COVID-19 Modelling with SEIRV Model

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COVID PROJECT

Introduction

We are using the SEIRV model to estimate the total number of infected people with the SARS-CoV-2 virus. Knowing the estimated number of people who will be infected with the SARS-CoV-2 virus in Karnataka is an essential step towards the correct management of resources and the enforcement of necessary precautions to curb the spread.

The aim of this project is to predict the total number of infected cases for a *period of days* or *on a particular date* or to *predict the cases by forwarding the model till Dec'21* for each district of Karnataka by adjusting the contact rate **β**. We are using the traditional SEIRV model, in which differential equations are used to find the values of states for the next day.

Methods

- **Task 1**

  In this task, we are calibrating the contact rate **β** by using susceptible, infected and recovered fractions matched to the round-1 seroprevalence data projected to 11 October 2020. The contact rate and other parameters have been tuned during 11 - 31 October 2020 to match the number of reported cases on 01 November 2020 to within 10%.

  We are using 3 functions named SEIRVModel(), Lossfunction() and minimizeParameter().

  - **SEIRVModel()**- It gives the values of S(t), E(t), I(t), R(t), V(t) and CIR(t) for the next timestep using the differential equations of the SEIRV model.
  - **LossFunction() :-** This function uses the values returned by the SEIRVModel(), and also the predicted number of cases for 1st Nov'21. Then, the absolute difference between the predicted and reported cases has been calculated to compute the loss Waning population is calculated using the Weibull distribution.
  - **Optimization() :-** This function uses the scipy.optmize library to minimize the loss by calibrating the contact rate till it reaches the optimal value. "Nelder-Mead" method has been used in the scipy.optimize.minimize function.

Results

- **Task1**

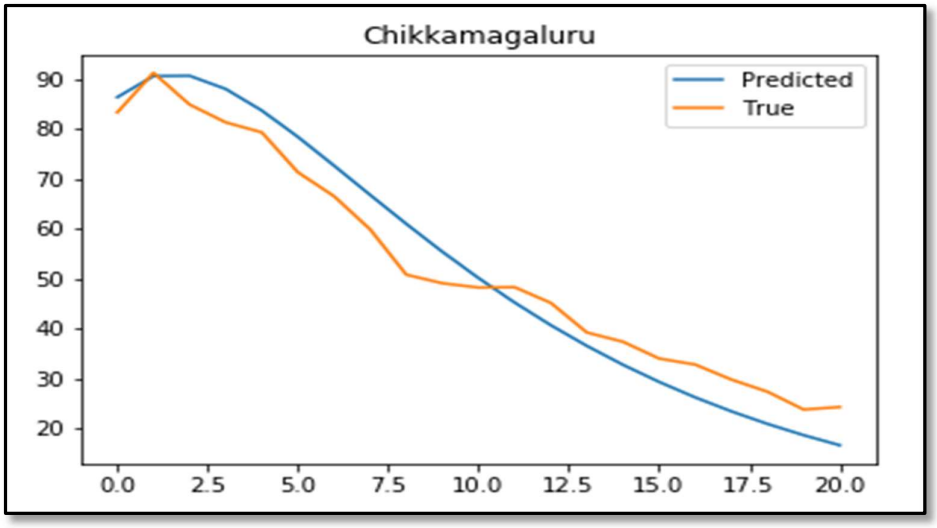


Figure 1 plot of Chikkamagaluru district for predicted and reported cases vs timestep

