Spread of COVID-19 in Odisha (India) due to Influx of Migrants and Stability Analysis using Mathematical Modelling

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Aswin Kumar Rauta · Yerra Shankar Rao · Jangyadatta Behera

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Abstract This paper deals with the investigation on spread of COVID-19 and its stability analysis (both local and global stability) in Odisha, India. Being the second most populous country in the world, It is urgent need to investigate the spread and control of disease in India.However, due to diversity of vast population, uncertainty of infection, varying rate of recovery,state wise different COVID-19 induced death rate and non uniform quarantine policy of the states, it is strenuous to predict the spread and control of disease accurately in the country. So, it is crucial to study the aspects of disease in each state for the better prediction. We have considered the state Odisha (India) having population nearly equal to the population of Spain because the entry of huge migrants to the state suddenly enhanced the number of COVID-19 patients from below two hundred to more than eight hundred within one week even after forty days of lock-down period. We have developed $SIAQR$ epidemic model fabricated with influx of out-migrants diagnosed at compartment (A), then sent to the compartment (I) for treatment those have confirmed the disease and the remaining healthy individuals are sent to quarantine compartment (Q) for a period of twenty one days under surveillance and observation. The set of ordinary (nonlinear) differential equations are formulated and they are solved using Runge-Kutta fourth order method. The simulation of numerical data is performed using computer software MATLAB. As there is no specific treatment, vaccine or medicine available for the disease till the date, so the only intervention procedure called quarantine process is devised in this model to check the stability behavior of the disease. The numerical and analytical results of the study show that the disease free equilibrium is locally stable when basic reproduction number is less than unity and unstable when it is more than unity. Further the study shows that it persists to endemic equilibrium for global stability when basic reproduction number greater than unity. As per the current trends,this study shows that the prevalence of COVID-19 would remain nearly 250 to 300 days in Odisha as far as the infected migrants would have been entering to the state. This mathematical modelling embedded with important risk factor like migration could be adopted for each state that would be helpful for better prediction of the entire country and world.

Keywords Global and Local Stability · Equilibrium · Modelling Migration · Quarantine · Virus

Abbreviations

Not applicable

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Nomenclature

β	Rate of Contact
δ_1	Death rate other than COVID-19.
δ_2	Death rate due to COVID-19.
γ	Rate at which the infected population is quarantined
λ	Migrant Population
A	Diagnosed Compartment
I	Infected Compartment
P	Proportion of migrants detected COVID-19.
Q	Quarantine Compartment
R	Recovered Compartment
R_0	Basic Reproduction Number
S	Susceptible Compartment
ϵ	Rate at which Quarantine population is recovered
T	Rate of new born

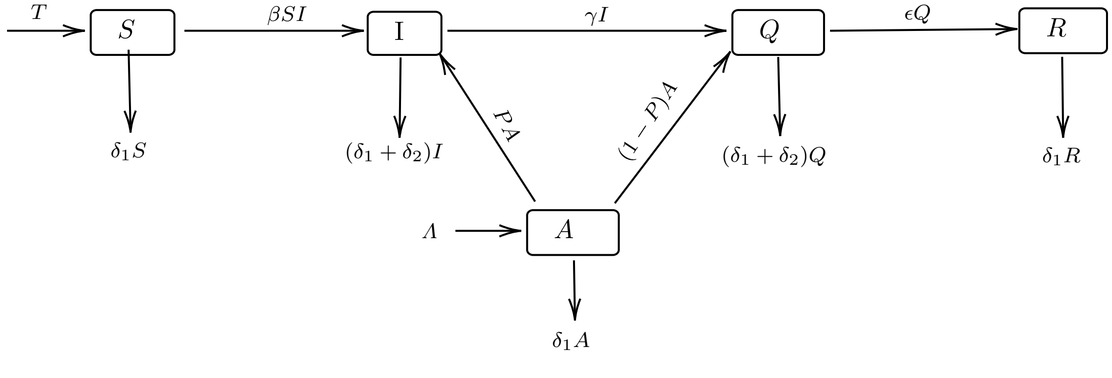
1 Introduction

An unknown and unexpected disease having symptoms of fever, cough, cold, fatigue, headache, and shortness of breath leading to severe pneumonia that causes death was first detected in Wuhan city of China in December 2019. The disease is confirmed as due to novel corona virus that is phylogenetically SARS-CoV-2 clade called COVID-19. Then the disease spread almost all countries of world by the end of March 2020. The socio-economic conditions of world has deteriorated and collapsed. Global business has interrupted. Many persons have lost their livelihoods and jobs. Large numbers of industries and employment sectors have closed. Migration and immigration of individuals is a great challenge for every nation due to the pandemic disease COVID-19. In India, the first COVID-19 case was detected from the state of Kerala on 30th January 2020. The patient was a student from Wuhan returnee. Gradually, many cases have been reporting from different states of the country everyday [9–15]. In Odisha the first COVID-19 patient [16,17,19,21–23] was detected from a 31 year young man in Bhubaneswar (state capital) on 16th March 2020 who was returned from Italy and second case a 77 year old man from U.K. returnee was detected on 20th March 2020. Then on 21th March 2020 the state government declared lock-down for five districts and supported the Janata curfew on 22nd March 2020 appealed by the prime minister of India.The government of India declared the 1st complete lock-down in the entire country from 24th March 2020 midnight to 15th April 2020 to break the transmission chain of COVID-19. The first death case due to COVID-19 in the state is reported on 6th April 2020.The deceased was a 72 year old man from Bhubaneswar who was also suffering from pre-existing diseases. Odisha is the first state in India that had extended the 2nd lock-down up to 30th April 2020. By the time, the government of India implemented second, third and fourth lock-downs from 16th April 2020 to 3rd May 2020, 4th May 2020 to 17th May 2020 and 18th May 2020 to 31st May 2020 respectively with relaxations in some services. The number of cases enhanced in the state after the government of India allowed the migration of workers across the country. Odisha was a least concerned state regarding COVID-19 till 6th may 2020 with only below 200 members of cases reported but suddenly the number raised after the entry of huge numbers of migrants during the third lock-down period from different hot-spot areas like Surat(Gujarat), Mumbai(Maharashtra), Chennai(Tamilnadu), Kerala,West Bengal,New Delhi and other parts of the country. Especially the migrants of Surat (India) returnee are detected more positive cases in the state that enhanced the number of positive cases from 200 (during first and second lock-down period) to more than 800 within one week. It is seen that the districts where more number of migrants entered from different hot spot areas of the country are reported more positive cases than the districts where less number of migrants are entered. These hot spot districts are Ganjam, Jajpur, Balasore, Bhadrak, Khurda, Kendrapara,Puri, Sundargarh, Cuttack, Anugul, Mayurbhanj .But the disease has been spread twenty three districts out of thirty districts of the state. Ganjam district was free from COVID-19 till 6th may 2020 but became the hot-spot area of the state after the entry of at least fifty thousand Surat returnees to the district. More than four lakh workers [18] of Ganjam district are working in Surat town only. Nearly six lakh migrants from different parts of the country have registered for return to the state. Around one lakh fifty thousand migrants from different districts of state have reached to the state till 18th May 2020. So it is a great concern to predict or forecast the spread of disease and its control if all the migrant people will enter to the state. The government of Odisha have made temporary health centers in the villages and urban areas for providing quarantine facilities of all migrant people coming to the state to control the disease.

The mathematical models developed on COVID-19 for India are very few and perhaps no model has been developed on Odisha regarding COVID-19 so for our knowledge. Chayu Yang et.al[1] have investigated the spread of COVID-19 in Wuhan,China using SEIR mathematical model emphasizing on the concentration of corona virus in the environmental reservoir and its role on the spread of disease. Their study included birth rate but lack of influx of immigrants and migrants. Shilei Zao et. al [2] have developed the SUQC mathematical model to study the dynamics of COVID-19 in China and interpreted the role of quarantine effects on the control of disease. Rajesh Singh et.al [3] have used age structured SIR model to study the spread of COVID-19 in India. They have suggested the social distancing as the most effective means of mitigation. They have found three week lockdown in India was insufficient to prevent the resurgence of disease. Their forecast of stability in India is about the periodic relaxation of lockdown for 67 days or completely lockdown of 49 days. P.V. Khrapov et.al [4] have considered the simple SIR model but modified the equations based on the difference of time period between the onsets of the disease, its diagnosis, recovered or death to study the development of COVID-19 in China. They simply computed the numerical simulations without undergoing the analysis of stability. Manav. R. Bhatanagra[5] has proposed a mathematical model on community spread of COVID-19 using the data of USA, Italy and India and forecasted the increasing numbers of COVID-19 and preventing measures. Kaustuv Chatterjee et.al [6] have developed SEIR model on COVID-19 in India and predicted that the peak of infection will be during the month of July 2020 and spread will be overwhelmed by the end of May. They have suggested proper health care ICU facilities to reduce the death rate. Palash Ghosh et. al.[7] have analysed state wise contact rate of COVID-19 in India.They have studied exponential,logistic and SIS model jointly for each state and observed some states are showing decreasing trend in contact rate and some states are showing increasing trend in contact rate. so they have suggested for lock-down policy to minimize the contact rate. Kaushalendra Kumar et. al.[8] have developed SIR model for study of COVID-19 in India and forecasted that 3 million people of India would be infected by October 2020. Further, their study reveals that the pandemic will persist from two month to more than six month. The investigation done on India regarding COVID-19 so far is insufficient and has lack of important parameters and risk factors of the disease. So detailed investigation of the disease by considering every aspect of spread and control the disease is an emerging necessity in the study of COVID-19 to provide better understanding of the disease control, make decision, implement public health policy and explore the research dynamics in the interdisciplinary subjects. Thus, the mathematical model developed in this paper to check the stability behaviour of the disease in Odisha (India), be adopted for investigation of whole India as well as world. The model includes the death other than COVID-19, death due to COVID-19, new born and migration. The detailed analysis is carried out and numerical simulations are validated with the analytical proofs. Therefore, the investigation done in this paper is innovative, authentic and original work.

2 Mathematical Modelling and Basic Assumptions

The total population is distributed into five compartments such as Susceptible (S) population for healthy individuals, Infected population (I)for attacked individuals, quarantine population (Q) for isolated individuals , Recovered populations(R) for cured individuals and those have reported negative in quarantine class and diagnosed population (A) for migrants who are screened at the check post (Railway Station, State Border or Quarantine centre). The whole populations is $N = S + I + Q + A + R$. The susceptible population enhanced by the new born (T) but decreased due to contact of infected population at the rate β and diminished by the death due to other reason at the rate δ_1. The infected population size increases with change of time but then reduced due to recovery and death. Quarantine population also increases initially then decreases due to recovery as well as death but recovered population always increase by huge susceptible and migrant individuals after they get out of quarantine class though there is small death rate δ_1 On the basis of this criteria, the flow of the model is shown in the following diagram.



