DISTRICT WISE ANALYSIS OF COVID-19 PANDEMIC TRENDS DURING SECOND WAVE IN THE STATE ANDHRA PRADESH, INDIA USING SEIR-RGS MODEL

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Abstract— Andhra Pradesh is one of the south Indian states in India and having 13 districts. This is one of the most Covid-19 effected state in India during first and second waves. In India district is the major administrative block for implementing government policies and schemes under control of district collector. So, estimating or forecasting trends in district level more important than state wise or entire country wise. In this paper we are proposing Susceptible, Exposed, Infected and Recovered – Regression and Grid Search (SEIR-RGS) model for analyzing Covid -19 district wise trends during second wave. The SEIR-RGS, initially collects daily wise covid data for each district from Department of Health, medical and family welfare, AP and estimates the model parameters like contact rate, incubation rate and recovery rate. To calculate recovery rate the proposed model uses regression technique between daily active cases vs cumulative recoveries. The present model uses two phases for estimating contact rate and incubation rate using grid search approach. After that the proposed method calculates the infectious period, incubation period and basic reproduction of infection in all 13 districts to analyze trends in the state during second wave and also to predict possibility of third wave in each district.

Keywords— **Andhra Pradesh, SEIR, contact rate, incubation period, infectious period, regression, grid search**

I. INTRODUCTION

At present entire world suffering from corona virus as a pandemic. Generally, viruses infect people with varying abilities. This virus initially detected in chain Wuhan lab in the end of December 2019. This outbreak entered into different waves and effected millions of the people globally. To reduce the effect of covid – 19 outbreak different counties took different strategies to minimize transmission of this pandemic like imposing lockdowns, face masking, social distancing, frequent handwash, restriction on international transports etc.

India is one of the Asian countries which has huge number of populations nearly 134 crores people. In the first wave, government of India initially took lot of precautionary steps by imposing country wide lockdown to reduce outbreak of the corona pandemic. This decision helped for so many people's lives. Of course, effected on Indian GDP and also effected mainly on daily wage peoples. Due to this government started different unlock strategies in the phase wise to improve the Indian economy and allow the people to start their routine works. Later because of Kumbh mela, different elections in different states this pandemic entered into second wave and effected millions of people lives and families. As of now 3,34,47,010(three cores thirty-four lacs forty sever thousand and ten) people, 3,26,64,351(three cores twenty-six lacs sixty-four three hundred and fifty-one) people and 4,44,869(four lac forty-four thousand eight hundred and sixty-nine) people infected, recovered and died with this virus respectively [32] till now. Now we are in almost end of second wave.

Andhra Pradesh is one of the south Indian states in India. Telangana, Karnataka, Tamil Nādu, Chhattisgarh and Orissa are bordering states of AP and its population around nine Crores. Agriculture is the major economy of the people in this state. More than 62 percent people depends on agriculture. This state can be divided into two regions namely coastal Andhra and Rayalaseema. Out of 13 districts nine districts comes under coastal Andhra and remining four districts comes under Rayalaseema. Uttara Andhra is another region in this state. Srikakulam, Vizianagaram and Visakhapatnam comes under in this region. In this state majority of the people prefer to migrate to other places for better employment or better livelihood. Initially very, few cases recorded in both first and second waves. But due to lockdown or micro contaminants in various places migrated people prefer to come back to their native place. Because of this reason covid – 19 transmitted to even very remote places in the state and more people infected than expected. This is one of most covid effected state in India. During first wave 8,85,005(eight lac eighty-five thousand and five) people infected from Covid-19 and totally 99.05% (8,76,609) people recovered from this pandemic. In

the second wave 11,49,453 (eleven lac forty-nine thousand four hundred and fifty-three) people infected and 98.23 percent (1129135) people recovered from this pandemic. 7,154 (seven thousand one hundred fifty-four) and 6907 (six thousand nine hundred and seven only) people lost their life in the first and second wave respectively.

The present model collected daily covid cases information of each 13 districts from Department of Health, medical and family welfare daily bulletin [31] and estimates the trends of all thirteen districts during second wave from 1-2-2-21 to 18-09-2021 i.e., totally 230 days. This department provides the detailed information about the covid infection among people of Andhra Pradesh district wise. This data contains the very detail information about the positives last 24 hours, Total positives, Total active cases, Total recovered and total deceased daily wise. And also provides the total number of samples tested for the disease on the current day. The present model uses SEIR model for forecasting or predicting covid cases. This model calculates model parameters using regression and grid search method mechanism. The proposed model estimates the contact rate(β) i.e., likelihood of new infections, incubation rate (ε), recovery rate (γ) and basic reproduction (R_0) of each district in the state of AP. From these parameters we can estimate Infectious period, incubation period and average basic reproduction(R_0) of each district in this state.

Currently so many papers available in the literature [1 – 29, 33-36] for modeling epidemics. In 4,9,10,11,12,13,14,15,20,21,22.23] authors used SEIR model for predicting and estimating model parameters. Some authors [16 18 21 34 35 36] used artificial intelligence, machine learning and deep learning techniques to estimate covid -19 trends. Authors in [24 25 26 27] used SIR model for predicting parameters while in [28 29] authors used SAIR model. In [6] authors presented mathematics of infectious disease. In 1927, William Ogilvy Kermack and A. G. McKendrick [7] introduced SIR (susceptible, Infected, and removed) mathematical model for analyzing the epidemics. Gaurav Goswamia[2] et. al. reconstructed effect contact rate of Covid. [8] addresses the asymptomatic cases of pandemics. In [1] authors proposed SUTRA model with addressing asymptomatic patients. Taarak Rapolu et al [4] used Time dependent SEIR model for transmission dynamics of covid. In [8] modified SEIR model for prediction of covid – 19 proposed. Bogdan Marincaa et at.[10] used Optimal Auxiliary Functions Method (OAFM) for solving nonlinear SEIR model dynamics. Using vaccination and isolation factors Suwardi Annas et al [11] proposed covid spread in Indonesia. This paper [12] analyzes India and Brazil as case study for SEIR model. Multi-stage SEIR model used in [13] to predict new cases before and after lockdown in KSA. Analytical solution for SEIR model described in [14] and via asymptotic approximation for analytic solution provided in [15]. Time dependent Deep learning-based prediction provided in [16].

