TREND ANALYSIS, MODELLING AND IMPACT ASSESSMENT OF COVID-19 IN NEPAL

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ABSTRACT

With the continued global expansion of COVID-19 transmission and the mounting threat of the disease, the timely analysis of its trend in Nepal and forecasting the potential situation in the country has been deemed necessary. We analyzed the trend, modelling, and impact assessment of COVID-19 cases of Nepal from 23rd January 2020 to 30th April 2020 to portray the scenario of COVID-19 during the first phase of lockdown. Exponential smoothing state-space and autoregressive integrated moving average (ARIMA) models were constructed to forecast the cases. Susceptible-infectious-recovered (SIR) model was fit to estimate the basic reproduction number (Ro) of COVID-19 in Nepal. There has been an increase in the number of cases but the overall growth in COVID-19 was not high. Statistical modelling has shown that COVID-19 cases may continue to increase exponentially in Nepal. The basic reproduction number in Nepal being maintained at a low level of 1.08 for the period of 23rd January to 30th April 2020 is an indication of the effectiveness of lockdown in containing the COVID-19 spread. The models further suggest that COVID-19 might persist until December 2020 with peak cases in August 2020. On the other hand, a basic reproduction number of 1.25 was computed for total cases reported for the 22nd March to 30th April 2020 period implying that COVID-19 may remain for at least a year in the country. Thus, maintaining social distance and stay home policy with an implementation of strict lockdown in the COVID-19 affected district is highly recommended.

Keywords: Autoregressive integrated moving average, COVID-19, Doubling time, Exponential smoothing, Susceptible-infectious-recovered model

INTRODUCTION

The ongoing Corona Virus Disease 2019 (COVID-19) caused by novel Severe Acute Respiratory Syndrome Coronavirus 2 (SARS CoV-2) was reported to have emerged from Wuhan, Hubei, China in late December 2019, where people in a seafood-wholesale wet market suffered from a mysterious pneumonia (Wu *et al.,* 2020). World Health Organization (WHO) declared the outbreak as public health emergency of international concern on 30th January 2020, announced a new name for this disease as COVID-19 on 11th February 2020 and pandemic on 11th March 2020 (WHO, 2020b). With rapid spread in Europe, America, and Asia, COVID-19 was confirmed globally in 3,090,445 people with 217,769 deaths by 30th April 2020 (WHO, 2020a). The highest infection and death toll have been recorded in the USA followed by countries in Europe, Eastern Mediterranean, South-East Asia, Western Pacific, and least in Africa (WHO, 2020c).

The first case of COVID-19 in Nepal reported in a 32 years old Nepalese male who was admitted to the hospital upon exhibiting mild symptoms, later discharged on 17th January 2020 after improvement in clinical condition was a returnee from Wuhan City on 9th January 2020 (Bastola *et al.,* 2020).

On 24th January 2020, the infection was officially confirmed COVID-19 after reported positive from WHO reference laboratory in Hong Kong (Bastola *et al.,* 2020; MoHP, 2020). Later the second case was confirmed on 23rd March 2020 in a 19 years old female who returned from France via Doha, Qatar (Pun *et al.,* 2020). On 24th March 2020, the Government of Nepal implemented a nationwide lockdown advising residents to stay at home. Until 13th April 2020, the cases in Nepal were reported from the people who recently returned from abroad, and Indian nationals residing in Nepal where the latter case was in majority.

The first case of indigenous transmission confirmed on 4th April 2020 in a 34-year-old woman from Kailali District was a relative of the infected patient who travelled from India (Pun *et al.,* 2020). By the end of the first phase of lockdown of 28th April 2020, 54 cases have been confirmed with documentation of no deaths (MoHP, 2020). COVID-19 has spread in 10 districts of Nepal with Udayapur reported the maximum number of 25 cases.

Considered as the standard laboratory test for the diagnosis of COVID-19 the cases were confirmed by Reverse Transcription Real-Time Polymerase Chain Reaction (RT-PCR) (Paudel *et al.,* 2020; Yip, *et al.,* 2020). Until 30th April 2020, a total of 12,011 RT-PCR tests and 46860 Rapid Diagnostic Test (RDT) were performed in Nepal out of which 57 were tested positive. In consideration of numerous COVID-19 cases being detected in Nepal, it has been essential to let the Nepal Government be prepared for the most predictable upcoming situation to tackle the COVID-19 pandemic. This paper, therefore, assessed the descriptive and trend analysis on the growth of cases, its doubling time, statistical and epidemiological model.