The following set of ordinary differential equations is generated as per the principle of Epidemic models;

$$\begin{aligned}
\frac{dS}{dt} &= T - \beta SI - \delta_1 S \\
\frac{dA}{dt} &= \Lambda - PA - (1-P)A - \delta_1 A \\
\frac{dI}{dt} &= \beta SI + PA - (\gamma + \delta_1 + \delta_2)I \\
\frac{dQ}{dt} &= (1-P)A + \gamma I - (\epsilon + \delta_1 + \delta_2)Q \\
\frac{dR}{dt} &= \epsilon Q - \delta_1 R
\end{aligned} \tag{1}$$

Subject to the initial conditions $S(0), I(0), Q(0), R(0)$ and $A(0)$ all are positive.

2.1 Basic assumptions

1. COVID-19 spreads due to direct or indirect contact between susceptible and infected individuals.
2. Latent period is ignored i.e. instantly the disease spreads.
3. It is assumed that the population is homogeneous i.e. the rate of contact is independent of population size.
4. Out -migrants who have registered in government portal for return to the state are taken into consideration.
5. Birth and death rate are considered as constant.

Since the above set of equations is not in closed form, so, it could not be solved using any standard form of Ordinary Differential Equations. Hence, Runge-Kutta 4th order numerical method is employed to find the solutions with the help of MATLAB software.

2.2 Existence of boundedness and Positive invariant of the solutions

Here, total population size,

$$\begin{aligned}
N &= S + A + I + Q + R \\
\Rightarrow \frac{dN}{dt} &= \frac{dS}{dt} + \frac{dA}{dt} + \frac{dI}{dt} + \frac{dQ}{dt} + \frac{dR}{dt} \\
\Rightarrow \frac{dN}{dt} &= T + \Lambda - \delta_1 N - \delta_2 (I + Q)
\end{aligned}$$

In the absence of any diseases, $\frac{dN}{dt} = T + \Lambda - \delta_1 N$ Then, total population carries $N \rightarrow \frac{T+\Lambda}{\delta_1}$ as $t \rightarrow \infty$ Thus, it follows the solution of (1) exists in the region defined by $\Gamma = \{(S, A, I, Q, R) \in R^5_+ \ : \ S + A + I + Q + R \leq \frac{T+\Lambda}{\delta_1}\}$.

2.3 Basic Reproduction Number and Existence of Equilibrium

Basic reproduction number of the system (1) will be obtained as;

$$R_0 = \frac{\beta S_0}{(\gamma + \delta_1 + \delta_2)}$$

Two equilibrium points are

1. Diseases free equilibrium $\Gamma_{DFE}(S_0 = 1, \ A = 0, I = 0, Q = 0, R = 0)$
2. Endemic Equilibrium $\Gamma_{EE}(S = S^*, \mathrm{A} = A^*, \ \mathrm{I} = l^*, \ Q = Q^*, \ \mathrm{R} = R^*)$

For the steady state conditions, the endemic equilibrium $\Gamma^*_{EE}(S^*, \ A^*, I^*, Q^*, R^*)$ of the system 1 is determined by the equations

$$\begin{aligned}
T - \beta SI - \delta_1 S &= 0 \\
\Lambda - PA - (1-P)A - \delta_1 A &= 0 \\
\beta Sl + PA - (\gamma + \delta_1 + \delta_2)l &= 0 \\
(1-P)A + \gamma l - (\epsilon + \delta_1 + \delta_2)Q &= 0 \\
\epsilon Q - \delta_1 R &= 0
\end{aligned} \tag{2}$$

Solving above equations simultaneously; we get

$$\begin{aligned} S^* &= \frac{T}{\beta I^* + \delta_1} \\ A^* &= \frac{\Lambda}{\delta_1 + 1} \\ Q^* &= \frac{\Lambda(1-P) + \gamma I^*(\delta_1+1)}{(\delta_1+1)(\delta_1+\delta_2+\epsilon)} \\ R^* &= \frac{\epsilon\Lambda(1-P) + \gamma I^*(\delta_1+1)}{\delta_1(\delta_1+1)(\delta_1+\delta_2+\epsilon)} \end{aligned}$$

2.4 Local Stability Analysis

The local stability analysis of system 1 is performed using the Jacobian matrix at the equilibrium points.

Theorem 1 *If* $\mathrm{R}_0 < 1$*, the disease free equilibrium* $\Gamma_0(1,0,0,0)$ *of the system 1 is locally asymptotically stable in the region F. If* $\mathrm{R}_0 > 1$ *then* Γ *is unstable and it continue to be endemic equilibrium.*

Proof At the diseases free equilibrium point $\Gamma_0(S=1,0,0,0)$, the Jacobian matrix is

$$J_{DFE} = \begin{pmatrix} -\delta_1 & 0 & -\beta & 0 \\ 0 & -(\delta_1+1) & 0 & 0 \\ 0 & P & (\beta-(\gamma+\delta_1+\delta_2)) & 0 \\ 0 & (1-\ P) & \gamma & -(\delta_1+\delta_2+\epsilon) \end{pmatrix}$$

Clearly, the Eigen values are

$$\begin{aligned} \lambda_1 &= -\delta_1 \\ \lambda_2 &= -(\delta_1+1) \\ \lambda_3 &= -(\delta_1+\delta_2+\epsilon) \\ \lambda_4 &= \beta-(\gamma+\delta_1+\delta_2) \end{aligned}$$

For,

$$\frac{\beta}{(\gamma+\delta_1+\delta_2)} < 1 \Rightarrow R_0 < 1$$

Thus, all the Eigen values have negative real parts. Therefore, by Routh-Hurwitz criterion of stability, the system 1 is locally asymptotically stable at the Diseases free equilibrium points.

Theorem 2 *The endemic equilibrium* $\Gamma^*(S^*,\ A^*, I^*, Q^*, R^*)$ *is locally asymptotically stable when* $\mathrm{R}_0 > 1$

Proof At the endemic equilibrium $\Gamma^*(S^*,\ A^*, I^*, Q^*, R^*)$, the Jacobian matrix is

$$J = \begin{pmatrix} -(\delta_1+\beta I^*) & 0 & -\beta S^* & 0 & 0 \\ 0 & -(1+\delta_1) & 0 & 0 & 0 \\ \beta I^* & P & -((\gamma+\delta_1+\delta_2)-\beta S^*) & 0 & 0 \\ 0 & (-P+1) & \gamma & -(\epsilon+\delta_1+\delta_2) & 0 \\ 0 & 0 & 0 & \epsilon & -\delta_1 \end{pmatrix}$$

After calculation, the Eigen values are

$$\begin{aligned} \lambda_1 &= -\delta_1 \\ \lambda_2 &= -(\delta_1+\delta_2+\epsilon) \\ \lambda_3 &= -(1+\delta_1) \end{aligned}$$

Other two Eigen values are obtained from the Quadratic equation of the form $\lambda^2 + a_1\lambda + a_2 = 0$ Where

$$\begin{aligned} a_1 &= \beta I^* + 2\delta_1 + \delta_2 + \gamma - \beta S^* > 0 \\ a_2 &= (\beta I^* + \delta_1)(\delta_1 + \delta_2 + r - \beta S^*) + \beta^2 I^* S^* > 0 \end{aligned}$$

If $\mathrm{R}_0 > 1$, then $\mathrm{a}_1\mathrm{a}_2 > 0$. Again by the Routh-Hurwitz Criterion, the system is locally asymptotically stable.

2.5 Global Stability for the endemic equilibrium

Theorem 3 *If* $\mathrm{R}_0 > 1$*, then the endemic equilibrium* $\Gamma^*(S^*, \ A^*, I^*, Q^*, R^*)$ *is globally stable in the given region*

Proof Since the first and third equation of the system 1 are independent of Quarantine and Recovered class, so we can apply the Dulac's criteria with multiplier D = 1/I Let's consider equations

$$M_1 = T - \beta SI - \delta_1 S$$
$$M_2 = \beta SI - (\delta_1 + \delta_2 + \gamma) + PA$$

Then,

$$DM_1 = \frac{T}{I} - \beta S - \frac{\delta_1 S}{I}$$
$$DM_2 = [\beta S - (\delta_1 + \delta_2 + r)] + \frac{PA}{I}$$

So we have,

$$\frac{\partial(DM_1)}{\partial S} + \frac{\partial(DM_2)}{\partial I} = -(\beta + \frac{\delta_1}{l} + \frac{PA}{I^2}) < 0$$

Hence by the Poincare -Bendixson theorem, all the solutions starting in the positive quadrant of SI plane with $\mathrm{I} > 0$ and $S + I \leq \frac{T}{\delta_1}$ approaches $(\mathrm{S}^*, \mathrm{I}^*)$ as $t \to \infty$. In this case the limiting forms for other three equations of the system 1 show $A \to A^*, Q \to Q^*, R \to R^*$. Thus, the endemic equilibrium$\Gamma \ \ {}^*(S^*, \ A^*, I^*, Q^*, R^*)$ is globally stable in the region$\Gamma \ \ \neg$ for the system 1.

3 Interpretation of the Numerical Results

Odisha is the only state in India that has adopted quarantine period of 28 days (21 days government quarantine and 7 days home quarantine) instead of 14 days quarantine when the infection spread in the state due to entry of migrants after the end of second lockdown in the country. Presently,total population of the state is around 4.5 crores [20,23] . The total number of migrants registered for return to the state[16,17] under government's custody is more than five lakh but some people have returned to the state by the means of cycle, walking or vehicles. We have fixed the initial conditions for all compartments as per the data [16,17,19,21,22,23] available up to 18th May 2020. Hence,the initial condition for diagnosed compartment of migrant individuals is set as $\mathrm{A}(0) = 600000$ and the initial condition for other compartments are assumed as $\mathrm{S}(0) = 45000000, \mathrm{I}(0) = 695, \mathrm{R}(0) = 220$ and $\mathrm{Q}(0) = 600052$.This study is carried out from 23th March 2020 to 18th May 2020 (approximately 55 days). For the sake of convenience to plot the graphs, the initial values are scaled to unity as $\mathrm{S}(0) = 1, \mathrm{I}(0) = 0.00013, \mathrm{Q}(0) = 0.013333, \mathrm{R}(0) = 0.00061555$ and $\mathrm{A}(0) = 0.013333$. The parametric values are taken per unit time i.e. per day. The contact rate of Odisha is in between 0.01 to 0.13, So $\beta = 0.01$ to 0.13 The quarantine period at government level is 21 days .Therefore $\Gamma = 1/21 = 0.047$, $\epsilon = 1/21 = 0.047$. Since the crude birth rate and death rate are 20 and 8.3 per one thousand in the state, so per unit time $\mathrm{T} = (20/1000)/365 = 0.000054$ and $\delta_1 = (8.3/1000)/365 = 0.00022$. Again it has been reported that there are 4 deaths due to COVID-19 out of 876 confirmed infected cases in the period of 55 days, hence the death rate of this disease per day is $\delta_2 = (4/876)/55 = 0.000083$, The total migrants are assumed as $\Lambda = 10000000$ and rate of proportion of infected migrants is calculated as $\mathrm{P} = 0.0034$ Fig-1 is plotted for basic reproduction number $\mathrm{R}_0 = 0.943$ in support of theorem-l that shows the system is stable when $\mathrm{R}_0 < 1$i. e.no new infections occur.The susceptible population remain at the same level with slight increase due to entry of new born as long as no new infection occurs with progress of time or infection is reduced due to adoption of quarantine.It means that the disease will die out and susceptible class is stable without any impact on the share of other compartments that are at zero level except the recovered class that is just above the zero level because the recovery of infected individuals Theorem-1 states that the system is unstable when $\mathrm{R}_0 > 1$ i.e. the disease leads towards the endemic for some periods of time. This is illustrated in the figures 2, 3 and 4.