Xinhe Zhu et at. [17] presented Extended Kalman filter-based model for Covid -19. In [18] authors analyzed impact of coronavirus on various countries using machine learning techniques. Hybrid model using fuzzy techniques for predicting infected and death people in India presented in [19]. Trace and isolate approach to control the infection transmission rate and reduce the of death rates are discussed in [20]. In [21] used AI model in non-Wuhan areas with the help of trends in Wuhan. Syafruddin et al [22] used SEIR model on dengue fever for the country Malaysia. In [23] authors applied dynamic SEIR model for Saudi Arabia real time Covid data. In [24] Manuel De la Sen et al. described SIR model using two parameters Malthusian and carrying capacity. Saad Awadh Alanazi [25] et al. used SIR model in smart health care system using advised techniques. Community based SIR model proposed in [26]. Adaptive based SIR model proposed in [27]. In [28] authors proposed social network based SAIR model on Wuhan data. In [29] authors analyzed SAIR model based on asymptomatic infection spread. In [34] authors presented machine learning based time series analysis of COVID 19 disease in India. Classification of covid and non-covid patients using Deep neural network model using lung x ray images provided in [36].

The rest of the paper is organized as follows Section II contains the description of proposed method. Section III contains experimental results and conclusions are given in Section IV

II. PROPOSED ALGORITHM

The proposed model divides the population under consideration into four compartment namely susceptible, exposed, 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 Exposed represents the fraction of people whose body host for infection but not 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), E(t), I(t) and R(t) represents the susceptible, exposed, 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.
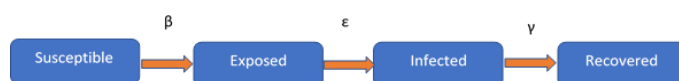
So S(t) + E(t) + I(t) + R(t) = 1   (1)

Fig. 1: SEIR model

The following four differential equations represents migration of people from one compartment to another compartment with

time variable t. in this equation β, ε, and γ represents contact rate, incubation rate and infection rate respectively. These parameters relate the model differential equations.

$$\frac{dS(t)}{dt} = -\beta * S(t) * I(t) \quad (2)$$

$$\frac{dE(t)}{dt} = \beta * S(t) * I(t) - \varepsilon * E \quad (3)$$

$$\frac{dI(t)}{dt} = \varepsilon * E - \gamma * I(t) \quad (4)$$

$$\frac{dR(t)}{dt} = \gamma * I(t) \quad (5)$$

In discrete form we can write as

$$S(t + 1) = S(t) - \beta * S(t) * I(t) \quad (6)$$

$$E(t + 1) = E(t) + \beta * S(t) * I(t) - \varepsilon * E \quad (7)$$

$$I(t + 1) = I(t) + \varepsilon * E - \gamma * I(t) \quad (8)$$

$$R(t + 1) = R(t) + \gamma * I(t) \quad (9)$$

The proposed method uses the following initial conditions
$$E(0) = 1/N, I(0) = 0 \text{ and } R(0) = 0 \quad (10)$$

$$\text{So } S(0) = 1 - E(0) - I(0) - R(0) \quad (11)$$

The proposed method for estimating contact rate, incubation rate and recovery rate using SEIR contains the following steps. The block diagram of proposed SEIR-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, ε and γ the proposed method uses following procedure.

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 [31].

From equation 5 we have
$$\frac{dR(t)}{dt} = \gamma * I(t)$$

It can be written as

$$R(t + T) - R(t) = \gamma * \int_t^T I(s)ds \quad (12)$$
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 [33] passing through origin and through these vectors using equation. The slope of this line gives the gamma value. This paper considers T as 7 days.
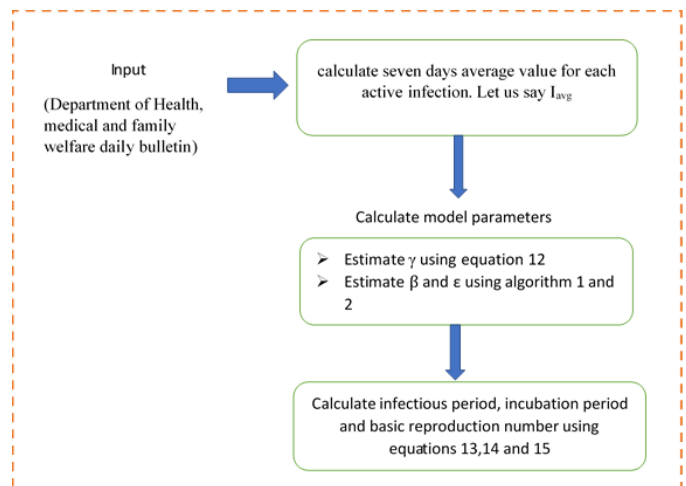

Fig. 2: Proposed SEIR-RGS model

Estimating β and ε:
The proposed method uses grid search method for estimating these parameters.
Grid search method initially identifies all possible range of values for each parameter. After that arrange these values into discrete grid and then calculates the model values from each combination of values in the grid. The optimal value of these combination of parameters gives the final solution.
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 i.e., transmission rate between 2 and 10
ε in the range between 0.1 and 0.5 with 0.001 increment i.e., incubation rate between 2 and 10 days

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 in both sides (Algorithm – 2).
Algorithm 1: Estimating each parameter two digits after decimal using proposed SEIR-RGS method

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Let β, ε and γ be transmission rate, incubation rate and infection rate respectively. Let $β \in [0.1\ 0.5]$, $ε \in [0.1\ 0.5]$ and γ be slope of the equation 2 using least square technique.

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

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

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

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

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

$$\text{Infectious period} = 1/ \mathbf{γ} \qquad (13)$$
$$\text{Incubation period} = 1/ ε \qquad (14)$$
$$\text{Basic reproduction number (R0)} = β/ \mathbf{γ} \qquad (15)$$

III. EXPERIMENT AND RESULT

The present paper considered the daily covid information of all thirteen districts from 1-2-2-2021 to 18-9-2021. Table 1 shows the total number population, 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.