MATERIALS AND METHODS

Data sources

The secondary data from the Ministry of Health and Population (MoHP, 2020), Nepal, Health Emergency Operation Centre, and data from relevant websites related to COVID-19 in Nepal were analyzed. Trend analysis was performed from daily compiled data of 102 days from the last week of January 2020 till the end of April 2020. Major variables associated with the disease; such as demographic variables of the cases, diagnostic tests including RT-PCR and RDT, number of cumulative and daily cases as well as that of recovered, quarantined, and isolated cases were considered. Additionally, analysis of important variables such as cases as percent of PCR tests, doubling time of COVID-19 cases for Nepal was weekly assessed and represented graphically. Finally, different time points were used to develop prediction models while impact assessments have been analyzed using the whole data.
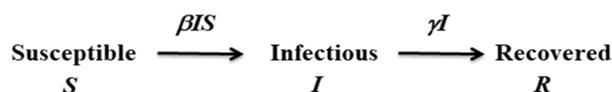
Statistical analysis: ETS and ARIMA models

The exponential smoothing state-space method (which comprises 'Error, Trend, and Seasonal' components in smoothing procedure of an event under consideration; hence named ETS model) which takes information into comprehensive consideration and ARIMA model (Hyndman & Athanasopoulos, 2018) were used to forecast COVID-19 cases for Nepal by fitting in R software using forecast package (Hyndman *et al.,* 2020). We selected the best ETS model and best ARIMA model for 99 days official cumulative COVID-19 cases from 23rd January to 30th April 2020 and forecasted the cases for the next 14 days (1st May – 14th May 2020). An attempt has been made in the direction of epidemiological modelling through application of SIR model (see next section for detail) based upon the suitable parameter values for Nepal.

Mathematical analysis: SIR model

We used the SIR model, a compartmental model where the population is divided into three compartments: susceptible, infectious and recovered. We need two types of rates to move from one compartment to another viz. rate of transmission (β) to move from Susceptible to Infectious compartment and rate of recovery (γ) to move Infectious to Recovered compartment as follows:

$$\textbf{Susceptible} \xrightarrow{\beta IS} \textbf{Infectious} \xrightarrow{\gamma I} \textbf{Recovered}$$
$$S \qquad\qquad I \qquad\qquad R$$

This type of model is a dynamic model as the population in these three compartments changes with each unit of time and this can be modelled using differential equations. The simple SIR model without vital dynamics i.e. births and deaths are modelled as follows:

$$\frac{dS}{dt} = -\frac{\beta IS}{N} \qquad \dots\dots\dots(i)$$

$$\frac{dI}{dt} = \frac{\beta IS}{N} - \gamma I \qquad \dots\dots\dots(ii)$$

$$\frac{dR}{dt} = \gamma I \qquad \dots\dots\dots(iii)$$

Where, S, I, and R were stock of susceptible, infected, and recovered population. Change in S, I, and R with respect to time was computed with an initial value of I = 1 and R = 0 to represent the first COVID-19 case of Nepal on 23rd January 2020. S was taken as 29 million, which is the projected population of Nepal for April 2020. Two SIR models were fitted, first with basic reproduction number (Ro) of 2.5 (global average of COVID-19) and 1.0 (to make COVID-19 endemic) in Nepal.

To solve differential equations (i), (ii), and (iii), we used the Runge-Kutta method available in the "deSolve" package (Soetaert *et al.,* 2010) in R software version 3.5.2. We also fitted the SIR model for the official COVID-19 cases between 23rd January and 30th April as well as between 22nd March and 30th April 2020 and computed Ro for these periods using the Limited Memory-Broyden-Fletcher-Goldfarb-Shanno (LM-BFGS) optimization algorithm in the R software. Since the second COVID-19 case was reported on 23rd March 2020, we also used a period between 22nd March and 30th April 2020 to check the effectiveness of the lockdown started from 24th March 2020 in Nepal. We created the change in the infected compartment for Nepal using these Ro values

and derived the time-based effect of COVID-19 cases for Nepal.