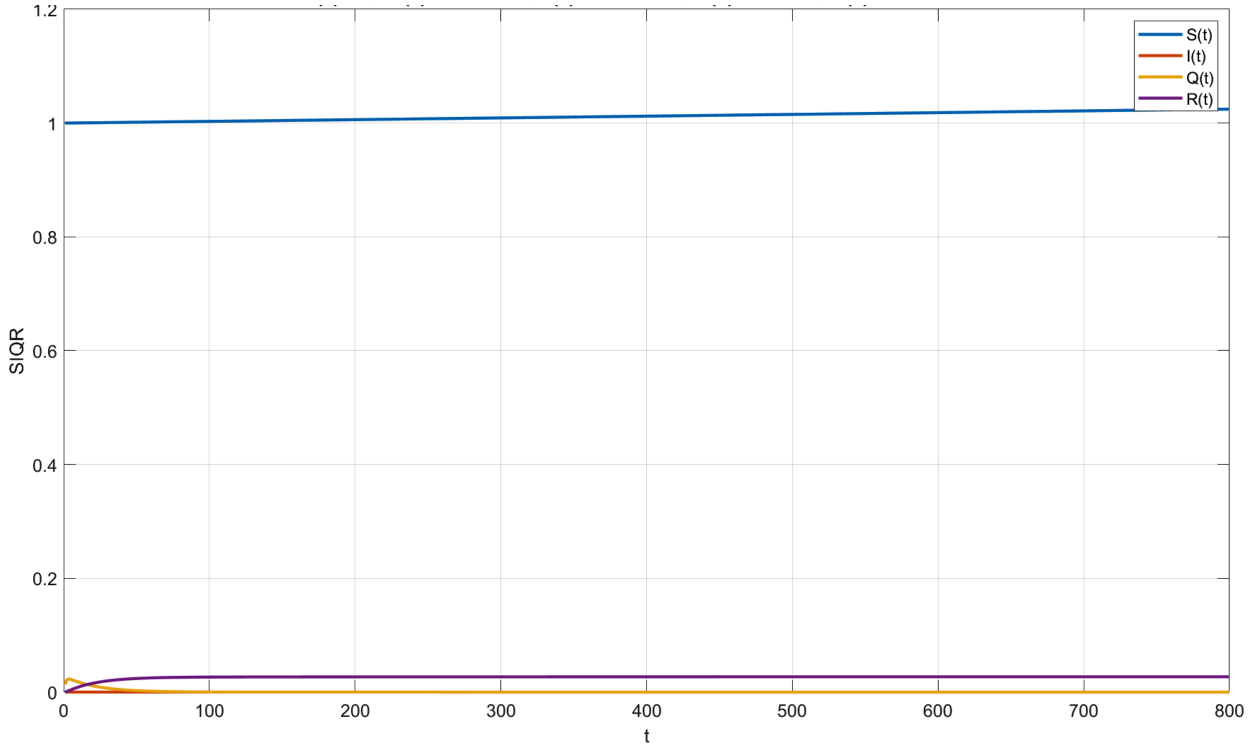


Fig. 1

$B = 0.000055, R_0 = 0.943, \epsilon = 0.047619, \gamma = 0.047619, \beta = 0.045, P = 0.003, T = 0.000054, \delta_1 = 0.000023, \delta_2 = 0.000083$

$S(0) = 1, A(0) = 0.013333, I(0) = 0.000013, Q(0) = 0.0133, R(0) = 6.1556e - 06$

Fig-2, Fig-3 and Fig-4 are drawn for $\mathrm{R}_0 = 1.68, \mathrm{R}_0 = 2.51$ and $\mathrm{R}_0 = 2.72$ respectively to validate theorem2 and theorem 3. Theorem-2 states that the endemic equilibrium is stable when $\mathrm{R}_0 > 1$ .The simultaneous study of $\mathrm{S}, \mathrm{I}, Q, R$ in fig-2,fig-3 and fig-4 illustrate that the susceptible class decreases for certain time period due to infection of susceptible class then becomes stable as the infection is declined by the quarantine process and large number of individuals are recovered in the long run. The infected population increases for particular period then diminished due to recovery and quarantine of large number of individuals. The recovered line shows the enhanced pattern due to low death rate and high recovery of infected and migrant individuals. The size of R increases for long time then asymptotically converges towards stability. This exhibits the global stability of the system that is analytically proved in theorem-3. The recovered class does not approaches to zero level indicates that the disease has disappeared before the infection spread over the whole susceptible population (S).

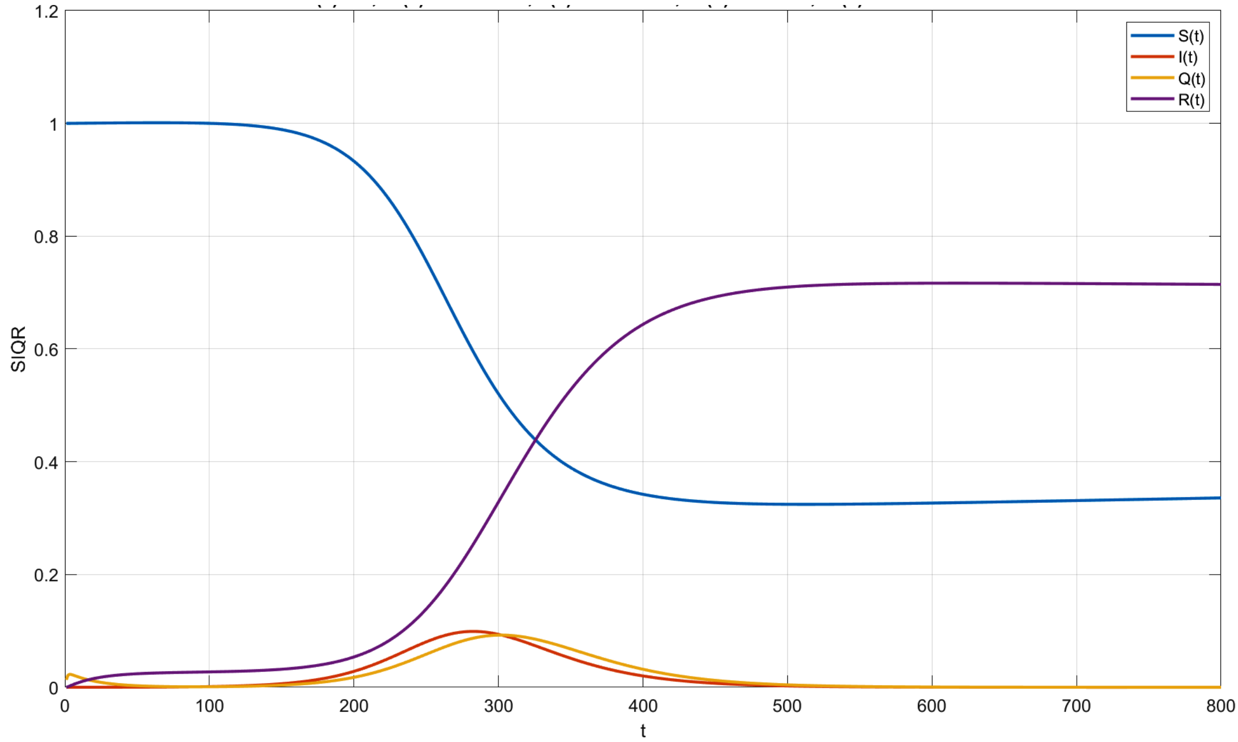


Fig. 2
$B = 0.000055, R_0 = 1.68, \epsilon = 0.047619, \gamma = 0.047619, \beta = 0.08, P = 0.003, T = 0.000054, \delta_1 = 0.000023, \delta_2 = 0.000083$
$S(0) = 1, A(0) = 0.013333, I(0) = 0.000013, Q(0) = 0.0133, R(0) = 6.1556e - 06$

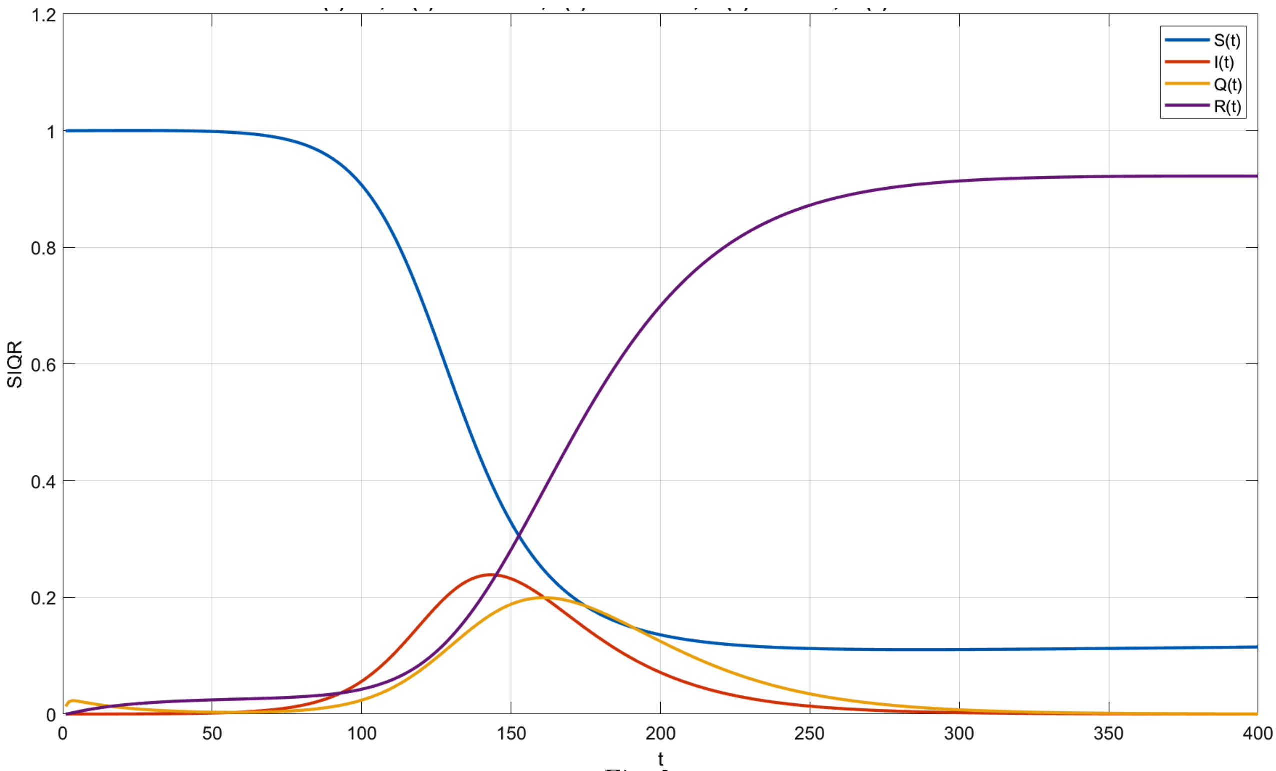


Fig. 3
$B = 0.000055, R_0 = 2.51, \epsilon = 0.047619, \gamma = 0.047619, \beta = 0.12, P = 0.003, T = 0.000054, \delta_1 = 0.000023, \delta_2 = 0.000083$
$S(0) = 1, A(0) = 0.013333, I(0) = 0.000013, Q(0) = 0.0133, R(0) = 6.1556e - 06$