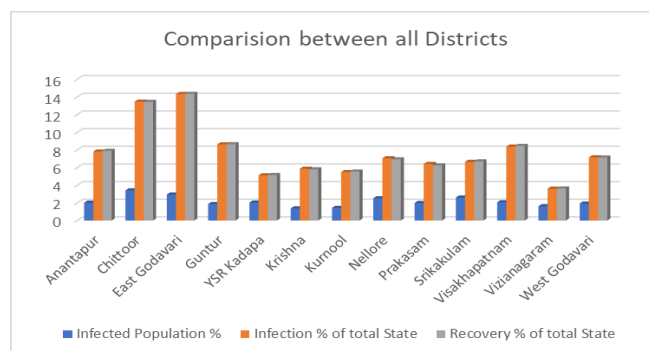| District Name	Population	Infections	Recoveries	Deaths
Anantapur	4424781	89849	89308	493
Chittoor	4525520	154816	151745	1038
East Godavari	5588288	164730	162011	636
Guntur	5299367	99154	97744	528
YSR Kadapa	2882469	58915	58227	173
Krishna	4897763	67538	65486	679
Kurnool	4394765	63150	62794	363
Nellore	3213088	81098	78268	522
Prakasam	3683513	73639	70611	501
Srikakulam	2930716	76407	75765	434
Visakhapatnam	4651857	96333	95504	552
Vizianagaram	2541879	41527	40997	431
West Godavari	4268459	82297	80675	557
Total AP	91702478	1149453	1129135	6907

Fig. 3: comparison of all districts

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

District Name	Infected Population %	Infection % of total State	Recovery % of total State
Anantapur	2.03	7.82	7.9
Chittoor	3.42	13.47	13.44
East Godavari	2.95	14.33	14.35
Guntur	1.87	8.63	8.65

YSR Kadapa	2.04	5.12	5.16
Krishna	1.38	5.87	5.8
Kurnool	1.44	5.49	5.56
Nellore	2.52	7.05	6.93
Prakasam	1.99	6.41	6.25
Srikakulam	2.61	6.65	6.71
Visakhapatnam	2.07	8.38	8.46
Vizianagaram	1.63	3.61	3.63
West Godavari	1.93	7.16	7.14
Total AP Cases	1.25	100	100

The present SEIR-RGS method estimated that β as 0.379, ε as 0.265 and γ as 0.098 for entire state AP. So average duration of infectious period as 10.20 days, duration of incubation period as 3.77 days and average basic reproduction (R_0) as 2.48 for total Andhra Pradesh during second wave i.e., from 1-2-2021 to 18-9-2021. Table 3 shows the estimated parameters of AP using proposed SEIR-RGS model and Fig 4 shows the daily active cases, confirms vs receives, SEIR-RGS model results and daily confirms vs predicted by proposed SEIR-RGS model of AP.

Table 3: Estimated parameters for Andhra Pradesh using proposed method

Parameter	Value
Contact rate	0.243
Infectious period	10.20 days
Incubation period	3.77 days
Basic reproduction (R_0)	2.48

(a) (b)

(c) (d)

Fig. 4: Andhra Pradesh (a) daily active cases (b) confirms vs recoveries (c) SEIR-RGS model results (d) daily confirms vs predicted by proposed SEIR-RGS model

Anantapur: Anantapur is one of Rayalaseema region district in the state of AP. As per [31] 89,478 (eighty-nine thousand four hundred and seventy-eight) people infected, 89308(eighty-nine thousand three hundred and eight) 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 SEIR-RGS method estimated that β as 0.476, ε as 0.156 and γ as 0.158. So average duration of infectious period as 6.33 days, duration of incubation period as 6.41 days and average basic reproduction (R_0) as 3.01. Table 4 shows the estimated parameters using proposed method and Fig 5 shows the SEIR-RGS model results.

Table 4: Estimated parameters for Anantapur district using proposed method

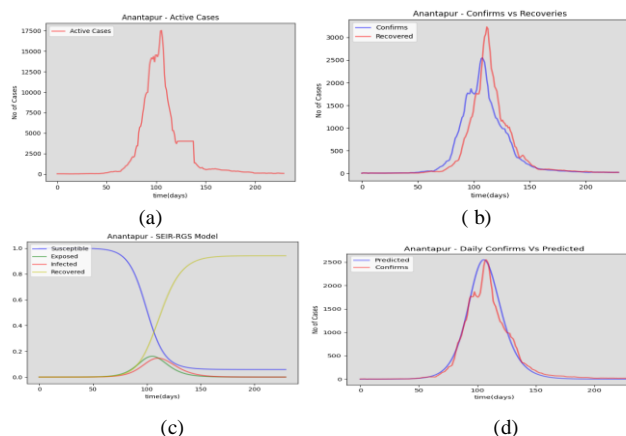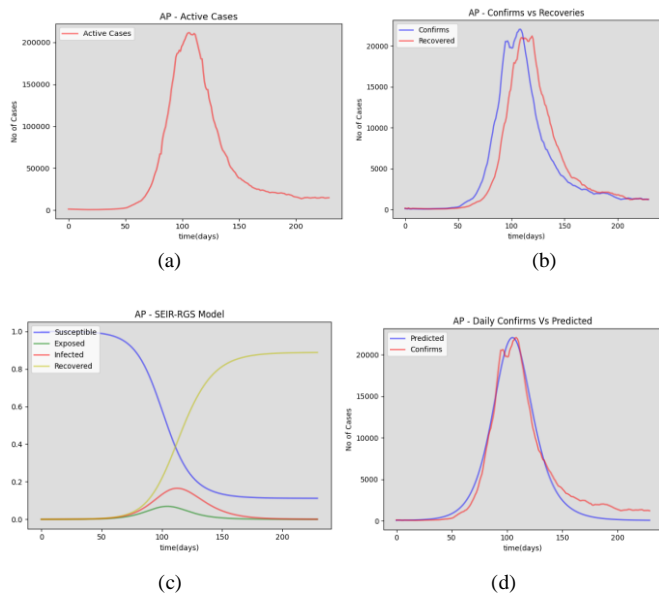| Parameter	Value
Contact rate	0.476
Infectious period	6.33 days
Incubation period	6.41 days
Basic reproduction (R_0)	3.01

(a) (b)

(c) (d)

Fig 5: Anantapur district (a) daily active cases (b) confirms vs recoveries (c) SEIR-RGS model results (d) . daily confirms vs predicted by proposed SEIR-RGS model

Chittoor: Chittoor is southernmost district of AP. It is bordering district with Tamil Nādu state. Its population around 45 lacs [30]. In second wave 1,54,816 (one lac fifty-four thousand eight hundred and sixteen) people infected with covid – 19 but 1,51,745(one lac fifty-one thousand seven hundred and forty-five) (98.02%) people recovered as on 18th September. This district recorded highest number of deaths i.e., 1038 (one thousand and thirty-eight) (14.92 %) out of total deaths in AP. As per proposed model, 0.222,0.292 and 0.101 are contact rate, incubation, and recovery rate respectively of this district during second wave. The infectious period of this district as 9.9 days, incubation period as 3.42 days and basic reproduction as 2.19. Table 5 shows the

estimated parameter using proposed model and Fig 6 shows the results of proposed SEIR-RGS model.

