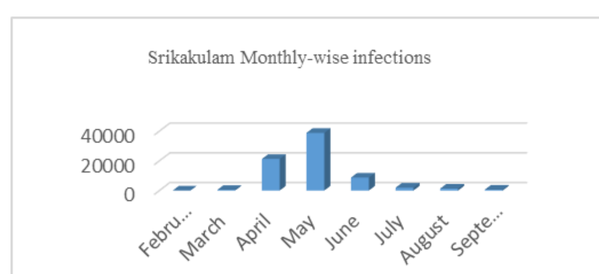
Fig. 11. Prakasam district (a) Monthly wise cases, (b) daily confirms vs. predicted by proposed SAIR-RGS model, (c) Asymptomatic vs. Symptomatic cases

Srikakulam: Srikakulam is one of coastal region district out of 9 districts in AP. The population of this district around 29 lacs according to estimated population 2021[30]. In this district totally 76597 (seventy-six thousand five hundred and ninety-seven) people suffered from covid during second wave i.e., 6.64% infections out of total infections and 437 people lost their life during second wave.

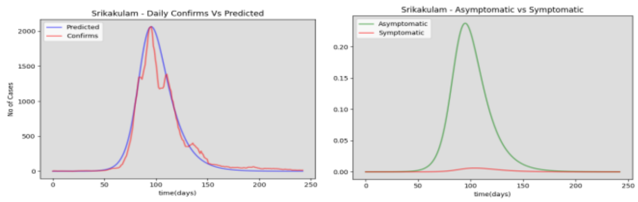
The present model estimated that β as 0.237, δ as 0.0028 and γ as 0.092. The average duration of infectious period (1/ γ) of this district as 10.87 days and average basic reproduction(R_0) as 2.57. Table 13 and Fig 14 shows results of proposed SAIR-RGS model results. The proposed model estimated that ration between asymptomatic and symptomatic cases is 32.98. So totally 2526169 people were asymptomatic in this district.

Table 12
Parameters table for Srikakulam district using SAIR-RGS model

Parameter	Value
Contact rate (β)	0.237
Infectious period (1/ γ)	10.87 days
Asymptomatic rate (γ/ δ)	32.98
Basic reproduction (R_0)	2.57



(a)



(b) (c)

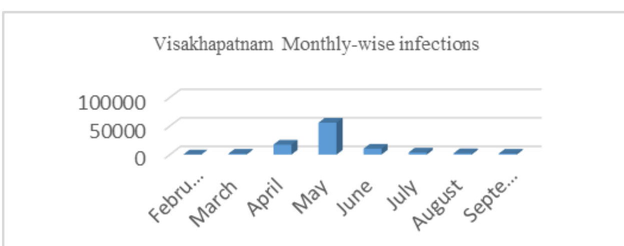
Fig. 12. Srikakulam district (a) Monthly wise cases, (b) daily confirms vs. predicted by proposed SAIR-RGS model, (c) Asymptomatic vs. Symptomatic cases

Visakhapatnam: Visakhapatnam comes under Uttar Andhra region coastal district in AP. Its population around 46 lacs [30]. It is economical capital AP. In second wave 96948 (ninety-six thousand nine hundred and forty-eight) people infected from covid. 96280 (ninety-six thousand two hundred and eighty) people recovered from this pandemic.

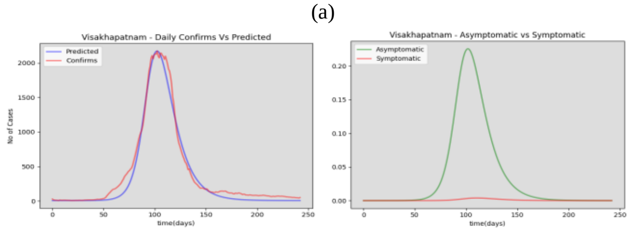
The present model estimated that β as 0.245, δ as 0.002 and γ as 0.099. The average duration of infectious period (1/ γ) of this district as 10.10 days and average basic reproduction(R_0) as 2.47. Table 14 and Fig. 14 shows the details of proposed SAIR-RGS model. The proposed model estimated that ration between asymptomatic and symptomatic cases is 49.64. So totally 4812498 people were asymptomatic in this district.

