This study aims to analyse the effectiveness of the lockdown measure taken to control the transmission of COVID-19 in India by examining the peak of the epidemic pre and post the adoption of stringent lockdown from 25 March 2020. Susceptible-exposed-infectious-recovered (SEIR) model has been developed to trace the peak of the outbreak. The study suggests that with the implementation of lockdown the peak of epidemic in India has delayed by two and a half month. Before lockdown peak was examined in end of May 2020 but post lockdown, it is expected to arrive in mid-August 2020. Thus lockdown measures has delayed the arrival of peak of epidemic which would be helpful in preparing the healthcare system in advance, to tackle worst situation if arises in future.

**KEYWORDS**

coronavirus, mitigation, pandemic, SEIR model

**JEL CLASSIFICATION**

C6; G12; I18

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**INTRODUCTION**

For the first time, world knew about the outbreak of novel Coronavirus disease on December 31, 2019 when China reported WHO about growing cases of pneumonia, the cause of which was unknown to them in Wuhan city in Hubei province. In no time the disease spread to other provinces in China and also to rest of the world. This virus was found to be similar to Severe Acute Respiratory Syndrome (SARS) and Middle East Respiratory Syndrome (MERS) and it has two fatal characteristics, its fatality rate is 3-30 times more than seasonal influenza, and it is 10 times more transmissible than SARS (WHO, 2020a, 2020b; Wilson et al., 2020). Realising the severity of the disease, WHO declared it a global health emergency on 30 January 2020 and a pandemic on 11 March 2020. According to WHO, as of 6 July 2020 globally, more than 216 countries have been affected and 532,340 people lost their lives due to this disease. Prediction of a mathematical modelling group at Imperial College suggests that by the end of the pandemic 7 billion or roughly 89% of the global population will get affected by it and 40 million people will experience fatality.

India reported its first case on 30 January 2020 and till now there are 259,557 active cases and 20,160 deaths. The pandemic hit India when the healthcare system and the economy of India are in vulnerable condition and the country is not well equipped to handle this crisis. According to National Health Profile (Central Bureau of Health Intelligence, 2019) in India, for 10,926 persons there is only one allopathic doctor and for serving 1.3 billion of huge population only 25,778 government hospitals with 7,13,986 beds. To manage the epidemics and natural disaster, the allocation in budget has never exceeded 100 crores and the budget estimate for health specific disaster management in 2018–2019 is 16.85 crore, half to that of year 2016–2017 budget estimate. This is a plausible reason why India is declared more vulnerable to epidemic than China and Italy where currently death toll is highest by Global Health Security Index, 2019 (Mint, 30 March 2020). Apart from healthcare system, Indian economy is also not ready to digest the shock from both the demand and supply side when it is already struggling with demand deficiencies (Subramanian & Felman, 2019). Economic growth of the country fell to 4.7% in 2019. Majority of the workforce in India is employed in informal sector. So India, having a vast informal sector is suffering in this pandemic due to job losses and disruption in livelihood. The unavailability of clinically approved drug and vaccine for it has made the situation more difficult for countries across the world.
They have no other options than to rely on non-pharmacological measures like spreading knowledge about the disease, its symptoms and precautionary measures to be taken among people, contact tracing and quarantining infected persons, social distancing and lockdown. The government of India also adopted these measures and announced lockdown for the first time on 24th March for 6 weeks and till now complete unlock has not been permitted by the government. The ambiguous nature of the disease is not easily traceable. Scholars worldwide have attempted to study it using mathematical modelling. Mathematical simulation techniques are very helpful while dealing with epidemics since, it gives a foresight of the disease and fixing of its optimum level. It also gives an insight on how many people will be in the trap of it? And also about the effectiveness of the policy measures taken to combat it. Thus, due to the appropriateness of mathematical simulation approach we have also tried to develop susceptible-exposed-infectious-recovered (SEIR) type epidemiological model to study the effectiveness of lockdown measure taken in India.

The rest of the paper is organised as follows. Section 2 deals with what literature talks about this issue. Section 3 gives an overview of the developed model. Section 4 describes the findings of this study and Section 5 presents the concluding remarks.