Table 5: Estimated parameters for Chittoor district using proposed method

Parameter	Value
Contact rate	0.222
Infectious period	9.9 days
Incubation period	3.42 days
Basic reproduction (R_0)	2.19

(a)

(b)

(c)

(d)
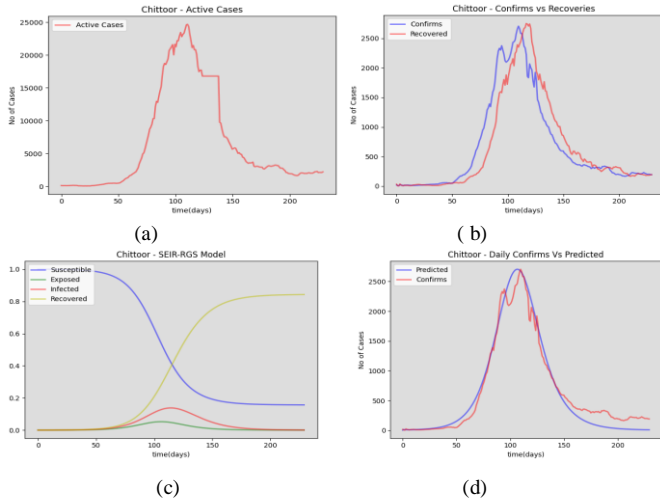
Fig 6: Chittoor district (a) daily active cases (b) confirms vs recoveries (c) SEIR-RGS model results. (d) daily confirms vs predicted by proposed SEIR-RGS model.

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], 1,64,730(one lac sixty-four thousand seven hundred and thirty) people infected from Covid – 19 during second wave i.e., 2.95% people infected from this pandemic and 1,62,011(one lac sixty-two thousand and eleven) (98.35%) people recovered from this as on 18th September. The proposed SEIR-RGS method estimated that β, ε and γ as 0.218,0.459 and 0.084 respectively. So, on an average one infected person transmits the disease to 4.59 people in the susceptible compartment. The average duration of infectious period (1/ γ) of this district as 11.9 days, duration of incubation period (1/ ε) as 2.18 and average basic reproduction(R_0) as 2.607. Table 6 shows the estimated parameters and Fig 7 shows the trends of this district.

Table 6: Estimated parameters for East Godavari district using proposed method

Parameter	Value
Contact rate	0.218
Infectious period	11.9 days
Incubation period	2.18 days
Basic reproduction (R_0)	2.59

Guntur: Guntur is one of coastal district in AP. It is one of bordering district with state of Telangana. According to [30] its population around 53 lacs. In this district totally 99,154 (ninety-nine thousand one hundred and fifty-four) people infected from covid during second wave. Nearly 8.63% people infected in this district out of total infections in the state of Andhra Pradesh. Out of total infections 97,744 (ninety-seven thousand seven hundred and forty-four) people recovered from covid. Only 1.87% people infected out of total population in this district. The present model estimated that β as 0.243, ε as 0.255 and γ as 0.096. The average duration of infectious period (1/ γ) of this district as 10.41 days, duration of incubation period (1/ ε) as 3.92 and average basic reproduction(R_0) as 3.95. Table 7 and Fig 8 shows the details of proposed SEIR-RGS model.
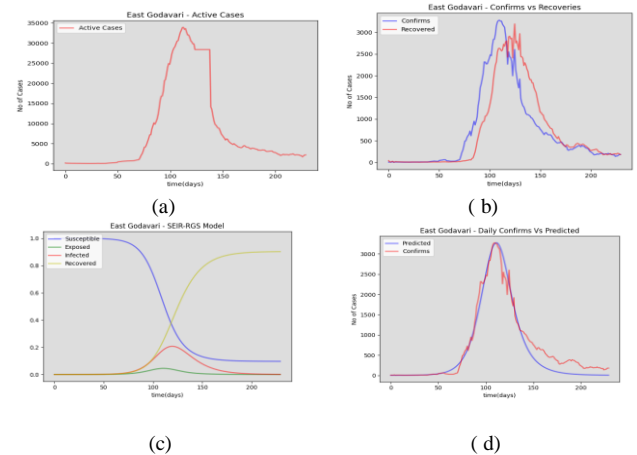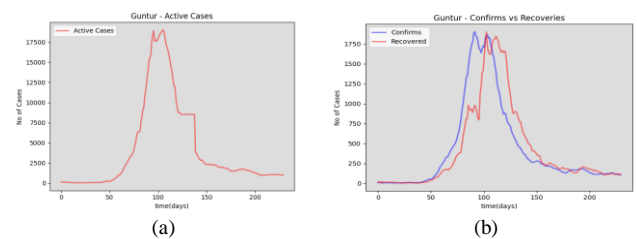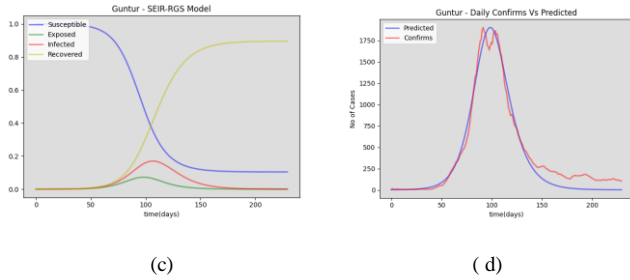

(a)

(b)

(c)

(d)

Fig 7: East Godavari district (a) daily active cases (b) confirms vs recoveries (c) SEIR-RGS model results (d daily confirms vs predicted by proposed SEIR-RGS model.

Table 7: Estimated parameters for Guntur district using proposed method

Parameter	Value
Contact rate	0.243
Infectious period	10.41 days
Incubation period	3.92 days
Basic reproduction (R_0)	2.53

(a)

(b)

(c)   (d)

Fig. 8: Guntur district (a) daily active cases (b) confirms vs recoveries (c) SEIR-RGS model results. (d) daily confirms vs predicted by proposed SEIR-RGS model

YSR Kadapa: Kadapa is centrally located Rayalaseema district in AP. Its population nearly 29 lacs [30]. 58915 (fifty-eight thousand nine hundred and fifteen), 58227(fifty-eight thousand two hundred and twenty-seven) and 173(one hundred and seventy-three) are total number of infected, recovered and deaths people respectively in this district during second wave. The present model estimated that β as 0.358, ε as 0.487 and γ as 0.139 The average duration of infectious period $(1/\gamma)$ of this district as 7.19 days, duration of incubation period $(1/\varepsilon)$ as 2.05 days and average basic reproduction(R_0) as 2.57. The proposed model details are shown in Table 8 and Fig 9.