Table 13
Parameters table for Visakhapatnam district using SAIR-RGS model

Parameter	Value
Contact rate (β)	0.245
Infectious period (1/ γ)	10.10 days
Asymptomatic rate (γ/ δ)	49.64
Basic reproduction (R_0)	2.47



(a)



(b) (c)

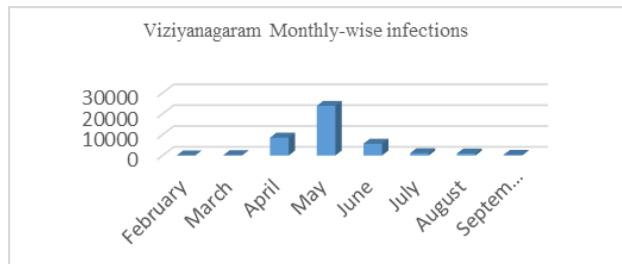
Fig. 13. Visakhapatnam district (a) Monthly wise cases, (b) daily confirms vs. predicted by proposed SAIR-RGS model, (c) Asymptomatic vs. Symptomatic cases

Vizianagaram: Vizianagaram is one of coastal district out 13 districts in AP. It is also bordering district of Orissa state. Its population around 25 lacs [30]. Totally 3.59% (41645) people infected with covid out of total infections in AP. 98.83% (41158) people recovered from this district.

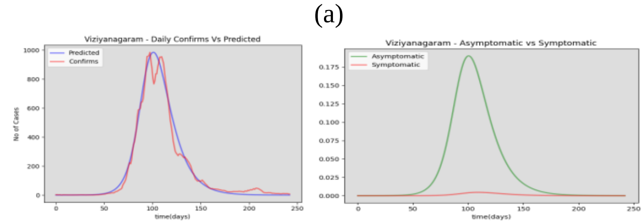
The present model estimated that β as 0.226, δ as 0.0028 and γ as 0.101 The average duration of infectious period (1/ γ) of this district as 9.94 days and average basic reproduction(R_0) as 2.25. Table 14 and Fig. 14 shows the details of the proposed SAIR-RGS model. The proposed model estimated that ration between asymptomatic and symptomatic cases is 35.95. So totally 1497137 people were asymptomatic in this district.

Table 14
Parameters table for Vizianagaram district using SAIR-RGS model

Parameter	Value
Contact rate (β)	0.226
Infectious period (1/ γ)	9.94 days
Asymptomatic rate (γ/ δ)	35.95
Basic reproduction (R_0)	2.25



(a)



(b) (c)

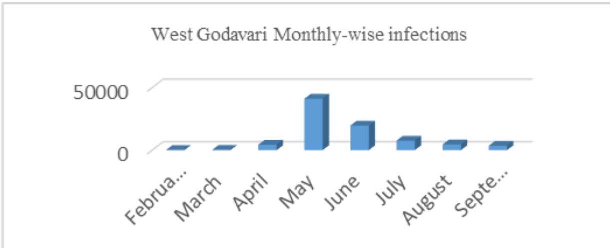
Fig. 14. Vizianagaram district (a) Monthly wise cases, (b) daily confirms vs. predicted by proposed SAIR-RGS model, (c) Asymptomatic vs. Symptomatic cases

West Godavari: West Godavari is one of coastal district out of 13 districts in AP. Its population nearly 43 lacs according to estimated population in 2021 [31]. 83685 (eighty-three thousand six hundred and eighty-five) people infected from covid during second wave in this district. 98.45% (82389) people recovered in this district out of total recoveries in AP.

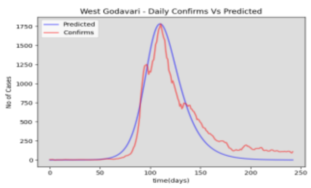
The present model estimated that β as 0.218, ε as 0.0028 and γ as 0.098 The average duration of infectious period (1/ γ) of this district as 10.20 days and average basic reproduction(R_0) as 2.22. More details about this district given in Table and Fig using proposed SAIR-RGS model. The proposed model estimated that ration between asymptomatic and symptomatic cases is 35.14. So totally 2940690 people were asymptomatic in this district.