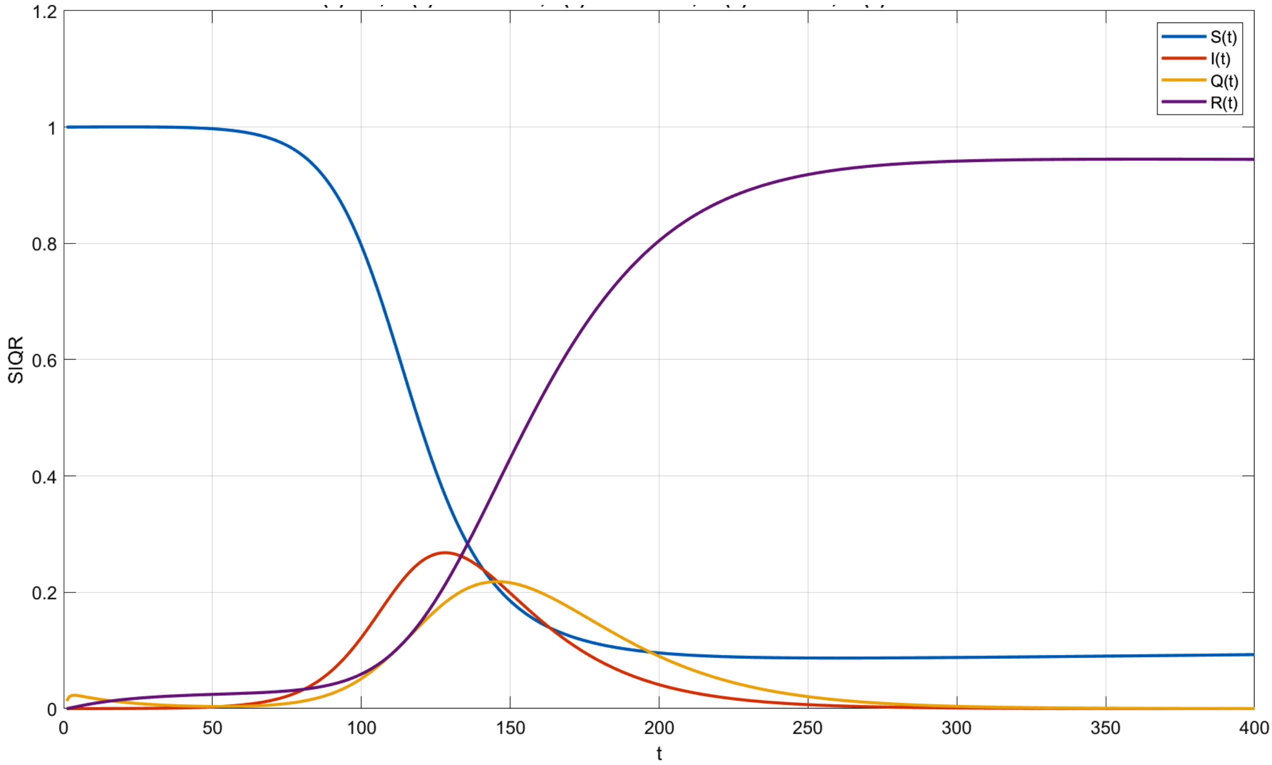


Fig. 4

$B = 0.000055, R_0 = 2.72, \epsilon = 0.047619, \gamma = 0.047619, \beta = 0.13, P = 0.003, T = 0.000054, \delta_1 = 0.000023, \delta_2 = 0.000083$

$S(0) = 1, A(0) = 0.013333, I(0) = 0.000013, Q(0) = 0.0133, R(0) = 6.1556e-06$

Fig-5 is drawn for infected versus time in the presence of migrants. It shows that the curves are rising with peak as the basic reproduction numbers increase due to influx of migrants in the early phase of epidemic, but due to effective quarantine policy of large individuals and recovery of huge population with low death rate, the curves become flat with higher slopes indicates the infected cases reduced and finally the system is stable. It is observed that the prevalence of COVID-19 is likely to be continued for long term approximately 300 days.

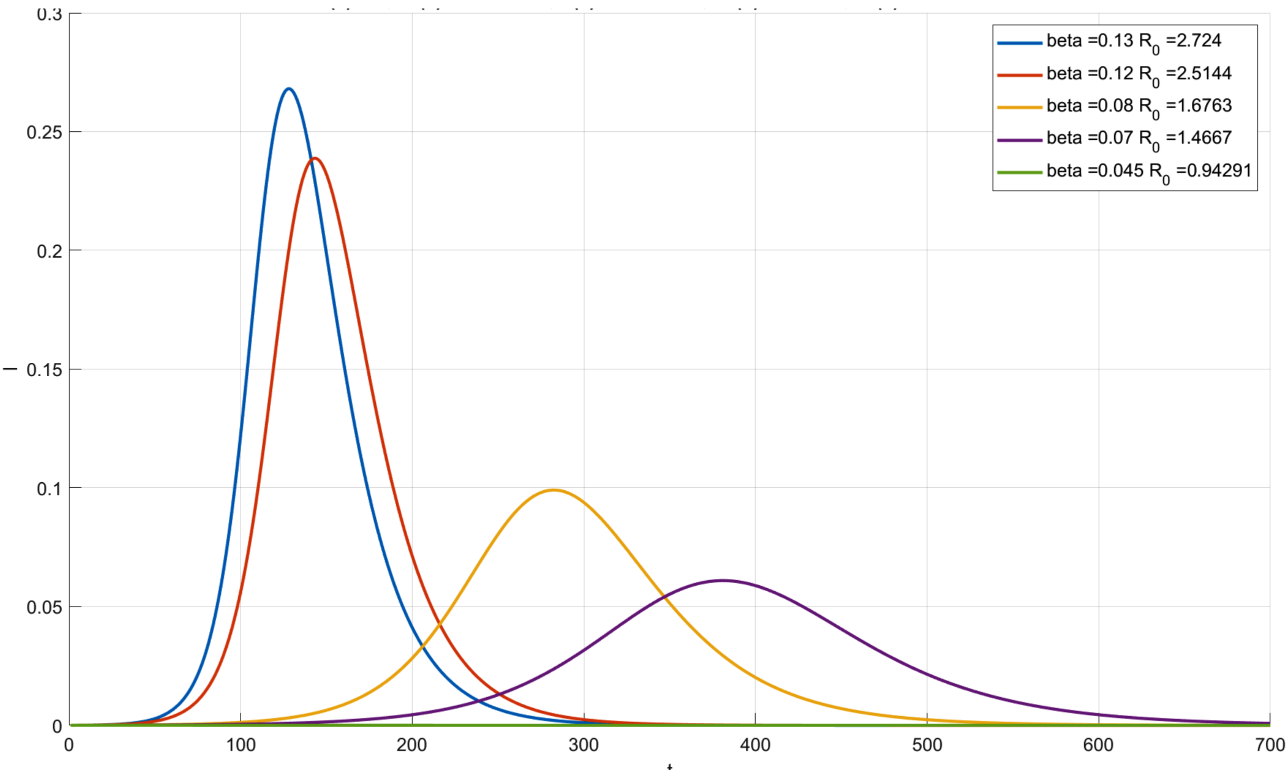


Fig. 5

$B = 0.000055, \epsilon = 0.047619, \gamma = 0.047619, P = 0.003, T = 0.000054, \delta_1 = 0.000023, \delta_2 = 0.000083$

$S(0) = 1, A(0) = 0.013333, I(0) = 0.000013, Q(0) = 0.0133, R(0) = 6.1556e-06$

Fig-6 shows the infected versus quarantine graph. It infers that the number of fresh infection is reduced due to increase number of quarantine individuals but do not approach to zero level due to persist of epidemic outbreak. The quarantined individuals do not infect other people also do not transmit the disease after come out from the quarantine compartment. So the infection is reduced on the time evolution.

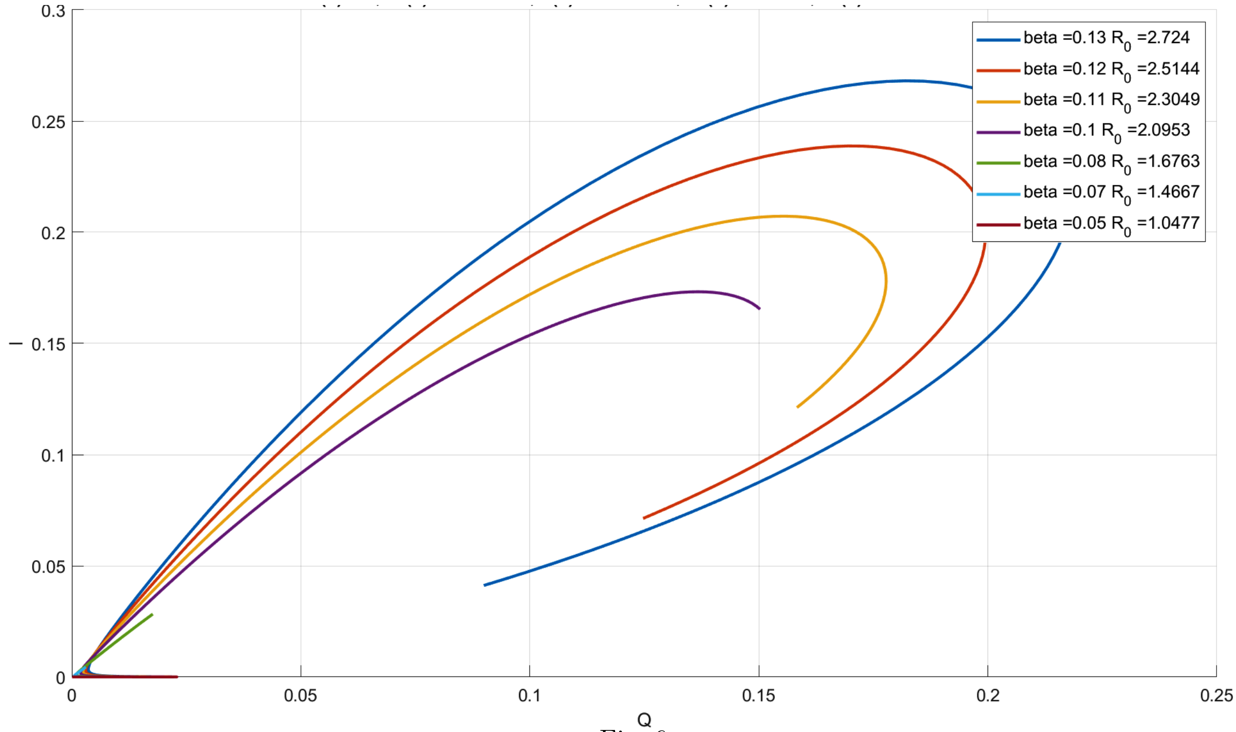


Fig. 6

$B = 0.000055, \epsilon = 0.047619, \gamma = 0.047619, P = 0.003, T = 0.000054, \delta_1 = 0.000023, \delta_2 = 0.000083$
$S(0) = 1, A(0) = 0.013333, I(0) = 0.000013, Q(0) = 0.0133, R(0) = 6.1556e - 06$

The phase portrait graph of S verses I is shown in figure-7. It interprets that the infection raised due to entry of infected migrants and other infected individuals but then decrease after progress of time due to huge recovery and low death rate upon the lockdown or quarantine rules.