Table 8: Estimated parameters for Kadapa district using proposed method

Parameter	Value
Contact rate	0.358
Infectious period	7.19 days
Incubation period	2.05 days
Basic reproduction (R_0)	2.57
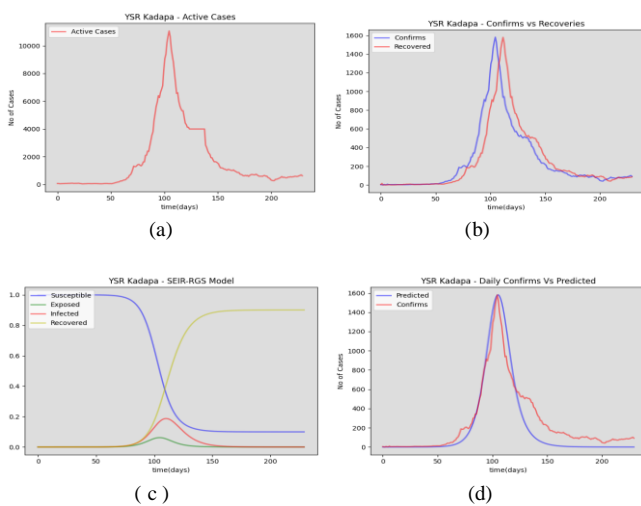
(a)   (b)

(c)   (d)

Fig 9: Kadapa district (a) daily active cases (b) confirms vs recoveries (c) SEIR-RGS model results (d) daily confirms vs predicted by proposed SEIR-RGS model

Krishna: Krishna is one of coastal district in AP. Some of part of this district border with state of Telangana. Its population nearly about 49 lacs [30]. In this district 67538 (sixty-seven thousand five hundred thirty-eight) population effected with covid second wave. But more than 96% people recovered from this pandemic. Totally 679 (six hundred and seventy-nine) people lost their life during second wave. The present model estimated that β as 0.179, ε as 0.409 and γ as 0.076. The average duration of infectious period $(1/\gamma)$ of this district as 13.15 days, duration of incubation period $(1/\varepsilon)$ as 2.44 days and average basic reproduction(R_0) as 2.35. Table 8 and Fig 9 shows the details of the proposed SEIR-RGS model.
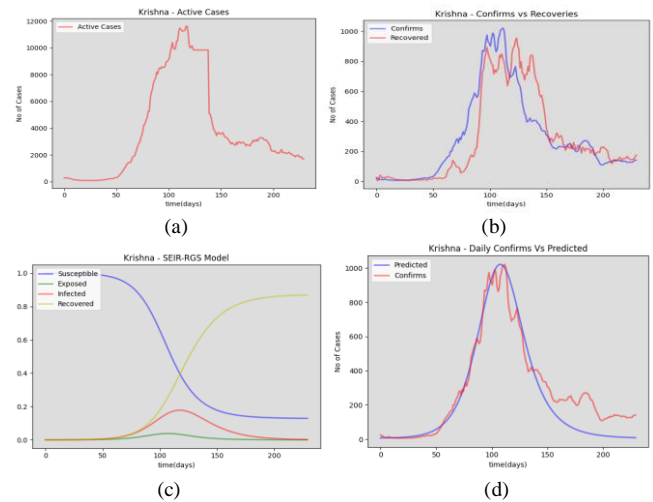
Table 9: Estimated parameters for Krishna district using proposed method

Parameter	Value
Contact rate	0.179
Infectious period	13.15 days
Incubation period	2.44 days
Basic reproduction (R_0)	2.35

(a)   (b)

(c)   (d)

Fig 10: Krishna district (a) daily active cases (b) confirms vs recoveries (c) SEIR-RGS model results (d) daily confirms vs predicted by proposed SEIR-RGS model

Kurnool: Kurnool was capital of AP between October 1953 and November 1956. It is one of Rayalaseema district out four districts in AP. Its population around 44 lacs according to estimated population 2021[30]. In this district 5.49% (63,150) effected with covid second wave out of total infections in the state of Andhra Pradesh. 5.56 % (62,794) people recovered out of total recoveries in AP. The present model estimated that β as 0.49, ε as 0.134 and γ as 0.133. The average duration of infectious period $(1/\gamma)$ of this district as 7.52 days, duration of incubation period $(1/\varepsilon)$ as 7.46 days

and average basic reproduction(R_0) as 3.68. Table 10 and Fig 11 shows the details of the proposed SEIR-RGS of this district.

Table 10: Estimated parameters for Kurnool district using proposed method

Parameter	Value
Contact rate	0.49
Infectious period	7.52 days
Incubation period	7.46 days
Basic reproduction (R_0)	3.68

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 78268 (seventy-eight thousand two hundred and sixty-eight) people recovered with percentage of 6.93 out of total recoveries in AP. But 522 people lost their life. The present model estimated that β as 0.209, ε as 0.489 and γ as 0.071. The average duration of infectious period (1/ γ) of this district as 14.08 days, duration of incubation period (1/ ε) as 2.04 days and average basic reproduction(R_0) as 2.94. The

(a)   (b)

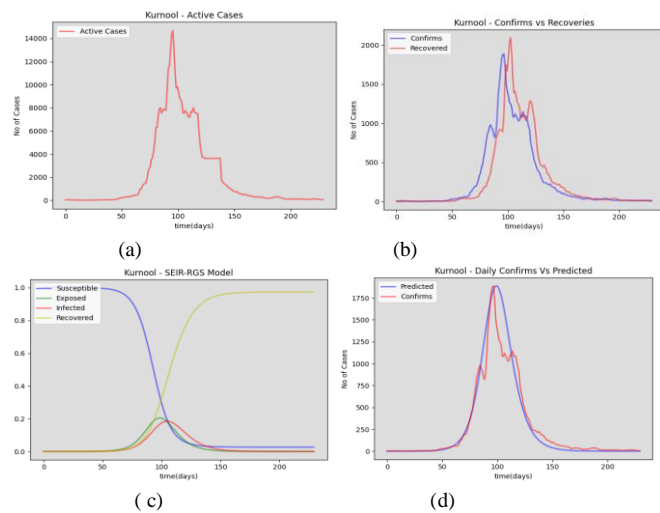(c)   (d)