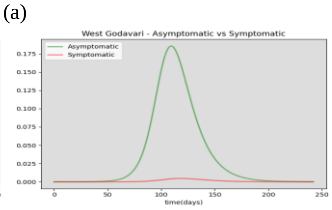
Table 15
Parameters table for West Godavari district using SAIR-RGS model

Parameter	Value
Contact rate (β)	0.218
Infectious period (1/ γ)	10.20 days
Asymptomatic rate (γ/ δ)	35.14
Basic reproduction (R_0)	2.22



(a)





(b) (c)

Fig. 14. West Godavari district (a) Monthly wise cases, (b) daily confirms vs. predicted by proposed SAIR-RGS model, (c) Asymptomatic vs. Symptomatic cases

Table 16
Parameters table for all districts using SAIR-RGS model

District	β	δ	γ	σ	γ/ δ
Anantapur	0.302	0.008	0.158	1.91	19.73
Chittoor	0.202	0.008	0.101	2.0	12.62
East Godavari	0.186	0.0028	0.084	2.21	30.07
Guntur	0.21	0.002	0.096	2.18	48.16
YSR Kadapa	0.281	0.0088	0.14	2.01	15.88
Krishna	0.182	0.002	0.076	2.39	38.01
Kurnool	0.275	0.0088	0.134	2.06	15.2
Nellore	0.209	0.0022	0.072	2.9	32.74
Prakasam	0.189	0.002	0.056	3.37	28.07
Srikakulam	0.237	0.0028	0.092	2.57	32.98
Visakhapatnam	0.245	0.002	0.099	2.47	49.64
Vizianagaram	0.226	0.0028	0.101	2.25	35.95
West Godavari	0.218	0.0028	0.098	2.22	35.14
AP	0.207	0.0028	0.098	2.1	35.15

5. Discussion

The proposed SAIR-RGS algorithm estimated that 35.5 times more asymptomatic cases than actual symptomatic cases in the state Andhra Pradesh. The ratio between asymptomatic and symptomatic cases in Guntur, Krishna, Visakhapatnam and Vizianagaram are more than total Andhra Pradesh. But in remaining all districts ratio is less than entire Andhra Pradesh. In west Godavari district ration between asymptomatic and symptomatic almost equal to entire state. In Rayalaseema region districts Anantapur district estimated a greater number of asymptomatic infections compare to symptomatic cases than reaming three districts i.e., Chittoor, YSR Kadapa and Kurnool. But in YSR Kadapa and Kurnool the proposed model estimated almost same ratio. In both Godavari districts East Godavari estimated with less ratio compared to West Godavari. In Uttar Andhra region both Srikakulam and Vizianagaram districts estimated almost same ration than Visakhapatnam (49.64).

Out of 13 districts the infectious period in Prakasam very high i.e., 17.82 days compare to remaining districts. That is the reason Prakasam district has a greater number of active cases even though a smaller number of infections (only 6.48%) compared to Chittoor (13.54%), East Godavari (14.41%) etc. The infectious period in Anantapur very less i.e., 6.34 days comparative to remaining all 12 districts. That is the reason in this district active infections very less i.e., only 77. Similarly in East Godavari, Krishna and Nellore recorded more active infections 2217, 1321 and 1637 respectively because of more infectious period than remaining districts. In Uttar Andhra districts Srikakulam estimated with highest infectious period (10.83 days) compared to remaining two districts.

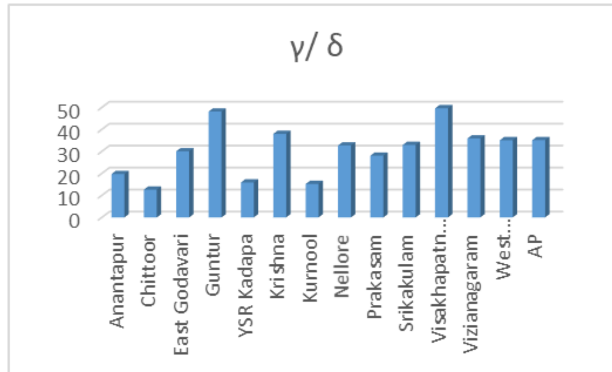


Fig. 15. Asymptomatic rate of all districts of AP

From experimental results we can observe that the basic reproduction number (R0) very high i.e., 3.37 in Prakasam district comparative to remaining all districts and Anantapur achieved very less i.e., 1.91 compared to remaining all districts. This number almost same in both Godavari districts and also in all Uttar Andhra region districts i.e., Srikakulam, Vizianagaram and Visakhapatnam. Except Anantapur remaining three Rayalaseema districts estimated almost same reproduction number. The reason for this is, in Anantapur the infectious period very less compared to remaining three districts in this region.