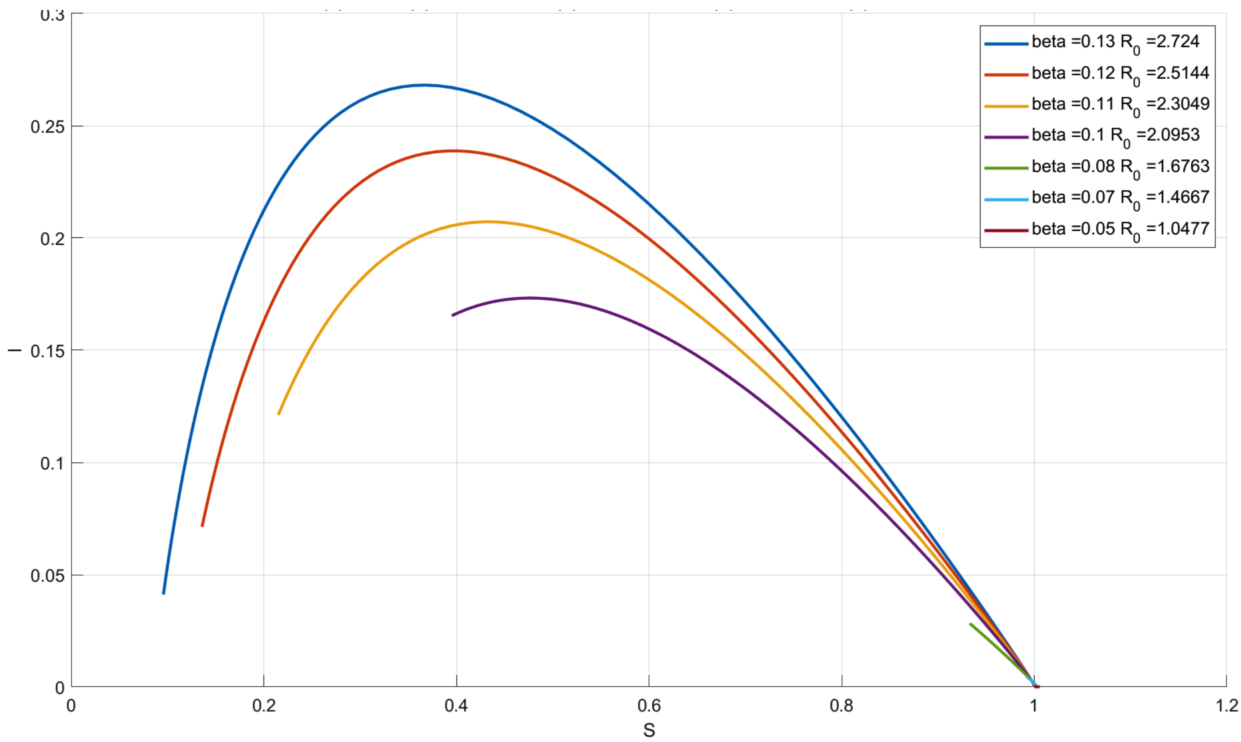


Fig. 7

$B = 0.000055, \epsilon = 0.047619, \gamma = 0.047619, P = 0.003, T = 0.000054, \delta_1 = 0.000023, \delta_2 = 0.000083$
$S(0) = 1, A(0) = 0.013333, I(0) = 0.000013, Q(0) = 0.0133, R(0) = 6.1556e - 06$

Fig-8 illustrates that the continuous entry of infected migrants enhance the infection curves to the peak. So quarantine is the only technique to control the infection.

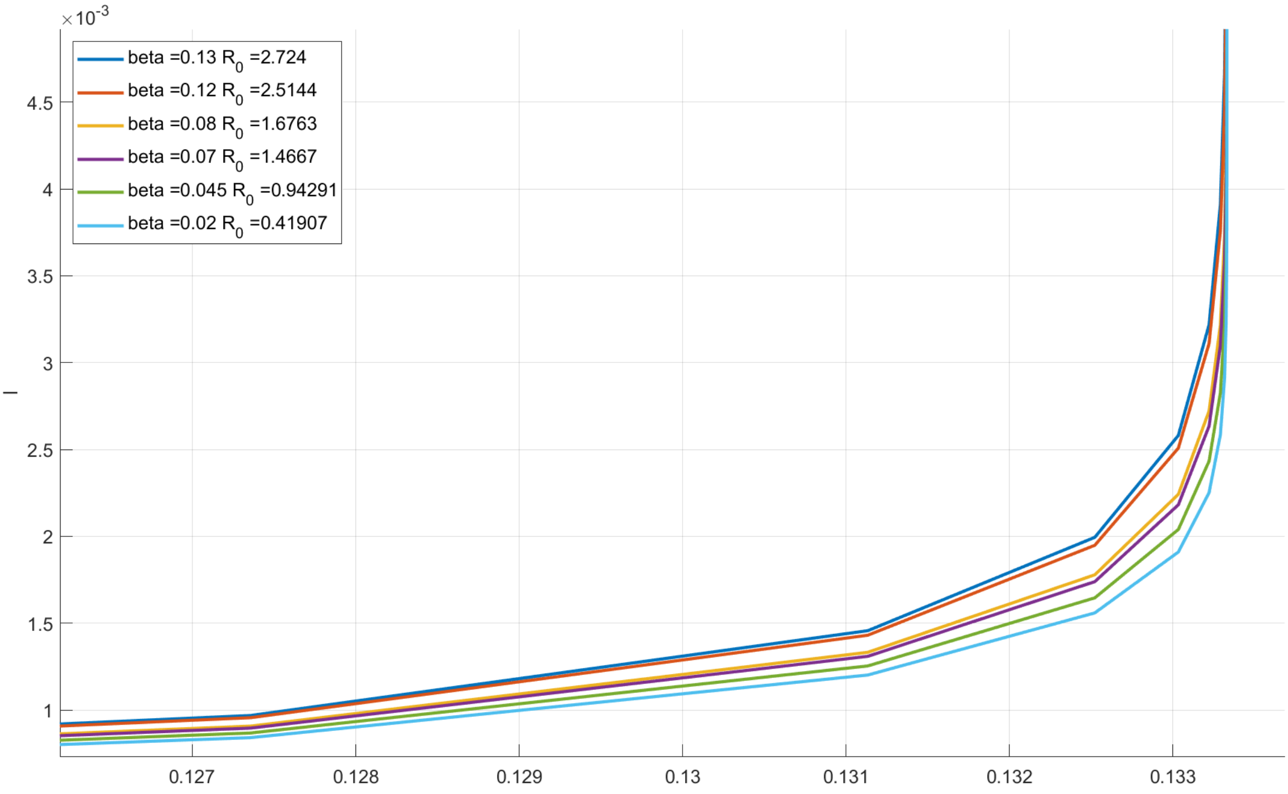


Fig. 8
$B = 0.000055, \epsilon = 0.047619, \gamma = 0.047619, P = 0.003, T = 0.000054, \Lambda = 0.13333, \delta_1 = 0.000023, \delta_2 = 0.000083$
$S(0) = 1, A(0) = 0.013333, I(0) = 0.000013, Q(0) = 0.0133, R(0) = 6.1556e - 06$

4 Conclusion

The model developed in this article is suited to the present scenario of COVID-19 in Odisha (India). The analytical and numerical interpretations of results are both in good agreements. The stability behaviour of the disease is analysed using different theorems that are supported by numerical simulation and graphs. It is found that the stability is characterised by migrant workers of the state. The absence of quarantine leads the system to be unstable. Both endemic and diseases free equilibriums are derived from the equations. The study shows that the system is stable at disease free equilibrium point when basic reproduction number (R_0) is less than one and is unstable for R_0 greater than one which persist to endemic or pandemic. Routh-Hurtwz condition is used for showing the stability of the differential equations at disease free and endemic equilibrium points. The endemic of disease is felt for certain period of time but global stability is achieved in long terms as per Dulac's criteria. The investigation done in this paper shows that the prevalence of COVID-19 will remain nearly 250 to 300 days in Odisha as for as the infected migrants would have been entering to the state as per the current trends. So, in order to reduce the spread of the disease, it is suggested that the proper screening of immigrants, more testing of susceptible as well as contact tracing of infectives is required in addition to the controlling technique quarantine policy.Many researchers as well as our investigation have forecasted the long term persistence of COVID-19 globally. So, it is suggested to survive with upliftment of socio-economy activities in addition to management of disease using all precautionary measures like social distancing, using mask, lockdown/ shutdown/ containment rules, hand washing, sanitization, cleanliness with the existing health care facilities and following the guidelines of world health organisation, otherwise there would create another devastation of economy. In the future scope of study, this investigation could be extended to other states of India as well as world. Other relevant parameters like saturated incidence, age structured may be considered. Also, this study may include exposed compartment and double quarantine classes. Any other approaches for stability behaviours may be employed and other epidemic model is encouraged to adopt in this problem.

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DECLERATION

1 Available of data and materials:

https://www.worldmeters.info
https:// www.covid19 india.org
https:// covid19.odisha.gov.in
https://www.who.int
https://health.odisha.gov.in
https://india.mohfw.gov.in
https//www.wikipedia
www.google.com

2 Competing interests:

The authors declare that we have no known competing interests or personal relationships that could have appeared to influence the work reported in this paper.
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YERRA SANKAR RAO, Yerra Shankar Rao

JANGYADATTA BEHERA, Jangyadatta Behera

3 Funding: No funding agency available for this research.

4 Authors' contributions:

This work is carried out in collaboration of all authors of this research article. Author Aswin Kumar Rauta have designed the investigation of the work presented in this article, wrote the first draft of manuscript, interpreted the result, verified the accuracy and validation of the result. Author Yerra Shankar Rao have performed the mathematical formulation, found the analytical solutions and managed the literature search. Author Jangyadatta Behera have devised the methodology, done numerical simulation and plotted the graphs. All authors have read and approved the final manuscript for submission.