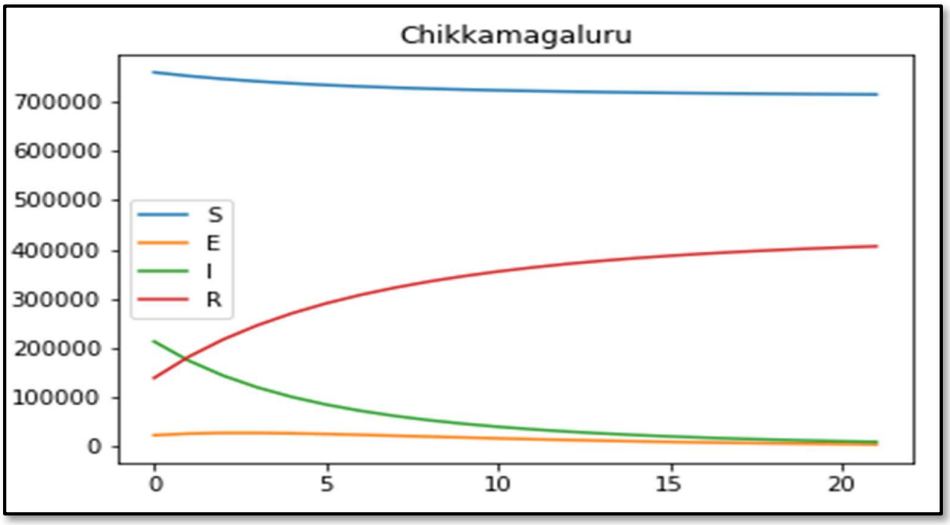


Figure 2 plot of Chikkamagaluru district for various parameters vs timestep

1st plot depicts that predicted cases are almost the same as reported cases. 2nd plot shows the general trend of the district Chikkamagaluru for the parameters S, E, I, R. we can see that the susceptible population, infectious, is decreasing. Initially, the exposed population is increasing, and then it decreases. And recovered population is increasing, which is correct according to the given data. During the given period vaccinations hasn't started, so value of parameter V is 0 for all the districts and for each date.

Parameter values obtained after calibration in task 1 are provided in the table below.

Unit	Error	Beta	Scale	Shape
BBMP-Bommanahalli	1.41E-05	0.090802504	156.791617	6.159284137
BBMP-Dasarahalli	0.000109757	0.110803211	143.1747049	5.693186892
BBMP-East	0.05563379	0.357	104.57	2.94
BBMP-Mahadevpura	0.000329056	0.085995583	156.727987	6.182022658
BBMP-RR-Nagar	0.000193096	0.087634046	157.145437	6.21983515
BBMP-South	0.00011058	0.190289386	77.42622126	2.80234667
BBMP-West	0.000395874	0.146910841	121.0610574	4.307377299
BBMP-Yelahanka	8.44E-05	0.108005895	144.1520812	5.712140718
Bagalakote	0.000717061	0.014955169	185.3463936	7.013326422
Ballari	0.000934862	0.027182144	178.8063205	6.86302439
Belagavi	3.10E-05	0.05314003	168.6266711	6.581204767
Bengaluru Rural	0.000179232	0.082291556	155.9691214	6.278194359
Bengaluru Urban	6.50E-05	0.07526237	156.6478053	6.394665588
Bidar	0.000195131	0.101031163	152.1675388	5.900311329
Chamarajanagara	1.31E-05	0.09891565	153.0784001	5.968004292
Chikkaballapura	0.000231392	0.070827826	162.9909207	6.473973349
Chikkamagaluru	0.000168594	0.055127089	166.5750832	6.611702134
Chitradurga	0.000299134	0.085873023	156.706019	6.184996877
Dakshina Kannada	0.00037514	0.056191508	166.666103	6.612531318
Davanagere	0.000378945	0.043390378	168.9953809	6.821599367
Dharwad	0.001146831	0.044571546	170.2702836	6.729713393
Gadag	0.001379738	0.025153416	179.8722024	6.838977844
Hassan	0.000212449	0.071389206	162.7045666	6.460081525
Haveri	0.00020702	0.03554319	170.4364472	6.813877918
Kalaburagi	9.45E-05	0.024689856	180.0642752	6.833957585
Kodagu	9.27E-05	0.106327914	147.976894	5.848817272
Kolar	0.000246418	0.085651635	156.699589	6.190283805
Koppal	0.000109939	0.069688593	163.0911204	6.477587813
Mandya	0.00023462	0.124676264	134.3943106	5.123697915
Mysuru	0.000121499	0.078340614	160.1265294	6.257940405
Raichur	0.000239118	0.031574424	177.2149648	6.844582712
Ramanagara	0.000494332	0.038566108	171.0473292	6.636682898
Shivamogga	0.000208548	0.031710648	177.091413	6.837203717
Tumakuru	0.000903111	0.058291214	166.5742448	6.594276043
Udupi	0.000115893	0.037565181	170.4384979	6.659984608
Uttara Kannada	0.000251078	0.052546554	169.7674244	6.583746559
Vijayapura	0.000122311	0.118301079	138.5788982	5.466951128
Yadgiri	0.001895019	0.018253365	184.224768	6.903893036