From the proposed modes we can observe that Anantapur, Kurnool, Srikakulam, Vizianagaram and Visakhapatnam district almost reached to normal situations. So, no chances of third wave if continuous like this but we can expect third wave in these districts when new mutations or variations comes into picture. We can observe small deviation in the right tail of remaining districts. So strict implementation of covid protocols very necessary in these districts to stop entry into third wave.

6. Conclusion

In this paper we introduced SAIR-RGS model for analyzing Covid 19 trends with asymptomatic patents for all 13 districts of AP India. This model collected 13 districts daily covid information from 2nd February to 30th September 2021 from Department of Health and family daily bulletin. From this model we also estimated contact rate, infectious period, and basic reproduction number of all 13 districts of AP. Th proposed model concludes that five districts i.e., Anantapur, Kurnool, Srikakulam, Vizianagaram and Visakhapatnam almost reached to normal situation but in remaining districts we need strict implementation of Covid protocols to reduce chances of third wave.

References

[1] Manindra Agrawal, Madhuri Kanitkar and Mathukumalli Vidyasagar," SUTRA: An Approach to Modelling Pandemics with Asymptomatic Patients,and Applications to COVID-19", 2021.

[2] Gaurav Goswamia, Jayanti Prasadb, and Mansi Dhuriac, "Extracting the effective contact rate of COVID-19 pandemic", Apr 2020.

[3] Santosh Ansumali, Shaurya Kaushal, Aloke Kumar, Meher K. Prakash, M. Vidyasagar," Modelling a pandemic with asymptomatic patients, impact of lockdown and herd immunity, with applications to SARS-CoV-2", Annual Reviews in Control, Volume 50, 2020, Pages 432-447.

[4] Taarak Rapolu, Brahmani Nutakki, T. Sobha Rani, S. Durga Bhavani," A Time-Dependent SEIRD Model for Forecasting the COVID-19 Transmission Dynamics", 2020.

[5] Yang Liu, Li-Meng Yan, Lagen Wan, et al. Viral dynamics in mild and severe cases of COVID19. The Lancet, 20(6):656–657, June 2020.

[6] Herbert W. Hethcote. The mathematics of infectious diseases. SIAM Review, 42(4):399–453, 2000.

[7] William Ogilvy Kermack and A. G. McKendrick. A contribution to the mathematical theory of epidemics. Proceedings of The Royal Society A, 117(772):700–721, 1927.

[8] Indian Supermodel for Covid-19 Pandemic, National Supermodel Committee.

[9] Samuel Mwalili, Mark Kimathi, Viona Ojiambo, Duncan Gathungu, and Rachel Mbogo," SEIR model for COVID-19 dynamics incorporating the environment and social distancing.

[10] Bogdan Marincaa, Vasile Marinca, Ciprian Bogdancd, "Dynamics of SEIR epidemic model by optimal auxiliary functions method",Chaos, Solitons & Fractals,Volume 147, June 2021, 110949

[11] Suwardi Annas, Muh. Isbar Pratama, Muh. Rifandi, Wahidah Sanusi, Syafruddin Side, "Stability analysis and numerical simulation of SEIR model for pandemic COVID-19 spread in Indonesia",Chaos, Solitons & Fractals, Volume 139, October 2020.

[12] Subrata Paul, Animesh Mahata, Uttam Ghosh, Banamali Roy, "Study of SEIR epidemic model and scenario analysis of COVID-19 pandemic", Ecological Genetics and Genomics, Volume 19, May 2021

[13] Nidhal ben Khedher, Lioua Kolsi, Haitham Alsaif, "A multi-stage SEIR model to predict the potential of a new COVID-19 wave in KSA after lifting all travel restrictions", Alexandria Engineering Journal, Volume 60, Issue 4, August 2021, Pages 3965-3974.

[14] Nicola Piovella,"Analytical solution of SEIR model describing the free spread of the COVID-19 pandemic", Chaos, Solitons & Fractals, Volume 140, November 2020.