RESULTS

Trend of the cases

From 21st January 2020 till 30th of April 2020, a total of 57 COVID-19 cases have been confirmed in Nepal. The increase in case was slow with only ten cases recorded between 21st March and 10th April, 2020, but due to a sudden sharp rise in new cases in some days, the trend of daily new cases was found erratic and inconsistent. The growth curve of the total cases in Nepal resembles a logistic curve where the total numbers of cases and the curve for active COVID-19 persons have also risen similarly but a dip in active cases has been observed lately (Fig. 1). The number of recoveries has also risen significantly in the recent past two weeks which is a positive sign.
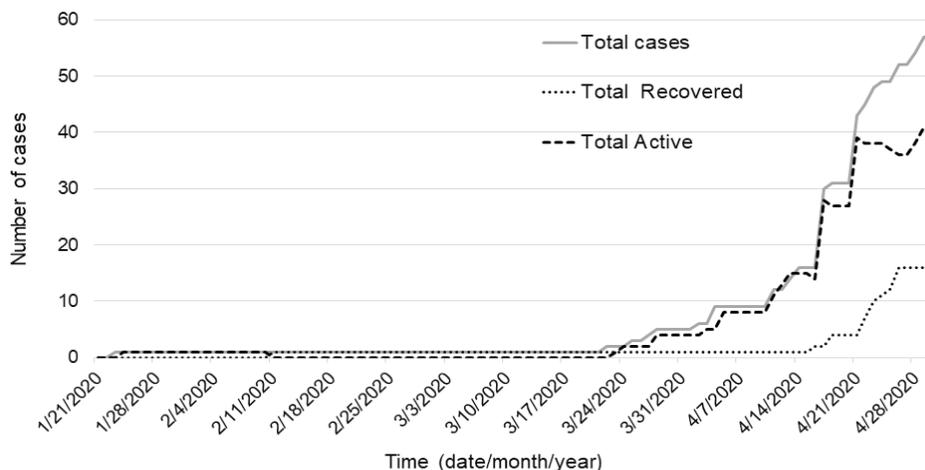

Fig. 1. Trend of active, recovered, and total number of COVD-19 cases with time

In Nepal, males with age between 21- 30 years are found more infected. The highest number of infected male populations may be related to the cases dominated by the male who lived in Bhulke, Triyuga Municipality, Udayapur district, and the person who came in contact with them. The majority of infected belong to the people who entered Nepal from India while some of the infected had a history of travel from other countries such as China, France, UAE, Belgium, UK, and Saudi Arabia (Pun *et al.,* 2020). The percent of cases indicated by RT-PCR tests rapidly decreased as the number of tests increased in the month of February and has remained consistently low between 0.2 to 0.5 % thereafter.

Doubling time of COVID-19 cases in weekly data analysis

Examination of doubling time of the COVID-19 cases in Nepal based upon weekly data analysis showed that there has been an increase in doubling time steadily starting around the third week of March till the second week of April from 3.5 to 14 days with a long period for doubling duration initially from one reported case to two. Thereafter, it dropped sharply followed by an unexpected sudden rise in the cases during the third week of April. After that, it has again increased to around 11 days showing a slowing down of trend of the infected persons. The overall picture shows that there have been ups and downs in the doubling time of the COVID-19 cases in Nepal and is currently around 11 days (Fig. 2).
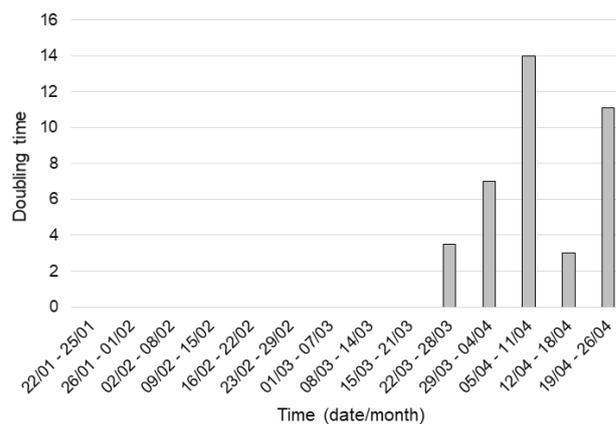

Fig. 2. Doubling time of COVID-19 cases in Nepal (Based upon weekly data analysis from 22nd January 2020 to end of April 2020