➢ TASK 2

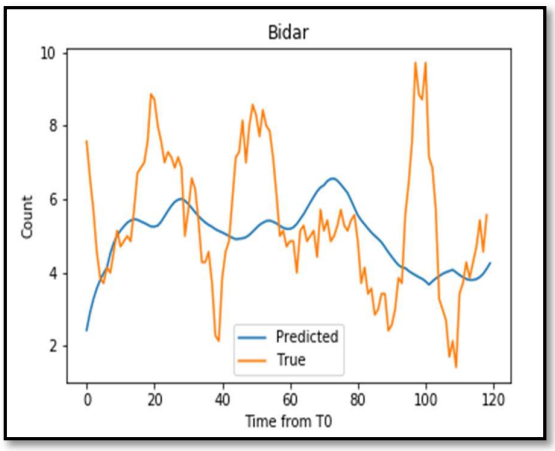


Figure 1 Plot of predicted cases vs reported cases

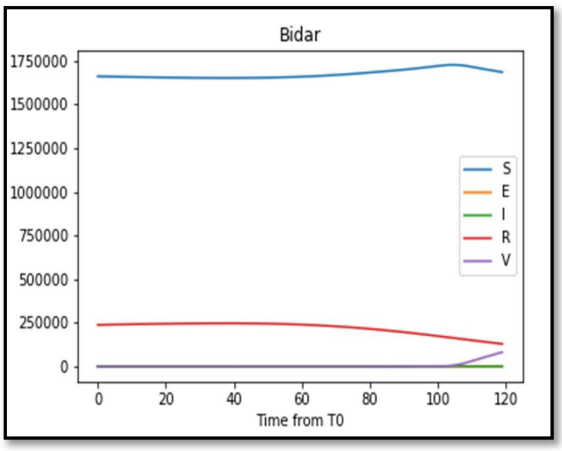


Figure 2 parameters value of SEIRV model for the given duration

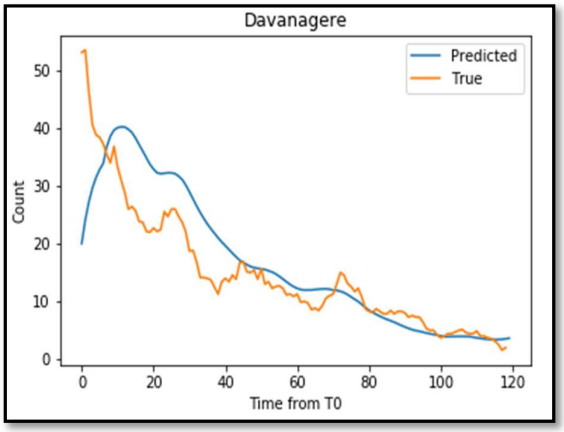


Figure 3 Plot of predicted cases vs reported cases

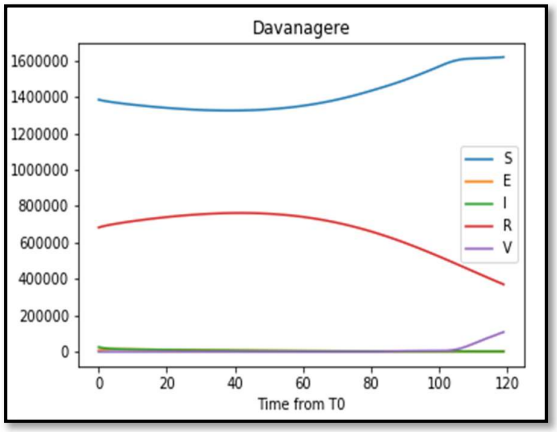


Figure 4 parameters value of SEIRV model for the given duration

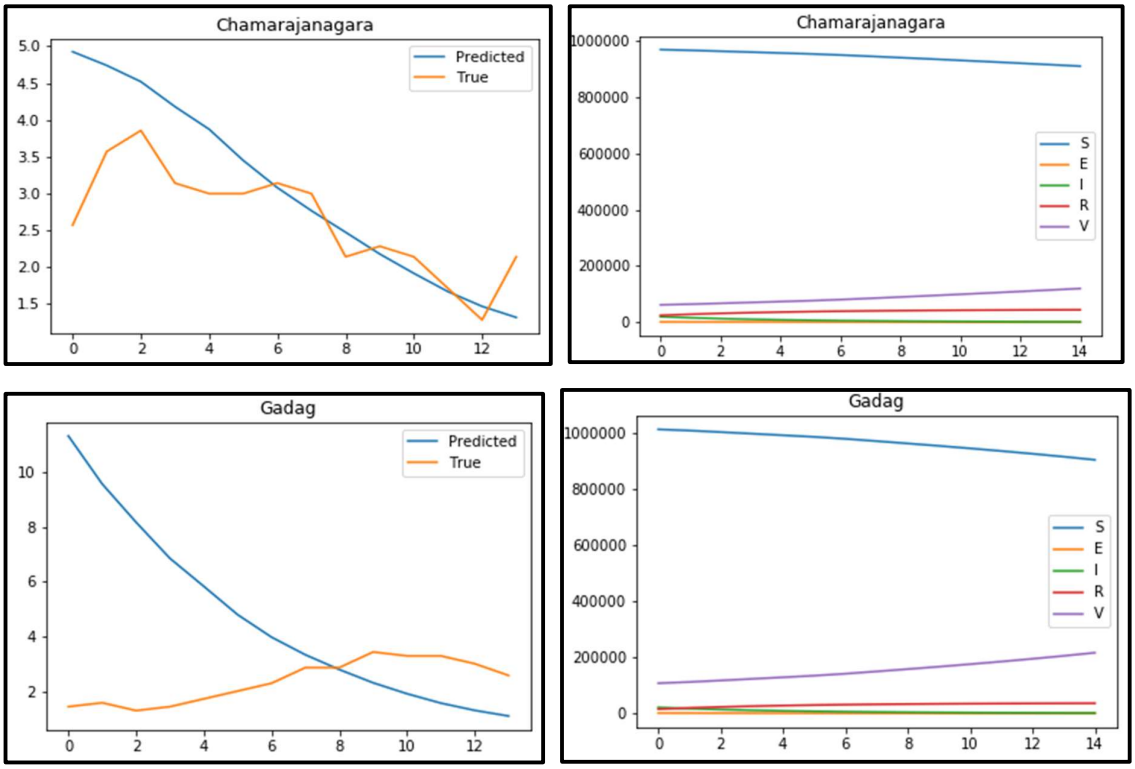
In the above figure 1, we can observe that the initial predicted number of cases is very different from the actual reported number, but our model follows the general trend very well. However, in the figure 3, the predicted number of cases is almost same except during the initial days.

In the figure 2 and 4, we can see that initially, for a brief number of days, the susceptible population is decreasing and the recovered population is increasing. When immunity waning starts, the recovered population starts decreasing, and the susceptible population increases, which is as expected. We can also see that the vaccinated population also increases as vaccination starts on 18th January, 2021.

Parameter values obtained after calibration in task 2 are provided in the table below.