[15] Steven J. Weinstein, Morgan S. Holland, Kelly, E. Rogers, Nathaniel S.Barlow, "Analytic solution of the SEIR epidemic model via asymptotic approximant", Physica D: Nonlinear Phenomena, Volume 411, October 2020.

[16] Zhifang Liao, Peng Lan, Xiaoping Fan, Benjamin Kelly, Aidan Innes, Zhining Liao," SIRVD-DL: A COVID-19 deep learning prediction model based on time-dependent SIRVD", Computers in Biology and Medicine, September 2021.

[17] Xinhe Zhu, Bingbing Gao, Yongmin Zhong, Chengfan Gu, Kup-SzeChoic,"Extended Kalman filter based on stochastic epidemiological model for COVID-19 modelling", Computers in Biology and Medicine, Volume 137, October 2021.

[18] Alavikunhu Panthakkan, S. M. Anzar, Saeed Al Mansoori, Hussain AlAhmad, "A novel DeepNet model for the efficient detection of COVID-19 for symptomatic patients", Biomedical Signal Processing and Control, Volume 68, July 2021.

[19] Niteesh Kumar, Harendra Kumar,"A novel hybrid fuzzy time series model for prediction of COVID-19 infected cases and deaths in India", ISA Transactions, July 2021.

[20] Veronika Grimm, Friederike Mengel & Martin Schmidt, "Extensions of the SEIR model for the analysis of tailored social distancing and tracing approaches to cope with COVID-19", Scientifc Reports, (2021) 11:4214.

[21] Shuo Feng, Zebang Feng, Chen Ling, Chen Chang, Zhongke Feng,"Prediction of the COVID-19 epidemic trends based on SEIR and AI models", 2021.

[22] Syafruddin S, and M. S. M. Noorani, "SEIR model for transmission of dengue fever in Selangor Malaysia", International Conference Mathematical and Computational Biology 2011, International Journal of Modern Physics: Conference Series, Vol. 9 (2012)380–389.

[23] Hamdy M. Youssef, Najat A. Alghamdi, Magdy A. Ezzat, Alaa A. El-Bary and Ahmed M. Shawky, "A new dynamical modeling SEIR with global analysis applied to the real data of spreading COVID-19 in Saudi Arabia", Mathematical Biosciences and Engineering, MBE, 17(6): 7018–7044, October 2020.

[24] Manuel De la Sen, Asier Ibeas, "On an Sir Epidemic Model for the COVID-19 Pandemic and the Logistic Equation", Discrete Dynamics in Nature and Society, 2020.

[25] Saad Awadh Alanazi, M. M. Kamruzzaman, Madallah Alruwaili, Nasser Alshammari, Salman Ali Alqahtani, Ali Karime, "Measuring and Preventing COVID-19 Using the SIR Model and Machine Learning in Smart Health Care", Journal of Healthcare Engineering, 2020.

[26] Ian Cooper, Argha Mondal, Chris G. Antonopoulos, "A SIR model assumption for the spread of COVID-19 in different communities", Chaos, Solitons and Fractals 139 (2020), Nonlinear Science, and Nonequilibrium and Complex Phenomena, 2020.

[27] Said Gounane, Yassir Barkouch, Abdelghafour Atlas, Mostafa Bendahmane, Fahd Karami and Driss Meskine,"An adaptive social distancing SIR model for COVID-19 disease spreading and forecasting", Epidemiol. Methods, 2021.

[28] Congying Liu, Xiaoqun Wu, Riuwu Niu, Xiuqi Wu, Ruguo Fan, "A new SAIR model on complex networks for analysing the 2019 novel coronavirus (COVID-19)", Springer Nature, 2020.

[29] Liu Ying, Tang Xiaoqing,"COVID-19: Is it safe now? Study of asymptomatic infection spread and quantity risk based on SAIR model", Chaos, Solitons & Fractals: X, Volume 6, June 2021.

[30] https://www.indiacensus.net/states/andhra-pradesh

[31] https://hmfw.ap.gov.in/covid_19_dailybulletins.aspx

[32] https://www.coronatracker.com/country/india/

[33] https://www.worldometers.info/coronavirus/?utm_campaign=homeAdvegas1?