Statistical modelling of COVID-19 cases of Nepal

The best ETS state-space model was found to be ETS (M, A, N) for the data i.e. exponential smoothing with **M**ultiplicative **E**rror, **A**dditive **T**rend, and **N**o **S**easonality model. This is equivalent to Holt's linear additive model (Hyndman & Athanasopolus, 2018).
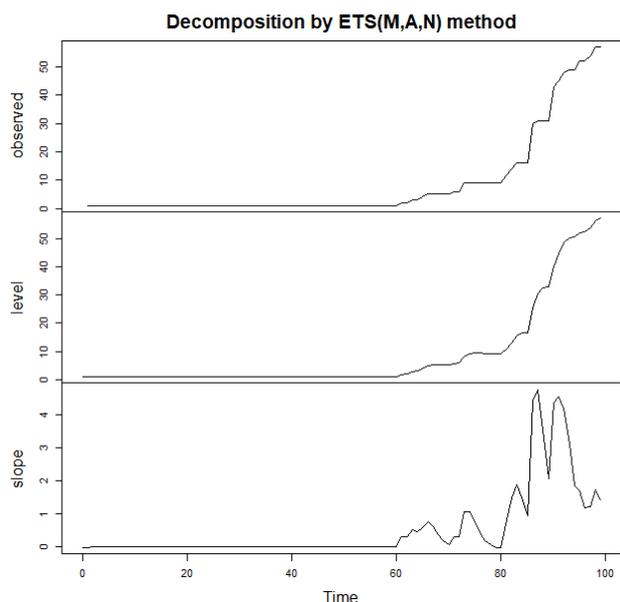
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Decomposition by ETS(M,A,N) method

Fig. 3. ETS decomposition of cumulative COVID-19 cases of Nepal (23rd January – 17th April, 2020)

Forecasted cumulative COVID-19 cases using ETS (M, A, N) model revealed that COVID-19 cases were increasing at the rate of 2 cases per day in Nepal (Table 1). The 95 % confidence interval of the forecasts was very wide, which means that standard errors are high and the precision of the estimation is low.

Thus, forecasted values may not coincide with the official reported values. The cumulative COVID cases in Nepal revealed the increasing trend of COVID-19 cases with wide variation (Fig. 4).
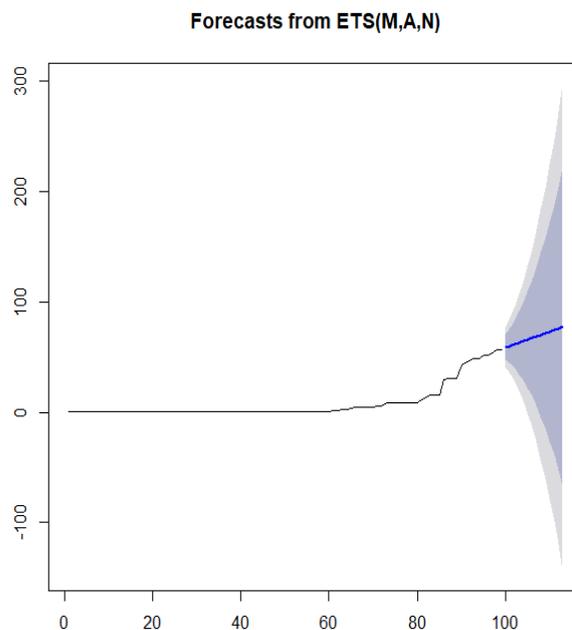
Forecasts from ETS(M,A,N)

Fig. 4. Cumulative COVID-19 cases of Nepal: 23rd January – 1st May, 2020 using ETS (M, A, N) model showing increasing trend