Unit	Error	Beta	Scale	Shape
BBMP-Bommanahalli	0.200754589	0.25083114	107.6441994	3.124621368
BBMP-Dasarahalli	0.196782477	0.215199782	117.3324304	3.445316381
BBMP-East	0.206004116	0.268660097	103.1078886	2.929042922
BBMP-Mahadevpura	0.195172851	0.209254594	119.6757401	3.614327104
BBMP-RR-Nagar	0.20684716	0.269060059	100.8160388	2.945271402
BBMP-South	0.347065044	0.474745587	46.62717385	0.844221982
BBMP-West	0.210333192	0.278790016	99.44954821	2.736988354
BBMP-Yelahanka	0.196948892	0.203301987	121.6088927	3.553262402
Bagalakote	0.300409758	0.166959655	122.9755516	3.814783901
Ballari	0.165112882	0.220405089	114.9231643	3.488442879
Belagavi	0.051327669	0.233131285	111.217367	3.4073833
Bengaluru Rural	0.375892567	0.256805545	102.944007	3.05811477
Bengaluru Urban	0.196174073	0.204008654	121.9246922	3.612444583
Bidar	0.153705652	0.235388882	111.3044485	3.350239944
Chamarajanagara	0.151185283	0.217911431	114.2306698	3.509804123
Chikkaballapura	0.133368639	0.207521068	121.5154541	3.562642392
Chikkamagaluru	0.08828155	0.245810278	103.5997323	3.118068131
Chitradurga	0.09816849	0.270642422	99.94374978	2.920174729
Dakshina Kannada	0.286332235	0.229854068	116.0993244	3.33652009
Davanagere	0.097040453	0.244242502	105.8821322	3.209858188
Dharwad	0.159727771	0.180036982	124.7828078	3.833822883
Gadag	0.100110215	0.173726824	126.2662539	3.807706048
Hassan	0.084709564	0.251581561	107.6054214	3.110540082
Haveri	0.450966957	0.187173433	123.2270985	3.734453938
Kalaburagi	0.102852887	0.239282168	109.3644413	3.306378652
Kodagu	0.163465024	0.267990465	100.3927512	2.934596007
Kolar	0.131146737	0.201024872	120.2062878	3.698370129
Koppal	0.308037461	0.165374452	123.4021614	3.824269856
Mandya	0.130975909	0.217783178	114.2982279	3.508273034
Mysuru	0.109147757	0.239792016	109.1183346	3.292178536
Raichur	0.158630508	0.209398802	119.3430918	3.587826056
Ramanagara	0.176872655	0.19404162	124.5463428	3.663411207
Shivamogga	0.153889965	0.197894067	121.6736315	3.600843666
Tumakuru	0.166861072	0.278910042	99.67678326	2.733473143
Udupi	0.350997769	0.241778104	107.8986138	3.273973852
Uttara Kannada	0.111513825	0.192126669	124.1926544	3.66605651
Vijayapura	0.144462605	0.237531637	110.3175906	3.320984748
Yadgiri	0.137837127	0.202678683	122.945252	3.602183394

➢ TASK 3



These plots are for the first calibration to be performed in task 3. In figure, projected vs true cases, as we can see that the predicted trend for the Gadag district is very different from the true curve, but for the Chamarajanagara district, the predicted trend is trying to follow the actual curve. This shows that our model is working correctly for some of the units and it is failing for a few. The other two plots are the usual parameter values of the SEIRV model over the given time period and it is correctly following the expected trend.