2 REVIEW OF LITERATURE

From the very beginning of the outbreak the nature, severity, mitigation measures and their effectiveness and economic impacts has gained the concern of scholars worldwide. Li et al. (2020) studied the first 425 cases of COVID-19 in Wuhan, China to analyse the characteristics of the disease and found its link with Hunan seafood wholesale market. They also found the evidence of human to human transmission. Later on the severity of the disease was revealed by Read et al. (2020). They found the mitigation and control of the transmission of this virus very difficult because of its higher reproductive number against other coronaviruses. Wu et al. (2020) also supported the severity of this virus and suggested to take immediate mitigation and containment measures to stop its rapid transmission. Scholars have also focused upon the effectiveness of such measures in their study. Ferguson et al. (2020) has emphasised that combination of containment measures like isolation and home quarantine if continuously done for 3 months, can reduce death by 31% as compared to taking no such actions.

In the context of India, Mandal et al. (2020) has initiated the modelling of interventions taken to minimise the transmission rate of the virus in India. In this study, they have predicted that if 90% of the asymptomatic persons are detected then there are chances that average time of epidemic will also get delayed by 20 days. Ghosh et al. (2020) and Mukhopadhyay and Chakraborty (2020) has suggested to combine detection measures with social distancing to tackle the situation effectively. Bholo et al. (2020) in their study has highlighted the importance of hygiene, improving immunity and social distancing measures and according to them these measures can help in flattening the epidemic curve. Bulchandani et al. (2020) has proposed contact tracing as an effective tool and has introduced a term ‘Digital herd immunity’ for it. For lockdown measures scholars opined that it has the potential of slowing down the increasing rate of transmission but it is not as effective to eradicate the disease completely (Pant et al., 2020; Paul et al., 2020). These mitigation measures have their intense effect on the global economy (Ozili & Arun, 2020) and it is the marginalised section of the society which has got worst affected and will have to bear this burden in long run also (Ataguba et al., 2011).

Thus in the light of the whole literature, the trade-off between these interventions and hampering economic activities is well understood. So, in order to take informed and balanced steps in future, it is very necessary to analyse the effectiveness of these measures, especially the lockdown measure which has greater potential to harm the economy. With this spirit, this study makes an attempt to investigate the efficacy of lockdown measure taken in India by comparing the peak of the epidemic pre and post intervention.

3 PROPOSED MODEL

We have used susceptible-exposed-infectious-recovered (SEIR) model to study the nature and magnitude of the pandemic (COVID 19). It is a type of compartmental model used in studying about infectious diseases. The structure of the model is represented through Figure 1.

This model divides the whole population into four compartments: susceptible, exposed, infectious and recovered where, susceptible persons are those that can potentially become infected. In our case, whole population falls into this group. People come under the exposed category when they have exposure with the virus but they are not yet infectious. Infectious people have the potential to transmit the virus to others and recovered people are those who have been recovered after getting affected by the virus. The parameters of the model $\beta$, $\gamma$ and $\delta$ are explained as follows:

$\beta = \frac{1}{\text{average period an infectious person makes an infecting contact}}$ 

$\gamma = \frac{1}{\text{average period of infectiousness}}$ 

$\delta = \frac{R}{T} \times \text{fraction of the infectious group that will recover}$

![SEIR model](image)

FIGURE 1 SEIR model
\[ \gamma = \text{Rate of infected individuals becoming infectious} \]
\[ \gamma = \frac{1}{\text{average duration of incubation}} \]

Further, the model is based upon certain assumptions like:

**Assumption 1.** \( S + E + I + R = N = \text{Total population, that is, the total number of people who are susceptible, exposed, infected and recovered if added should be equal to total population.} \)

**Assumption 2.** \( s + e + i + r = 1 \) where, \( s \), \( e \), \( i \) and \( r \) are the share of population that is susceptible, exposed, infected and recovered from the virus, respectively.