[34] Kenji Mizumoto, Katsushi Kagaya, Alexander Zarebski, Gerardo Chowe, "Estimating the asymptomatic proportion of coronavirus disease 2019 (COVID-19) cases on board the Diamond Princess cruise ship, Yokohama, Japan, 2020", Europe's journal on infectious disease surveillance, epidemiology, prevention and control, Volume 25, Issue 10, 2020.

[35] Oran, D. P., & Topol, E. J, "Prevalence of asymptomatic sars-cov-2 infection: A narrative review", Annals of Internal Medicine, 1–7.

[36] Sang Woo Park, Daniel M Cornforth, Jonathan Dushoff, Joshua S Weitz,"The time scale of asymptomatic transmission affects estimates of epidemic potential in the COVID-19 outbreak", Elsevier public Health Emergency collection, May 2020.

[37] Gemma Massonis, Julio R. Banga, and Alejandro F. Villaverde, "Structural identifiability and observability of compartmental models of the covid-19 pandemic," pp. 1–25, June 2020.

[38] Xiaoqi Bi and Carolyn L. Beck," On the Role of Asymptomatic Carriers in Epidemic Spread Processes", Mar 2021

[39] Paolo Di Giamberardino, Daniela Iacoviello, Federico Papa, Carmela Sinisgalli, "Dynamical Evolution of COVID-19 in Italy with an Evaluation of the Size of the Asymptomatic Infective Population", IEEE Journal of Biomedical and Health Informatics, Volume: 25, Issue 4, April 2021.

[40] Yiming Zhai; Yifan Liu; Ning Ding; Zhenyu Fan; Guosheng Fang, "Improved SEIR model based on asymptomatic infection of COVID-19", 2021 4th International Conference on Advanced Electronic Materials, Computers and Software Engineering (AEMCSE).

[41] Alaa A. R. Alsaeedy; Edwin K. P. Chong, "Detecting Regions at Risk for Spreading COVID-19 Using Existing Cellular Wireless Network Functionalities", IEEE Open Journal of Engineering in Medicine and Biology, June 2020.

[42] Francesc Aràndiga, Antonio Baeza, Isabel Cordero-Carrión, Rosa Donat, M. Carmen Martí, Pep Mulet and Dionisio F. Yáñez, "A Spatial-Temporal Model for the Evolution of the COVID-19 Pandemic in Spain Including Mobility", Mathematics, 2020.

[43] Joshuan J. Barboza, Diego Chambergo-Michilot, Mariana Velasquez-Sotomayor, Christian Silva-Rengifo, Carlos Diaz-Arocutipa, Jose Caballero-Alvarado, Franko O. Garcia-Solorzano, Christoper A. Alarcon-Ruiz, Leonardo Albitres-Flores, German Malaga, Patricia Schlagenhauf, Alfonso J. Rodriguez-Morales, "Assessment and management of asymptomatic COVID-19 infection: A systematic review," Travel Medicine and Infectious Disease, Volume 41, May–June 2021.

[44] Li, Jiu Zhong, Yong-Mao Ji, Fang Yang, "A new SEIAR model on small-world networks to assess the intervention measures in the COVID-19 pandemics", Results in Physics, Volume 25, June 2021.

[45] M.S.L.B. Subrahmanyam, V. Vijaya Kumar, B. Eswara Reddy, "A Robust Zonal Fractal Dimension Method for the Recognition of

Handwritten Telugu Digits", I. J. Image, Graphics and Signal Processing, 2018, 9, 42-55, September 2018.
[46] Donafeby Widyani1, Tulus Radiku,"The Correlation Between Job Crafting and Work Engagement at Manufacturing Companies During COVID-19 Pandemic", International Journal of Research in Engineering, Science and Management Volume 4, Issue 9, September2021.
[47] Kiran L. Maney, S. R. Saritha, Sukanya Hegde, "An Exploratory Study on the Challenges Faced by Teachers in Online Classes During Pandemic – COVID-19", International Journal of Research in Engineering, Science and Management, Volume 4, Issue 9, September2021
[48] Neha Arya, "IoT based Smart Health Monitoring Band for COVID-19 Patients", International Journal of Research in Engineering, Science and Management, Volume 4, Issue 7, July 2021.