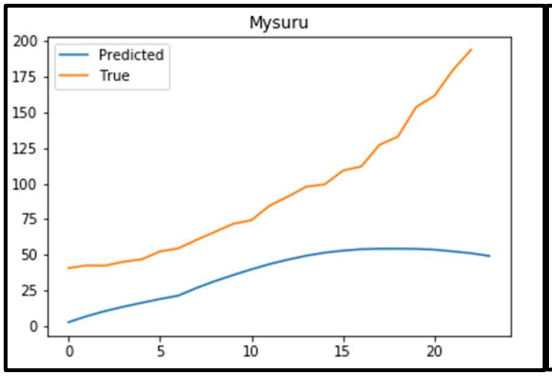


Figure 5 Plot of predicted cases vs reported cases

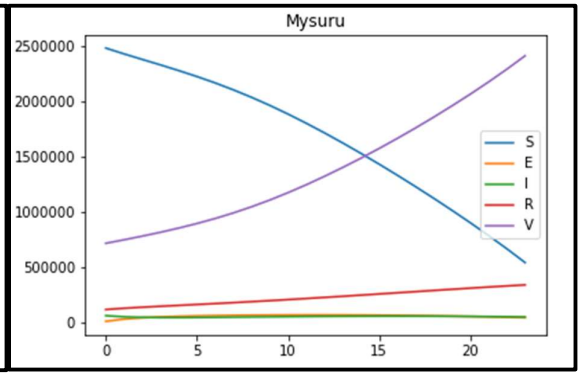


Figure 6 parameters value of SEIRV model for the given duration

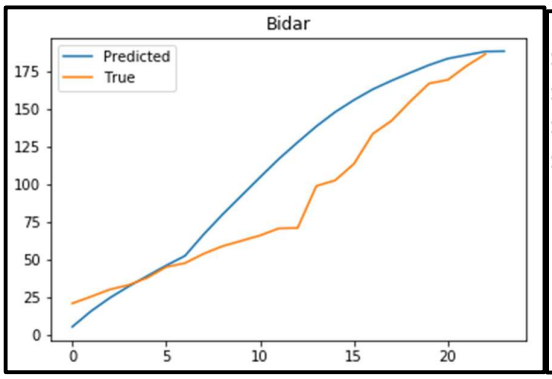


Figure 7 Plot of predicted cases vs reported cases

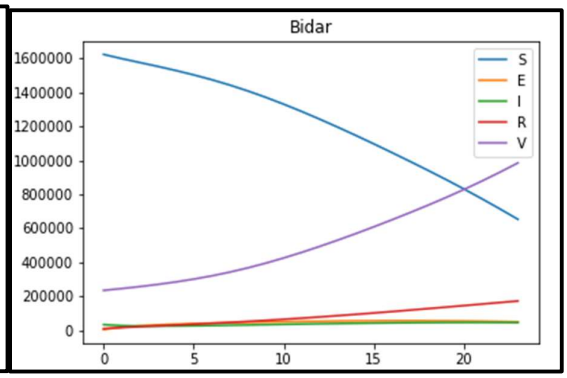


Figure 8 parameters value of SEIRV model for the given duration

These plots are for the second calibration to be performed in task 3. In figure 5, as we can see that the predicted trend is very different from the true curve, and in figure 7, the predicted trend is almost same as the true curve. This shows that our model is working correctly for some of the units and it is failing for a few. The figures 6 and 8 are the usual parameter values of the SEIRV model over the given time period and it is correctly following the expected trend.

Parameter values obtained after calibration in task 3 are provided in the table below.

Unit	Error	Beta	Scale	Shape
BBMP-Bommanahalli	0.063470212	0.5869246	17.52092591	-0.532245059
BBMP-Dasarahalli	0.059066476	0.613892352	6.587742543	-1.224327181
BBMP-East	0.063669908	0.585509079	17.11508142	-0.471489907
BBMP-Mahadevpura	0.068474671	0.565670592	25.9240624	0.07365129
BBMP-RR-Nagar	0.074360949	0.544129869	39.65617326	0.622395847
BBMP-South	0.061286834	0.599926336	11.09692803	-0.819675905
BBMP-West	0.064128533	0.584706568	18.90475816	-0.43422958
BBMP-Yelahanka	0.062258425	0.591747919	13.8579267	-0.612755603
Bagalakote	0.250635651	0.143468873	217.4867816	8.601314087
Ballari	0.33059421	0.141043432	215.353	8.678229322
Belagavi	0.085738677	0.207492554	201.7720987	7.667236307
Bengaluru Rural	0.058829466	0.404821219	98.34690856	3.309037254
Bengaluru Urban	0.087315237	0.50265465	63.16317848	1.188878696
Bidar	0.039840973	0.387098915	108.3611703	3.597103145
Chamarajanagara	0.264234829	0.22893174	188.8972202	7.516923392
Chikkaballapura	0.05075888	0.171374715	209.1972285	8.255626987
Chikkamagaluru	0.369447815	0.249479841	179.0305165	6.908429546
Chitradurga	0.199225872	0.1923955	207.0248755	7.585216938
Dakshina Kannada	0.051190993	0.331902987	139.1372011	4.935516599
Davanagere	0.355156357	0.129410151	221.6735254	8.781344307
Dharwad	0.284926377	0.148045165	212.486025	8.611872484
Gadag	0.229429624	0.197797068	204.8906893	8.015380658
Hassan	0.17289236	0.203187294	204.7036803	7.91530961
Haveri	0.037145456	0.264651118	165.4725078	6.423833456
Kalaburagi	0.098460458	0.367092349	119.0307033	4.061148104
Kodagu	0.051523329	0.355932361	141.2899473	4.369502409
Kolar	0.054256061	0.451001593	93.03851829	2.159349127
Koppal	0.068375285	0.377746781	113.0468991	3.794872967
Mandya	0.437636729	0.149333431	210.1604108	8.554299408
Mysuru	0.419557219	0.162147299	213.1385815	8.301762149
Raichur	0.232227219	0.18362885	209.1791762	8.096482321
Ramanagara	0.150400338	0.307352768	155.7651671	5.464762839
Shivamogga	0.051400491	0.597365641	11.85808393	-0.759009055
Tumakuru	0.594467364	0.200416667	202.0833333	8.216666667
Udupi	0.066848323	0.245839861	178.7485314	6.859420884