Fig 11: Kurnool district (a) daily active cases (b) confirms vs recoveries (c) SEIR-RGS model results (d) daily confirms vs predicted by proposed SEIR-RGS model

details of the proposed SEIR-RGS shown in Table 11 and Fig 12

Table 11: Estimated parameters for Nellore district using proposed method

Parameter	Value
Contact rate	0.209
Infectious period	14.08 days
Incubation period	2.04 days
Basic reproduction (R_0)	2.94

Prakasam: Prakasam is third largest and one of coastal region district in the state of AP. The estimated population in this

district around nearly 37 lacs [30] (according to 2021 estimation). During second wave 73639(seventy-three thousand six hundred and thirty-nine) people in this district effected with covid with percentage of 6.41out of total infections in AP. Only 1.99% people effected out of total population in this district. The present model estimated that β as 0.188, ε as 0.429 and γ as 0.056. The average duration of infectious period (1/ γ) of this district as 17.85 days, duration of incubation period (1/ ε) as 2.33 days and average basic reproduction(R_0) as 3.35. More details shown in Table 12 and Fig 13.

(a)   (b)

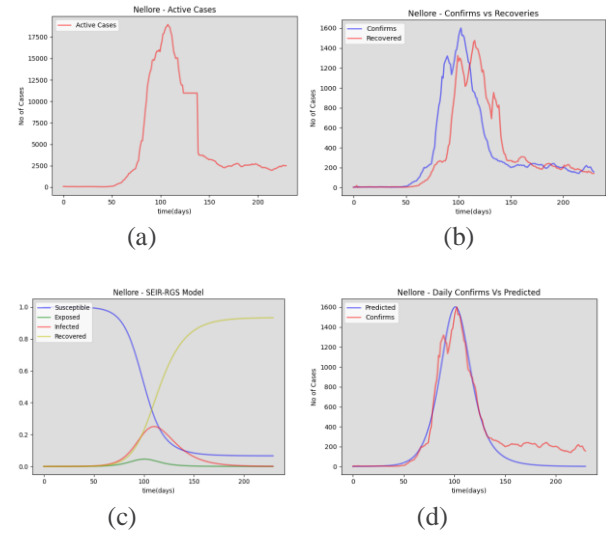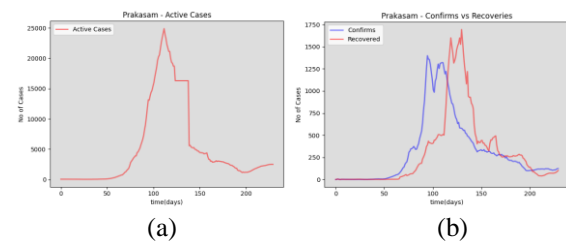(c)   (d)

Fig 12: Nellore district (a) daily active cases (b) confirms vs recoveries (c) SEIR-RGS model results (d) daily confirms vs predicted by proposed SEIR-RGS model

Table 12: Estimated parameters for Prakasam district using proposed method

Parameter	Value
Contact rate	0.188
Infectious period	17.85 days
Incubation period	2.33 days
Basic reproduction (R_0)	3.35

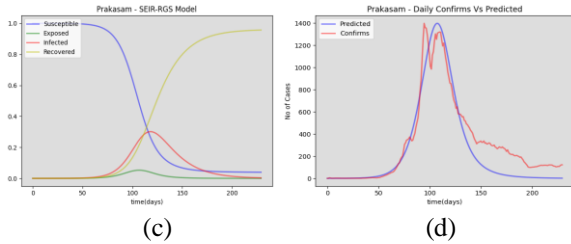(a)   (b)

(c) (d)

Fig 13: Prakasam district (a) daily active cases (b) confirms vs recoveries (c) SEIR-RGS model results (d) daily confirms vs predicted by proposed SEIR-RGS model

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 76,407(seventy-six thousand four hundred and seven) people suffered from covid during second wave **i.e.,** 6.65% infections out of total infections and 434 people lot their life during second wave. The present model estimated that β as 0.399, ε as 0.121 and γ as 0.092. The average duration of infectious period $(1/\gamma)$ of this district as 10.87 days, duration of incubation period $(1/\varepsilon)$ as 8.26 days and average basic reproduction(R_0) as 4.33. Table 13 and Fig 14 shows results of proposed SEIR-RGS model results.

Table 13: Estimated parameters for Srikakulam district using proposed method

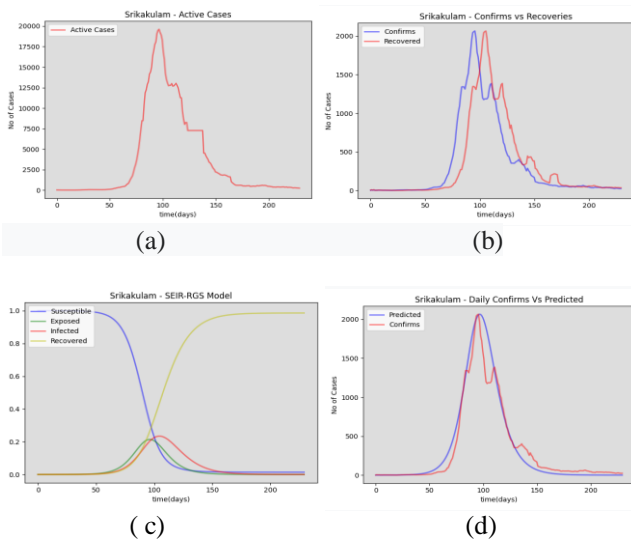| Parameter	Value
Contact rate	0.399
Infectious period	10.87 days
Incubation period	8.26 days
Basic reproduction (R_0)	4.33

(a) (b)

(c) (d)

Fig 14: Srikakulam district (a) daily active cases (b) confirms vs recoveries (c) SEIR-RGS model results (d) daily confirms vs predicted by proposed SEIR-RGS model

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 96333(ninety-six thousand three hundred and thirty-three) people infected from covid. 95,504(ninety-five thousand five hundred and four) (99.14%) people recovered from this pandemic. The present model estimated that β as 0.259, ε as 0.352 and γ as 0.099. The average duration of infectious period $(1/\gamma)$ of this district as 10.10 days, duration of incubation period $(1/\varepsilon)$ as 2.84 days and average basic reproduction(R_0) as 2.61. Table 14 and Fig 14 shows the details of proposed SEIR-RGS model.