5 Acknowledgements: Not applicable.

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Figures

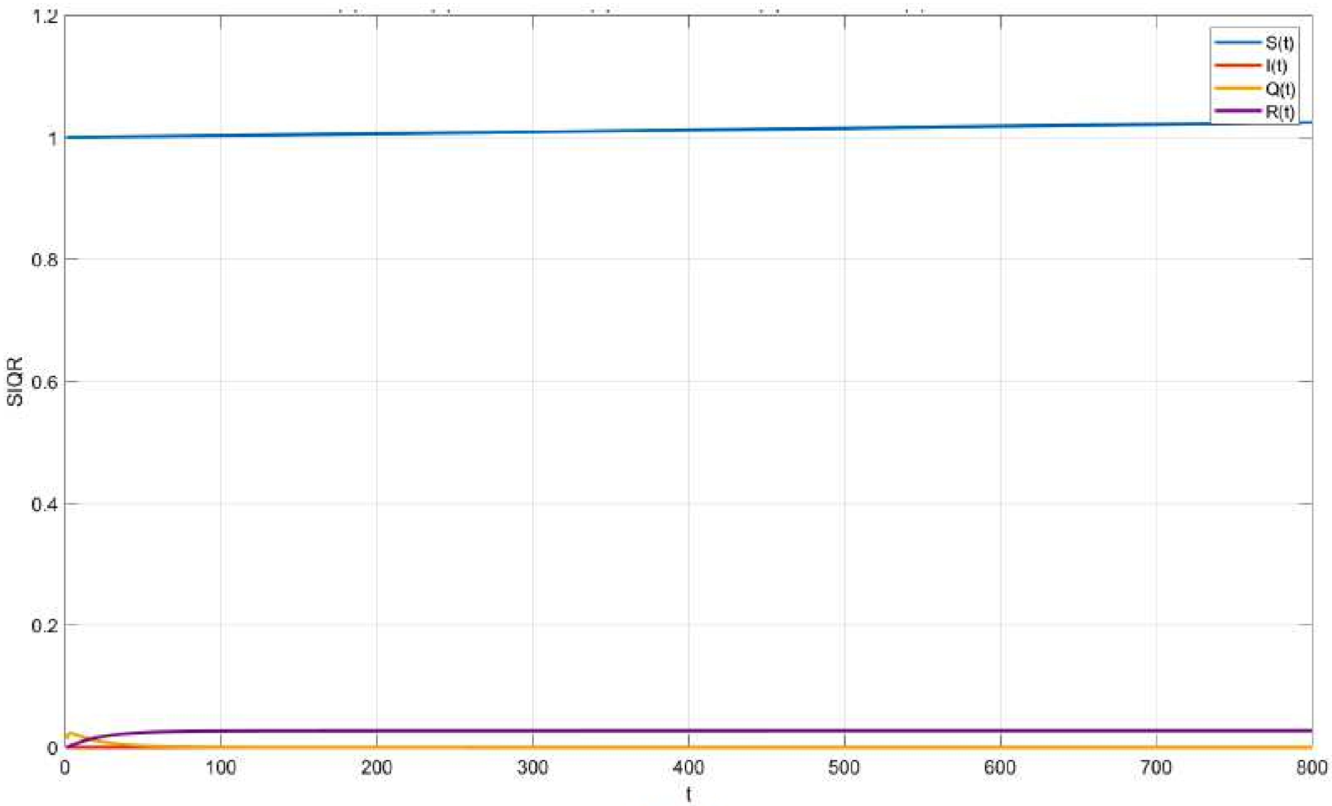

Fig. 1

$B = 0.000055, R_0 = 0.943, \epsilon = 0.047619, \gamma = 0.047619, \beta = 0.045, P = 0.003, T = 0.000054, \delta_1 = 0.000023, \delta_2 = 0.000083$

$S(0) = 1, A(0) = 0.013333, I(0) = 0.000013, Q(0) = 0.0133, R(0) = 6.1556e - 06$

Figure 1

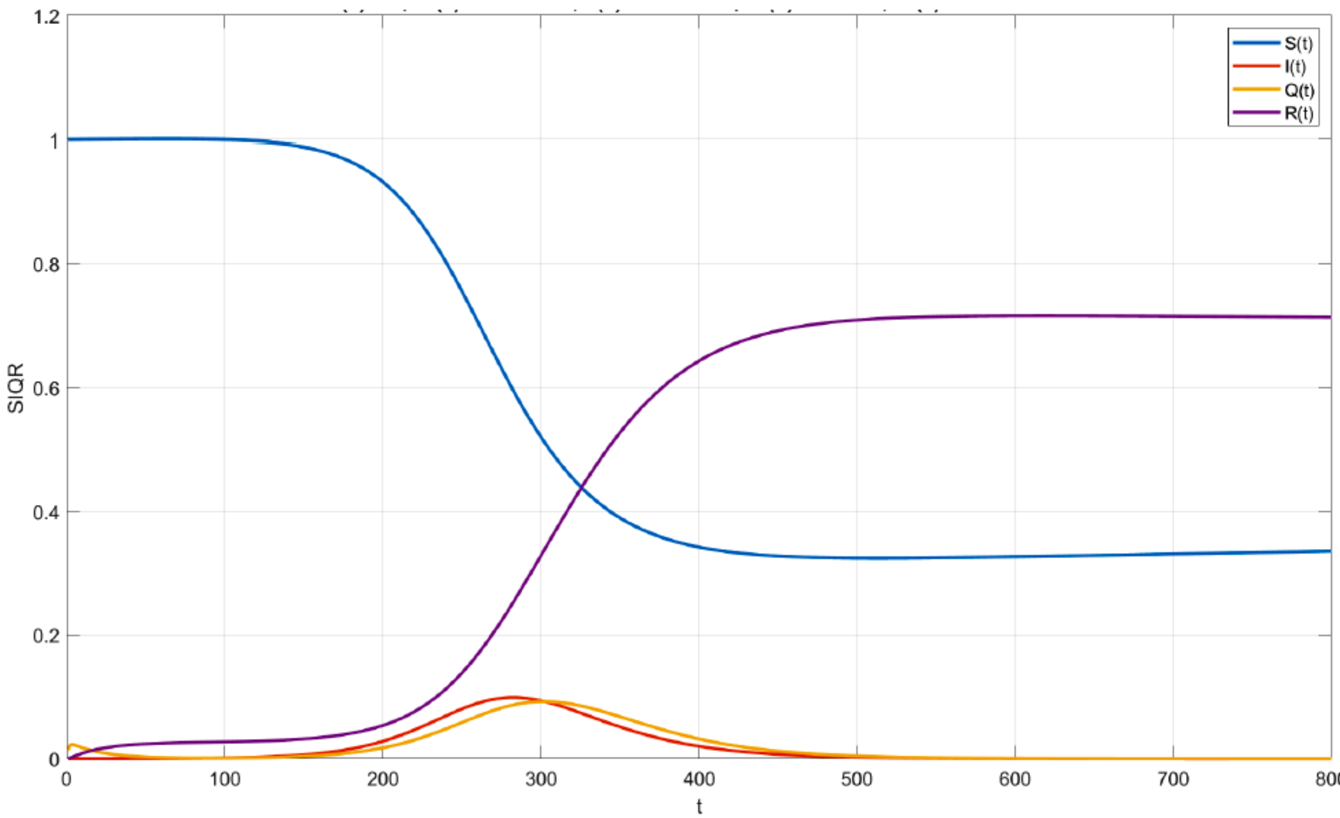

Fig. 2

$B = 0.000055, R_0 = 1.68, \epsilon = 0.047619, \gamma = 0.047619, \beta = 0.08, P = 0.003, T = 0.000054, \delta_1 = 0.000023, \delta_2 = 0.000083$

$S(0) = 1, A(0) = 0.013333, I(0) = 0.000013, Q(0) = 0.0133, R(0) = 6.1556e-06$

Figure 2

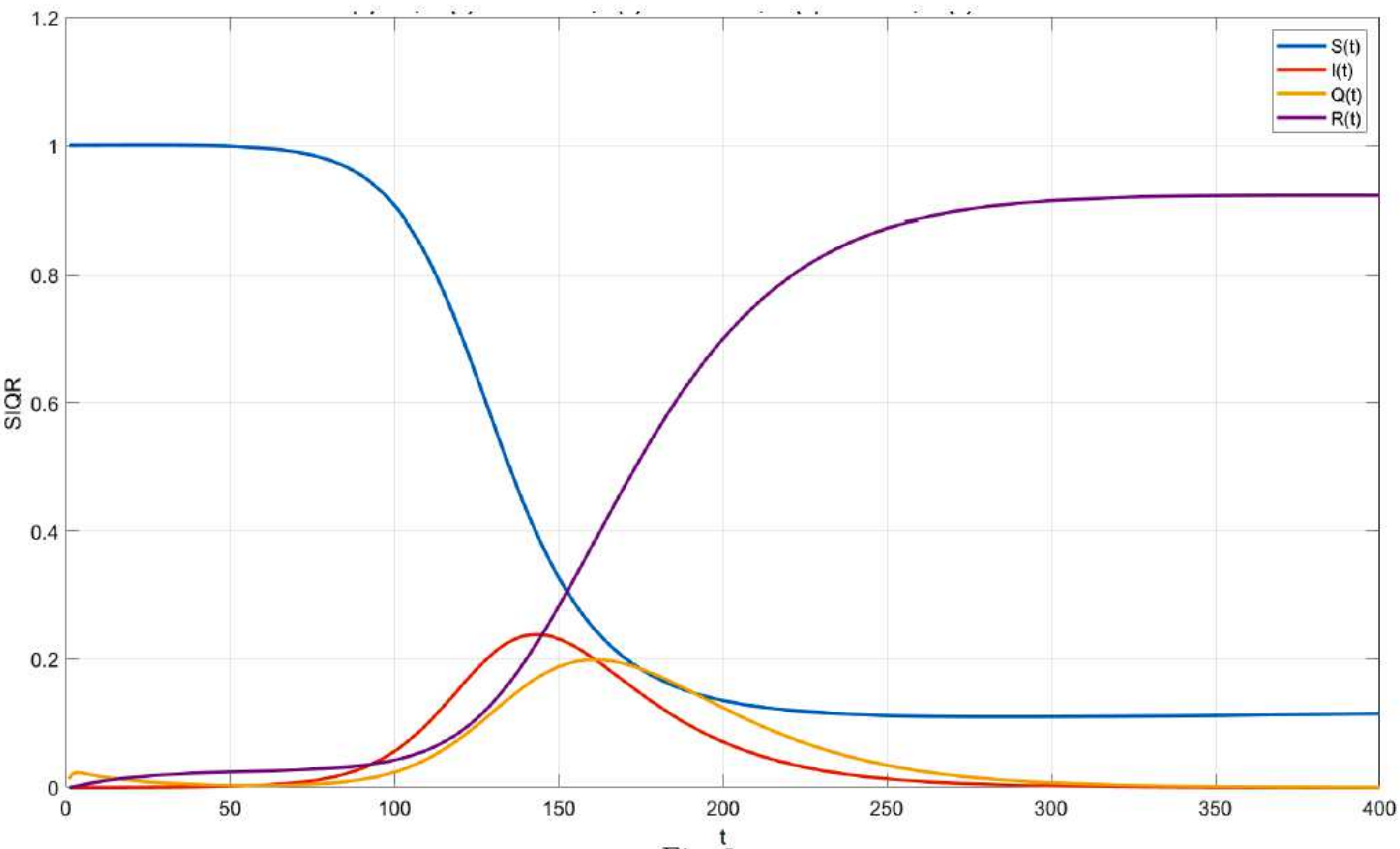

Fig. 3

$B = 0.000055, R_0 = 2.51, \epsilon = 0.047619, \gamma = 0.047619, \beta = 0.12, P = 0.003, T = 0.000054, \delta_1 = 0.000023, \delta_2 = 0.000083$