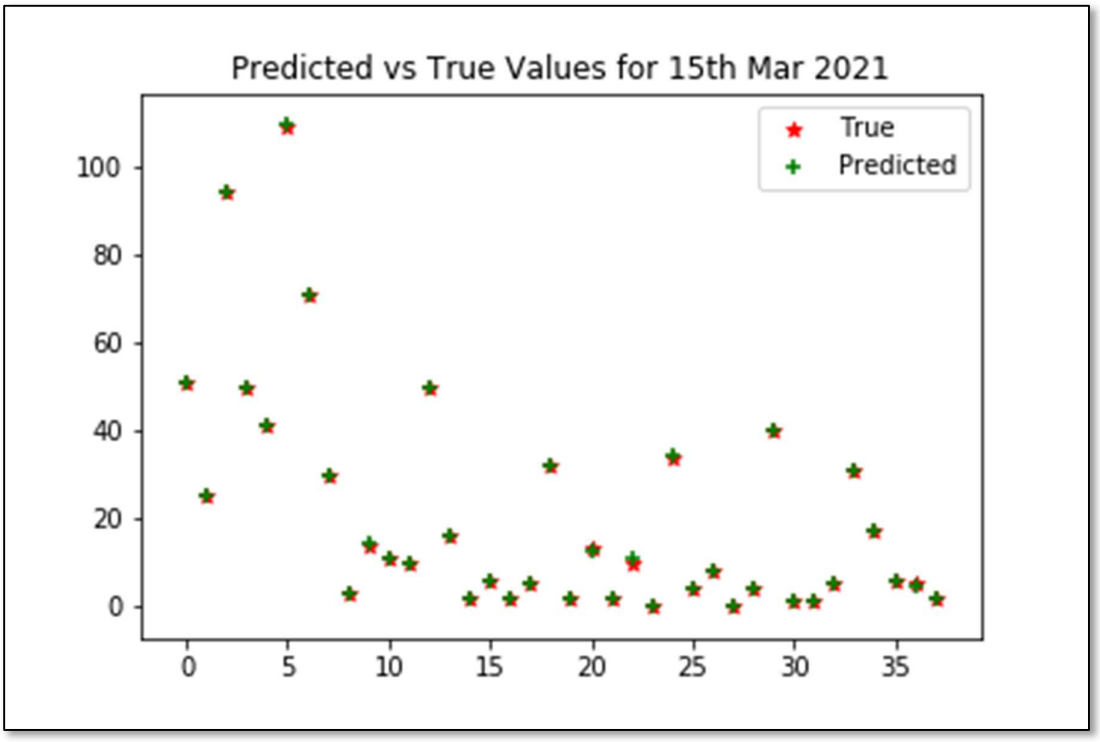
- **TASK 4**

For task 4, we are trying to tune parameters and compute the susceptible population, we somehow encountering negative values for some of the districts. These districts are derived from the Bengaluru Urban data, by distributing the cases, test data and vaccination count weighted by the populations. We have kept the CIR value same for all such districts.

Conclusion

In conclusion, we successfully implemented and calibrated an SEIRV model for the evolution of COVID-19 across 38 population units in Karnataka. We were able to optimize the parameters of the model to obtain pretty good matches to trends in the total number of active infections across all 38 units. The calibration was carried out over different time periods and presented us with challenges about the way our model should be initialized and what methods should be used to carry out the evolution of the model.

In the third task, first calibration, our initializations for the model leads to predictions very far from the true values. This shows that if our initializations are correct, we can correctly predict the model. But, we our model is correctly predicting the predicted cases on the final day, 15th march, which can be seen the graph below.



Our model is calibrated well to the given time series data and also satisfies the numbers in the 2 Sero Survey rounds in Karnataka. Although our aim was to use our model to predict the evolution of COVID-19 cases into the future and obtained realistic estimates for the number of cases, our failure on task 4 prevented this achievement. These predicted values may have been useful to management and mitigation agencies for preventing the spread of the virus and planning resources for dealing with cases that do arise.