Table 14: Estimated parameters for Visakhapatnam district using proposed method

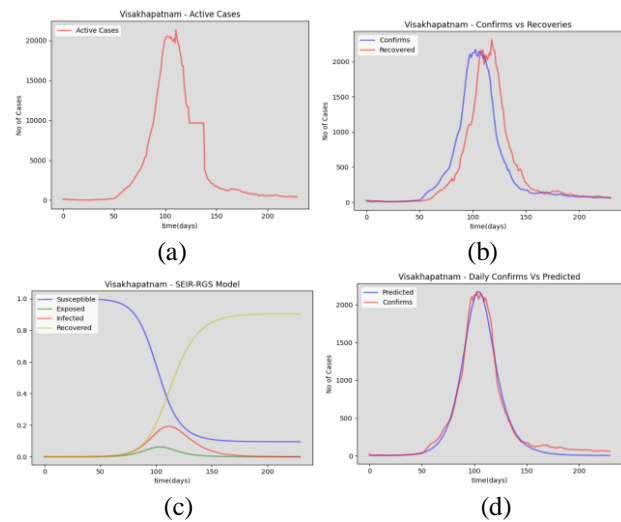| Parameter	Value
Contact rate	0.259
Infectious period	10.10 days
Incubation period	2.84 days
Basic reproduction (R_0)	2.61

(a) (b)

(c) (d)

Fig 15: Visakhapatnam district (a) daily active cases (b) confirms vs recoveries (c) SEIR-RGS model results (d) daily confirms vs predicted by proposed SEIR-RGS model

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 3.61**%** **(**41,527) people infected with covid out of total infections in AP. 98.72% (40,997) people recovered from this district**.** The present model estimated that β as 0.259, ε as 0.478 and γ as 0.100 The average duration of infectious period $(1/\gamma)$ of this district as 10 days, duration of incubation period $(1/\varepsilon)$ as 2.09 days and average basic reproduction(R_0) as 2.59. Table 15 and Fig 16 shows the details of the proposed SEIR-RGS model.

Table 15: Estimated parameters for Vizianagaram district using proposed method

Parameter	Value
Contact rate	0.259
Infectious period	10 days
Incubation period	2.09 days
Basic reproduction (R_0)	2.59

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]. 82,297 (eighty-two thousand two hundred ninety-seven) people infected from covid during second wave in this district. 98.03% (80675) people recovered in this district out of total recoveries in AP. The present model estimated that β as 0.260, ε as 0.499 and γ as 0.098 The average duration of infectious period (1/ γ) of this district as 10.20 days, duration of incubation period (1/ ε) as 2.00 days and average basic reproduction(R_0) as 2.65. More details about this district given in Table and Fig using proposed SEIR-RGS model.

(a) (b)

(c) (d)

Fig 16: Vizianagaram district (a) daily active cases (b) confirms vs recoveries (c) SEIR-RGS model results (d) daily confirms vs predicted by proposed SEIR-RGS model

Table 16: Estimated parameters for West Godavari district using proposed method

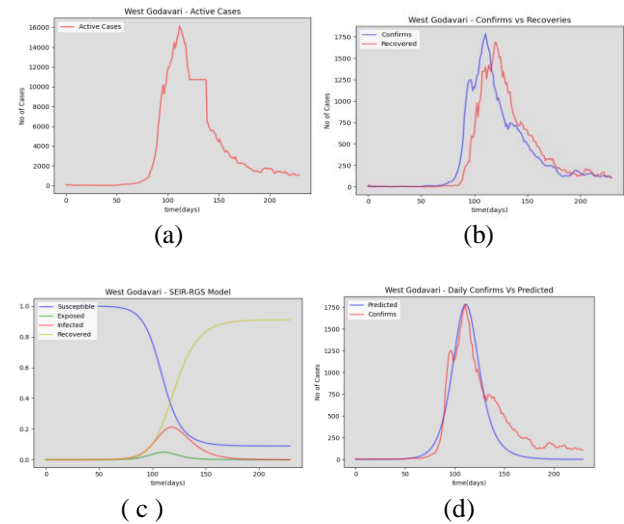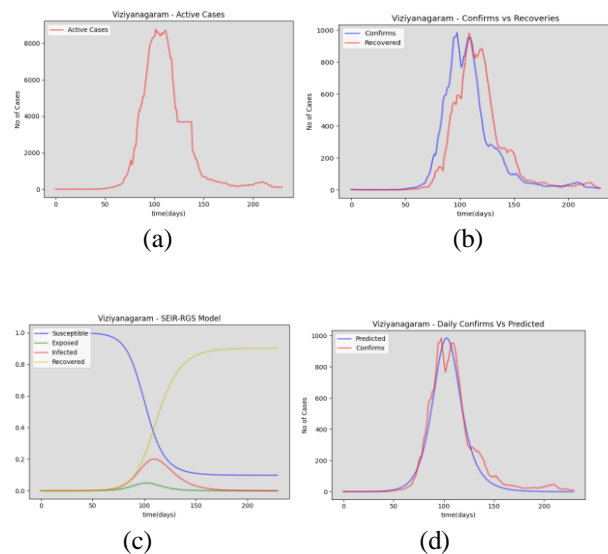| Parameter	Value
Contact rate	0.260
Infectious period	10.20 days
Incubation period	2.00 days
Basic reproduction (R_0)	2.65

(a) (b)

(c) (d)

Fig 17: West Godavari district (a) daily active cases (b) confirms vs recoveries (c) SEIR-RGS model results (d) daily confirms vs predicted by proposed SEIR-RGS model

Table 17 shows the estimated parameters using proposed SEIR-RGS model of all thirteen districts of AP. Fig 18, Fig 19 and Fig 20 shows the comparison of all thirteen districts infectious period and incubation period, contact rate and basic reproduction number respectively.