$S(0) = 1, A(0) = 0.013333, I(0) = 0.000013, Q(0) = 0.0133, R(0) = 6.1556e-06$

Figure 3

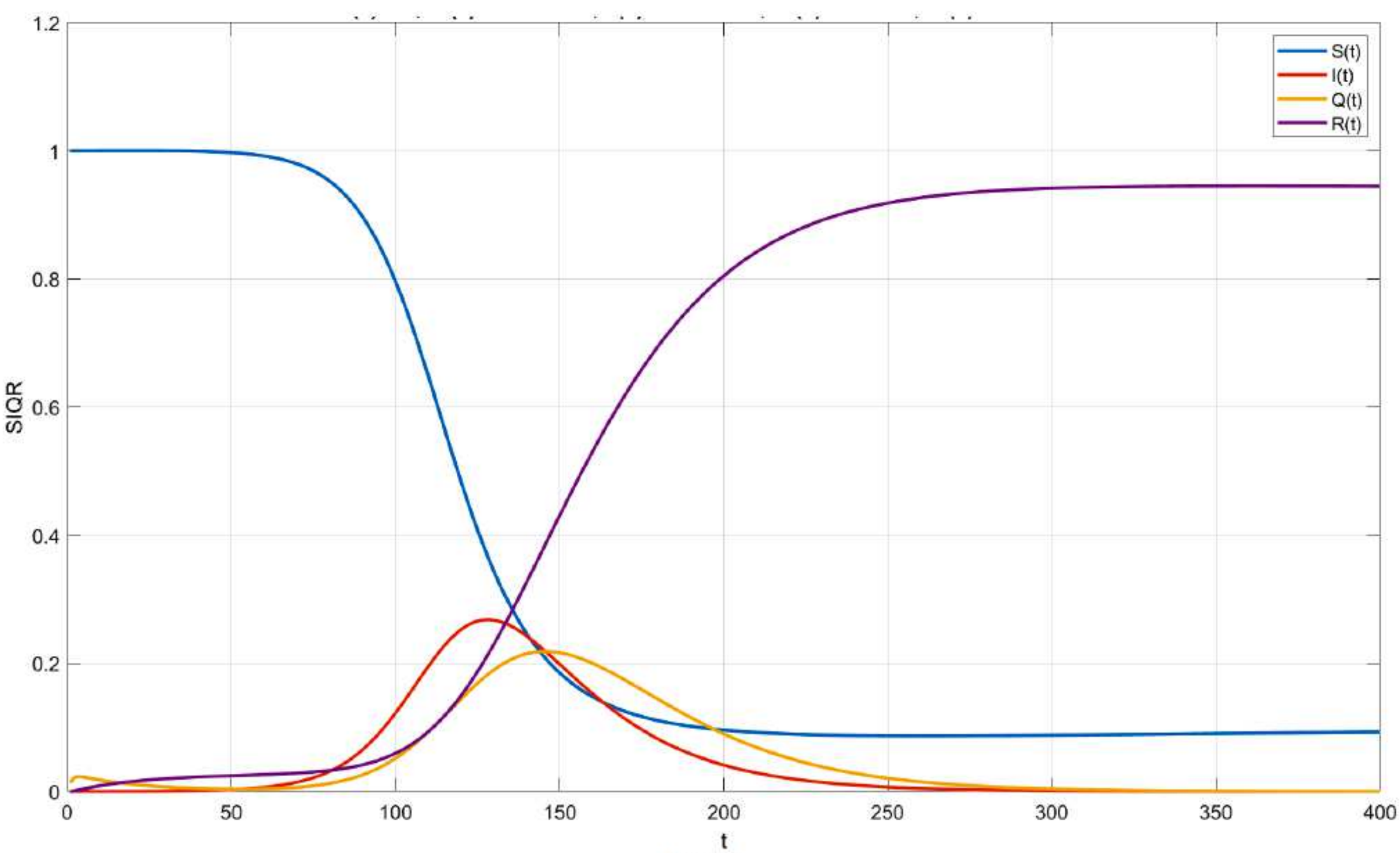

Fig. 4

$B = 0.000055, R_0 = 2.72, \epsilon = 0.047619, \gamma = 0.047619, \beta = 0.13, P = 0.003, T = 0.000054, \delta_1 = 0.000023, \delta_2 = 0.000083$

$S(0) = 1, A(0) = 0.013333, I(0) = 0.000013, Q(0) = 0.0133, R(0) = 6.1556e - 06$

Figure 4

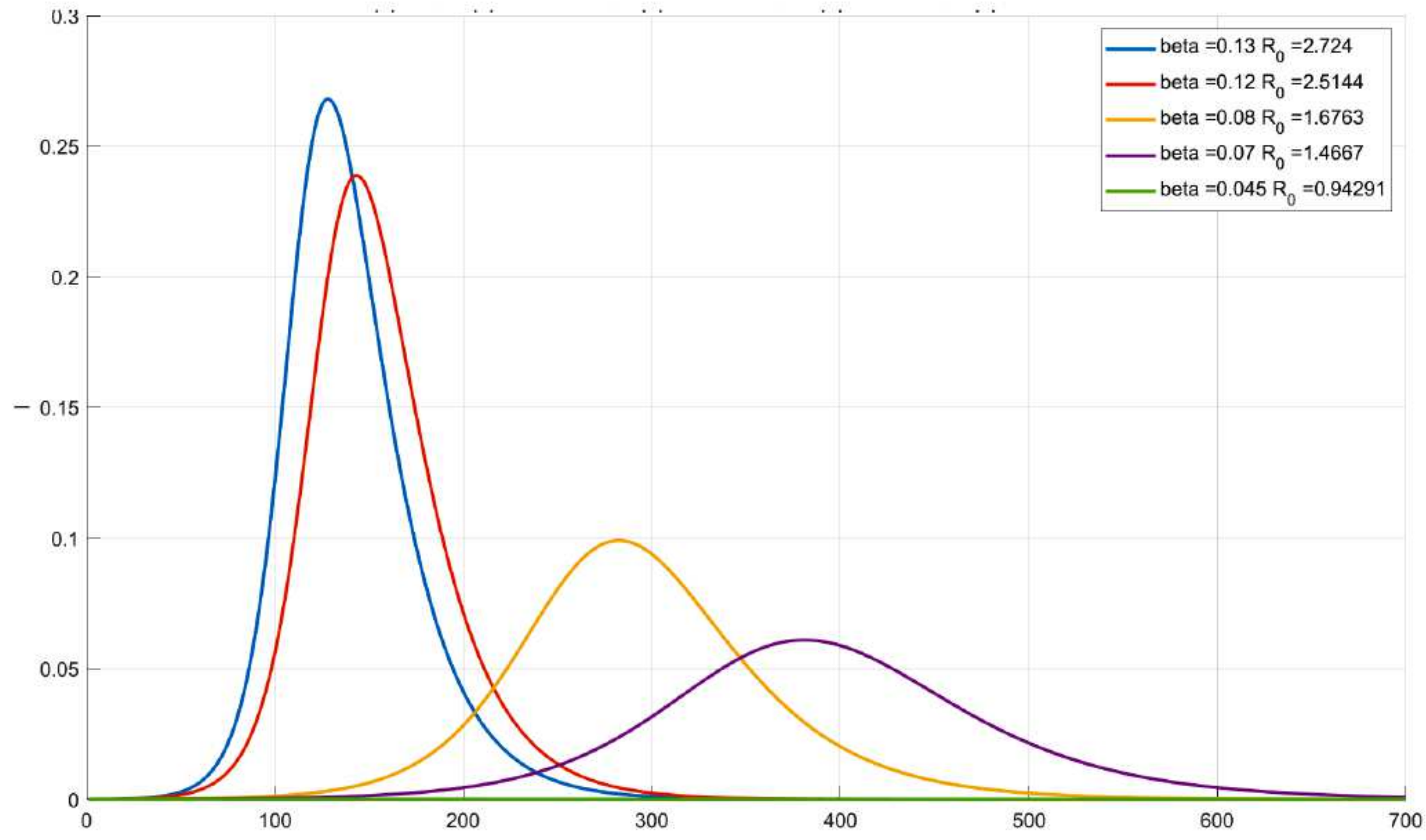

Fig. 5

$B = 0.000055, \epsilon = 0.047619, \gamma = 0.047619, P = 0.003, T = 0.000054, \delta_1 = 0.000023, \delta_2 = 0.000083$