**Assumption 3.** If a person has recovered, then there is no chance of him or her to be infected again.

**Assumption 4.** Natural birth and death will balance each other.

**Assumption 5.** International migration has not been considered, thus the population will be taken as constant.

Given these four variables \( (s, e, i, r) \), three parameters \( (\beta, \gamma, \text{and } \delta) \) and aforementioned assumptions, this model can be represented through the following differential equations:

\[
\begin{align*}
\frac{ds}{dt} &= -\beta s(t) i(t) \\
\frac{de}{dt} &= \beta s(t) i(t) - \delta e(t) \\
\frac{di}{dt} &= \delta e(t) - \gamma i(t) \\
\frac{dr}{dt} &= \gamma i(t)
\end{align*}
\]

These four equations are nonlinear in nature and can be solved to get solutions for:

\[
\begin{align*}
s(t) &= s(t-1) - \beta s(t-1) i(t-1) \\
e(t) &= e(t-1) + \beta s(t-1) i(t-1) - \delta e(t-1) \\
i(t) &= i(t-1) + \delta e(t-1) - \gamma i(t-1) \\
r(t) &= r(t-1) + \gamma i(t-1)
\end{align*}
\]

With \( \Delta(t) = 1 \). These formula can be used to get the value of \( s \), \( e \), \( i \) and \( r \) over time.

Given the SEIR model, we reviewed the existing literature on Covid-19 in the context of India and assigned the value of \( \beta \), \( \gamma \) and \( \delta \). Simulation studies of some researchers (Jakhar et al., 2020) provide reference for such parameters. Assuming reproduction rate of around 1.5, that is, the number of the number of secondary infections each infected individual produces and considering sharp increase in positive cases in India we chose \( \beta \) to be .3 and \( \delta \) to be 0.1 where both parameters are defined earlier. Further, the value for \( \gamma \) is chosen to be 0.2 since the average period of infectiousness is assumed to be 5 days which is in consonance with current global scenario.

We have compiled the data from official website of Ministry of Health and Family Welfare, Government of India (https://www.mohfw.gov.in) and data is considered as of 7 July, 2020.

## 4 FINDINGS

After analysing the situation for pre and post lockdown phases in India, we have found that before the announcement of the stringent lockdown on 24 March 2020, the occurrence of peak of the epidemic would have arrived by the month of May 2020 (Figure 2) but after the imposition of nationwide complete lock down this peak has shifted to mid-August 2020 (Figure 3).

![SEIR Model](Figure 2) Pre lockdown epidemic situation

![SEIR Model](Figure 3) Post lockdown epidemic situation
Thus lockdown in India has delayed the epidemic by almost two and a half months. Further, we found the total number of infected people will reach the peak with an astounding value of around 150 million cases by the second half of August month. Population size is shown in vertical lines of both graphs and dates are plotted in horizontal axes. To assess the fatalities with current rate of around 2.6% in India, we calculated using same parameters mentioned earlier. Our finding from the analysis suggests that fatalities will be confined to a smaller size of near about 1 lakh people by the mid-August in India.

5 | CONCLUSION AND DISCUSSION

This study concludes that the lockdown measures taken in India seems to be helpful or effective in delaying the peak of epidemic by two and a half month. Thus, these measures are very helpful in buying time for preparedness of healthcare system. But there is also a bitter side of it which cannot be ignored. The economic activity which has got hampered due to these social distancing and lockdown measures is a potential threat for any economy from both the demand and supply side. According to IMF, there is high possibility that it will lead to global recession in 2020 (Elliott, 2020). Countries falling in high, medium and low income groups all have got hardly hit in this pandemic. On the one hand, they are incurring direct costs due to deaths, healthcare and uncertainty while on the other hand they also have to bear indirect cost like loss in productivity and economic growth due to mitigation measures. Economies that highly rely on exports, tourism and remittances for their revenue has got worst affected (Hausmann, 2020).

To revive the economy and to increase the capacity of public healthcare system scholars are suggesting to reorient the government expenditures, transferring funds directly in hands of those who have lost their jobs due to nationwide lockdown, encourage investors by tax rebates and direct lending and also to revive rural enterprises which have greater capacity to accommodate these informal workers by easing availability of credits. Above all the need of the hour is to establish a balance between the tasks of minimising the health risk due to pandemic and revival of the economy by adopting appropriate type and level of containment and mitigation measures.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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