Table 17 Estimated model parameters all thirteen districts of Andhra Pradesh

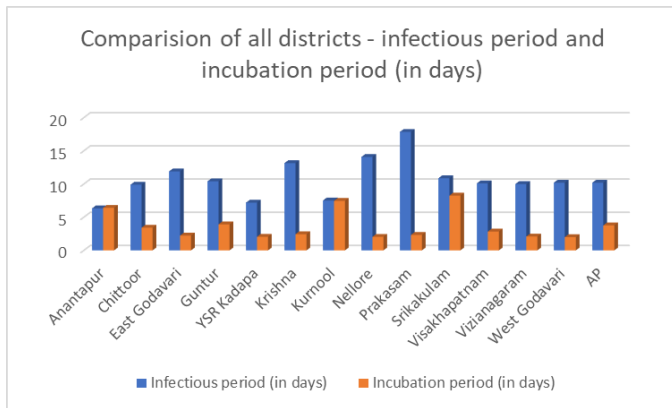| District	Contact rate	Infectious period (in days)	Incubation period (in days)	Basic reproduction number (R_0)
Anantapur	0.476	6.33	6.41	3.01
Chittoor	0.222	9.90	3.42	2.19
East Godavari	0.219	11.90	2.23	2.61
Guntur	0.243	10.41	3.92	2.53
YSR Kadapa	0.358	7.19	2.05	2.57
Krishna	0.179	13.15	2.44	2.35
Kurnool	0.490	7.52	7.46	3.68
Nellore	0.209	14.08	2.04	2.94
Prakasam	0.188	17.85	2.33	3.35
Srikakulam	0.399	10.87	8.26	4.33
Visakhapatnam	0.259	10.10	2.84	2.61
Vizianagaram	0.259	10.00	2.09	2.59
West Godavari	0.260	10.20	2.00	2.65
AP	0.243	10.20	3.77	2.48

Fig 18 Comparison of all districts infectious period and incubation period
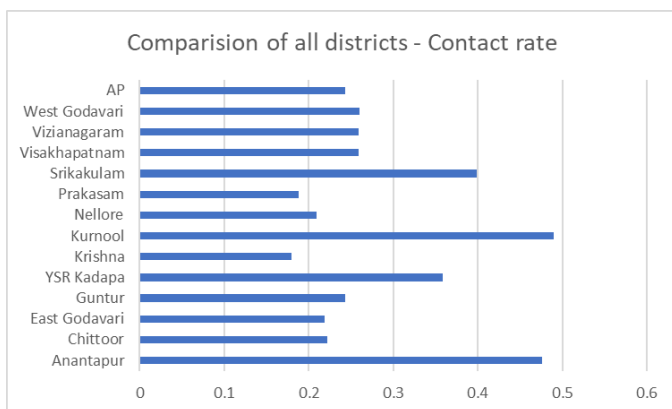

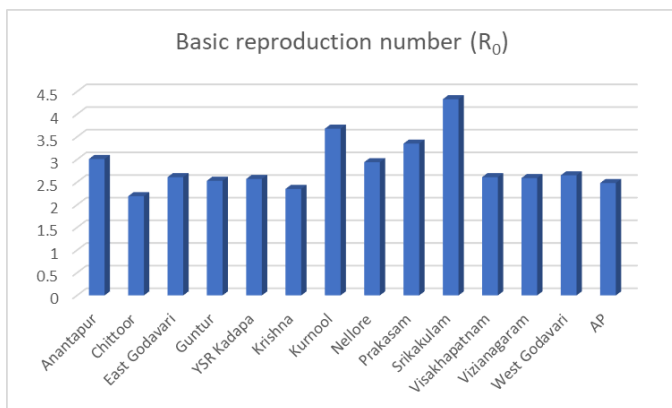Fig 18 Comparison of all districts contact rate

Fig 19 Comparison of all districts basic reproduction number (R_0)

Discussion:

The proposed SEIR-RGS model estimated that the average infectious period of entire state is 10.20. The infectious period in Anantapur, Chittoor, YSR Kadapa, Kurnool, Visakhapatnam and Vizianagaram less than infectious period of entire state. But in East Godavari, Guntur, Krishna, Nellore, Prakasam and Srikakulam infectious period more than entire state of Andhra Pradesh. In West Godavari district the infectious period exactly equal to total state of AP. Out of 13 districts the infectious period in Prakasam very high i.e., 17.85 days compare to remaining districts. That is the reason Prakasam district has more number of active cases even though less number of infections (only 6.35%) compare to Chittoor (13.42%) , East Godavari (14.33%) etc. The infectious period in Anantapur very less i.e., 6.33 days comparative to remaining all 12 districts. That is the reason in this district active infections very less i.e., only 95. Similarly in East Godavari, Krishna and Nellore recorded more active infections 2264, 2138 and 2056 respectively because of more infectious period than remaining districts.

From the estimated results we can observe that the proposed model SEIR-RGS model calculated average incubation period for entire state as 3.77 days. In both Godavari districts, YSR Kadapa, Krishna, Nellore, Prakasam, Visakhapatnam and Vizianagaram incubation period very less than average incubation period of total AP. Srikakulam districts has highest incubation period (8.26 days) than remaining all districts. Kurnool estimated second highest incubation period (7.46 days). In both Anantapur and Kurnool the average infectious period and incubation period almost same. These two districts come under Rayalaseema region and both are neighboring districts.

From experimental results we can observe that the basic reproduction number (R0) very high i.e., 4.99 in Srikakulam district comparative to remaining all districts. In this district people mainly prefer either government job or migrate to other places in pan India for better employment or livelihood. Initially in two waves very few cases noted but slowly increased than expected. Especially happened after lockdowns in different places in India. The basic reproduction number is greater than 2 for all districts. So, one person infected at least two persons in this state. As per Table 17 we can observe that the basic reproduction number for Anantapur, Kurnool, Prakasam also more than three. In Visakhapatnam and Vizianagaram infectious period, incubation period and basic reproduction number almost similar. Both districts come under Utter Andhra region, and both are neighboring districts. Also, in both Godavari districts basic reproduction number almost same.

The real data and predicted values from proposed model i.e., SEIR-RGS almost same for the districts Anantapur, Kurnool, Srikakulam, Visakhapatnam and Vizianagaram. Therefore, situation becoming normal for these districts. There are chances of third wave if any new mutations come into picture. But we observed that small deviation between real and predicted value in the right tail for remaining districts especially after August second week. So still situation not in good control for these districts. To become normal, we need to implement covid protocols very strictly in these districts otherwise may leads to third wave in these districts.

IV. CONCLUSION

This paper introduces SEIR – RGS model for estimating contact rate, incubation rate and recovery rate of 13 districts of AP. The proposed model collects daily covid information from Department of Health and family from first February 2021 to 18th September 2021. This model estimates the recovery rate of each district using least square method and calculates the remaining two parameters using grid search mechanism in two phases. From the calculated values the proposed model compares infectious period, incubation period and basic reproduction of covid transmission among people of AP district wise. From the results we can conclude that Anantapur, Kurnool, Srikakulam, Visakhapatnam and Vizianagaram are in stable condition, but remaining districts require strict implementation of covid protocols for reducing chances of third wave.

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