$S(0) = 1, A(0) = 0.013333, I(0) = 0.000013, Q(0) = 0.0133, R(0) = 6.1556e - 06$

Figure 5

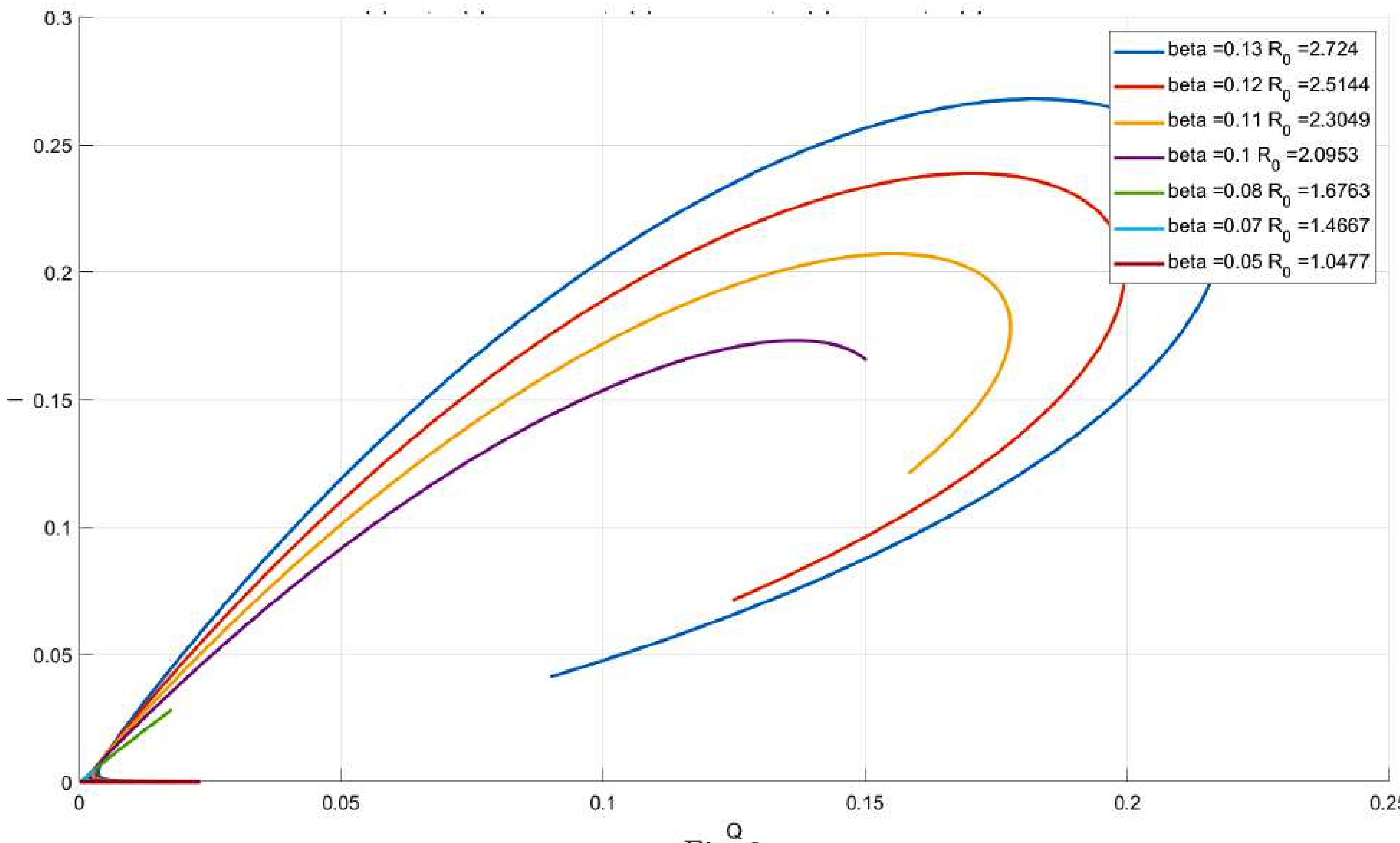

Fig. 6

$$B = 0.000055, \epsilon = 0.047619, \gamma = 0.047619, P = 0.003, T = 0.000054, \delta_1 = 0.000023, \delta_2 = 0.000083$$
$$S(0) = 1, A(0) = 0.013333, I(0) = 0.000013, Q(0) = 0.0133, R(0) = 6.1556e - 06$$

Figure 6

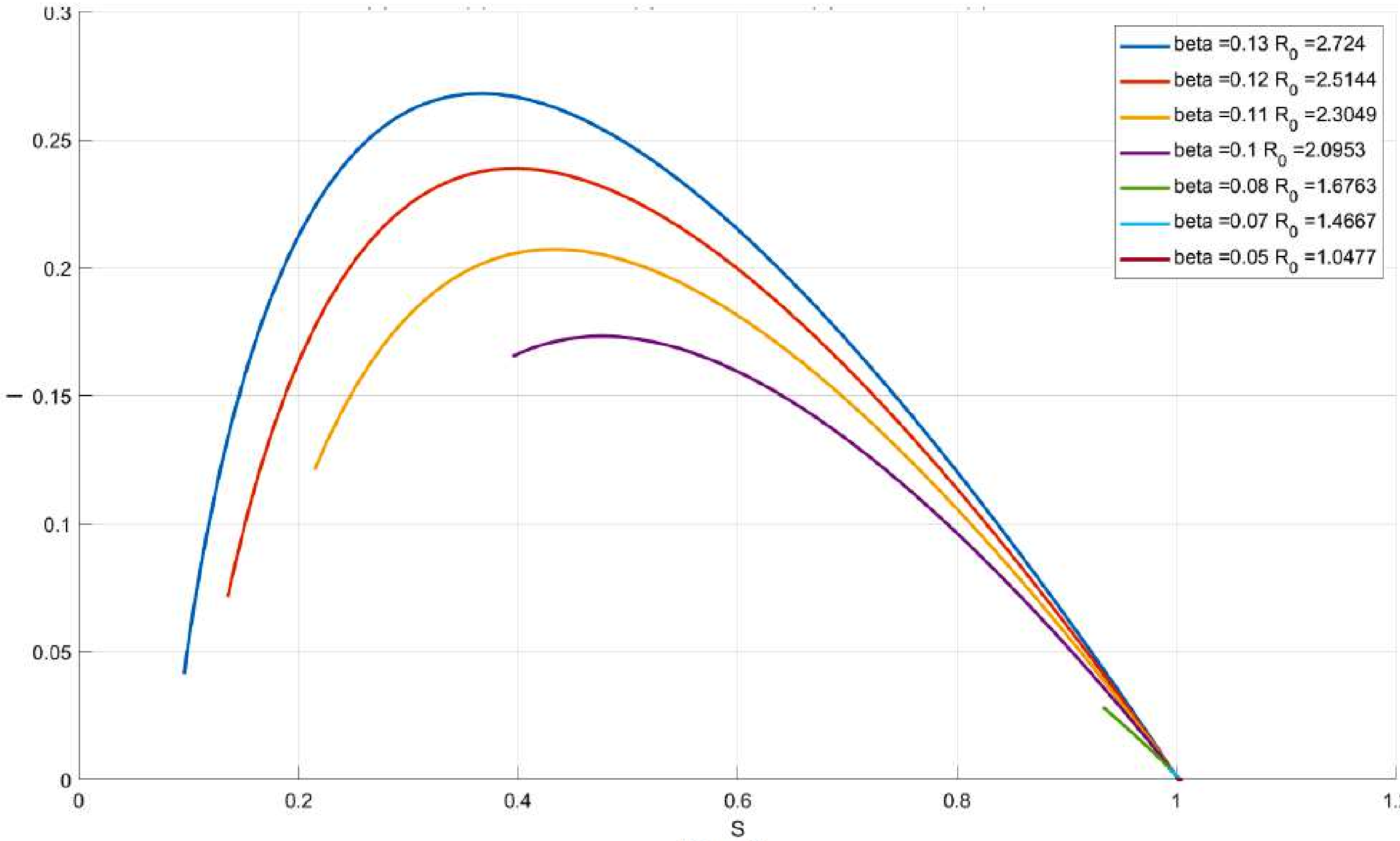

Fig. 7

$$B = 0.000055, \epsilon = 0.047619, \gamma = 0.047619, P = 0.003, T = 0.000054, \delta_1 = 0.000023, \delta_2 = 0.000083$$
$$S(0) = 1, A(0) = 0.013333, I(0) = 0.000013, Q(0) = 0.0133, R(0) = 6.1556e - 06$$

Figure 7

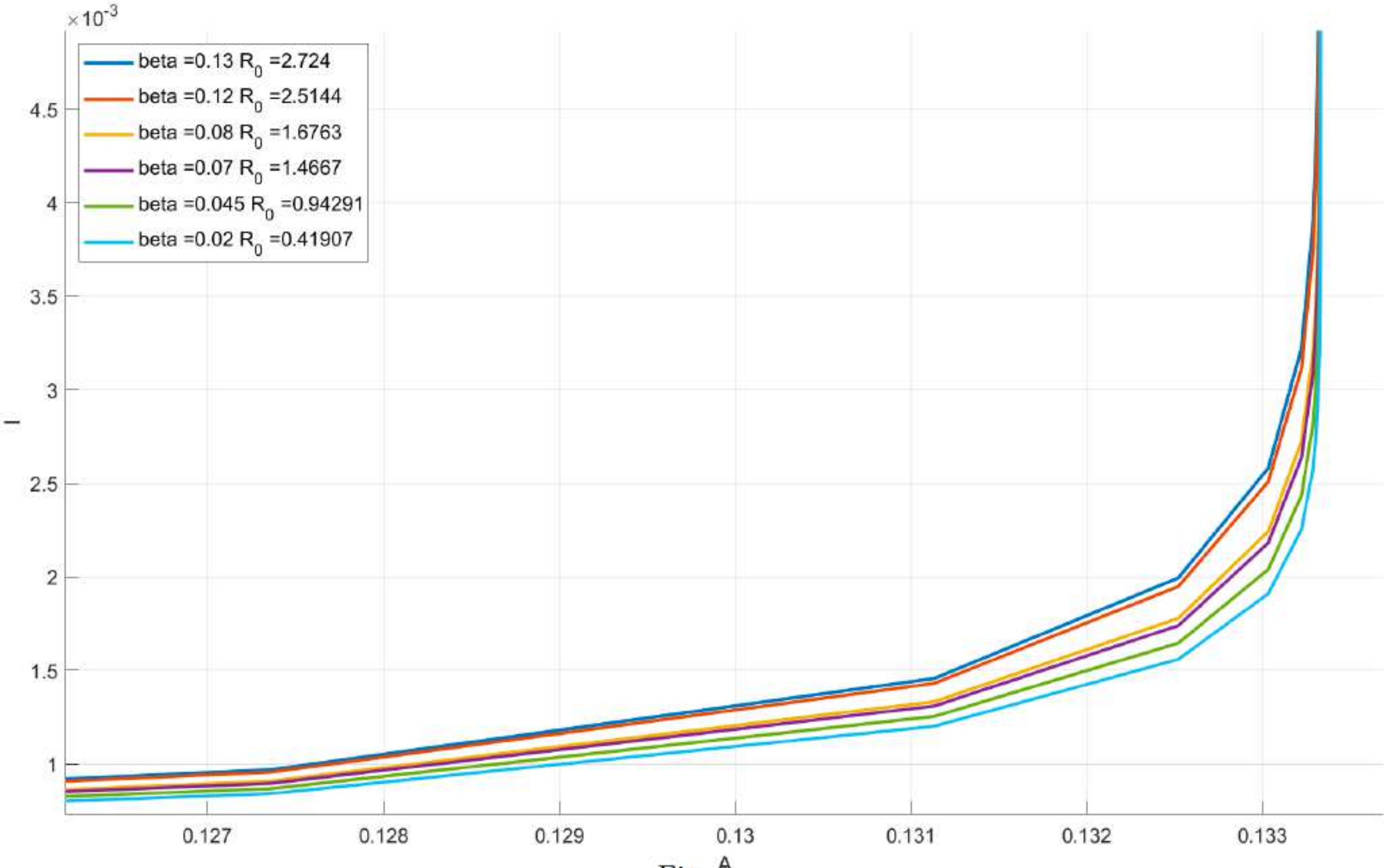

Fig. 8

$B = 0.000055, \epsilon = 0.047619, \gamma = 0.047619, P = 0.003, T = 0.000054, \Lambda = 0.13333, \delta_1 = 0.000023, \delta_2 = 0.000083$

$S(0) = 1, A(0) = 0.013333, I(0) = 0.000013, Q(0) = 0.0133, R(0) = 6.1556e - 06$

Figure 8