Table 1. Forecasted cumulative COVID-19 cases using ETS (M, A, N) model, Nepal

Date	Day	Forecast	Lo 80	Hi 80	Lo 95	Hi 95
1-May	100	58.81742	47.318412	70.31643	41.231205	76.40364
2-May	101	60.24833	44.396137	76.10053	36.00449	84.49218
3-May	102	61.67925	40.245795	83.1127	28.89961	94.45889
4-May	103	63.11016	35.07717	91.14316	20.2374	105.98293
5-May	104	64.54108	28.996946	100.08521	10.181018	118.90114
6-May	105	65.97199	22.051937	109.89205	-1.197936	133.14192
7-May	106	67.40291	14.253802	120.55201	-13.881634	148.68745
8-May	107	68.83382	5.591121	132.07652	-27.887543	165.55519
9-May	108	70.26474	-3.964673	144.49415	-43.259349	183.78882
10-May	109	71.69565	-14.456318	157.84762	-60.062415	203.45372
11-May	110	73.12657	-25.93925	172.19238	-78.381525	224.63466
12-May	111	74.55748	-38.480945	187.5959	-98.319873	247.43483
13-May	112	75.98839	-52.160735	204.13752	-119.998786	271.97557
14-May	113	77.41931	-67.069942	221.90856	-143.557931	298.39655

Note: The negative values in the table means zero cases.

The best ARIMA model for this 99-day data of Nepal is ARIMA (3,2,1). This means it required two times the difference of the series first to make the data stationary followed by a third-order autoregressive filter and first-order moving average filter to correct the autocorrelation and forecasting error in the data. Forecasted cumulative COVID-19 cases using ARIMA (3,2,1) model shows the forecasts obtained from this model for the next 14-day for Nepal (Table 2). COVID-19 cases increased at 2 cases per day in Nepal (Table 2). The 95 % confidence intervals

were found realistic. However, the forecasts may not coincide with the official reported cases.

Table 2. Forecasted cumulative COVID-19 cases using ARIMA (3,2,1) model, Nepal

Date	Day	Forecast	Lo 80	Hi 80	Lo 95	Hi 95
01-May	100	58.13008	55.92091	60.33926	54.75144	61.50873
02-May	101	59.77956	56.73407	62.82506	55.12188	64.43725
03-May	102	61.90513	58.17988	65.63039	56.20784	67.60242
04-May	103	62.92401	58.52157	67.32645	56.19105	69.65697
05-May	104	64.09565	58.49546	69.69583	55.53091	72.66038
06-May	105	65.56641	58.75999	72.37282	55.15689	75.97592
07-May	106	67.29525	59.33921	75.25128	55.12754	79.46296
08-May	107	68.63131	59.52688	77.73574	54.70728	82.55534
09-May	108	69.91791	59.47234	80.36349	53.94279	85.89304
10-May	109	71.3307	59.46664	83.19476	53.18619	89.47521
11-May	110	72.88073	59.58482	86.17663	52.5464	93.21505
12-May	111	74.3018	59.55531	89.0483	51.74899	96.85462
13-May	112	75.66426	59.37703	91.95149	50.75509	100.57344
14-May	113	77.06874	59.17249	94.96499	49.69879	104.43869

Forecast from ARIMA (3,2,1) model were lower than the official COVID-19 cases of Nepal between 1st and 14th May 2020 (Fig. 5). This means we need other approaches for modelling COVID-19 cases in Nepal.

average incubation period of COVID-19 cases) (Fig. 6). This gave basic reproduction number (Ro) as 0.5/0.2= 2.5, which is the average Ro around the world (Liu *et al.*, 2020).
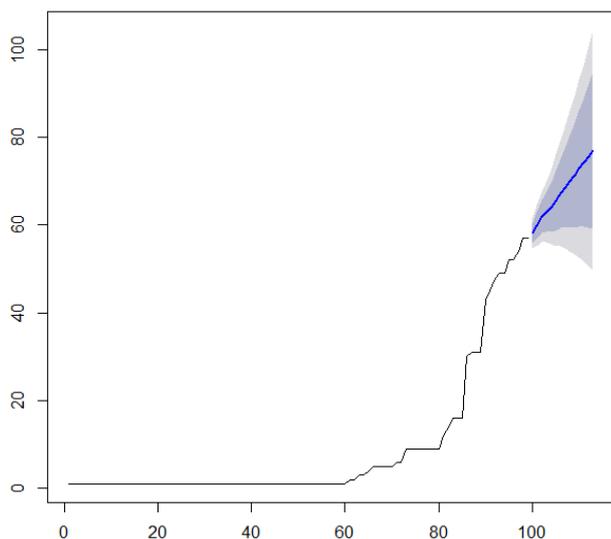

Fig. 5. Cumulative COVID-19 cases of Nepal: 23rd January – 1st May 2020 using ARIMA (3,2,1) model showing increasing trend

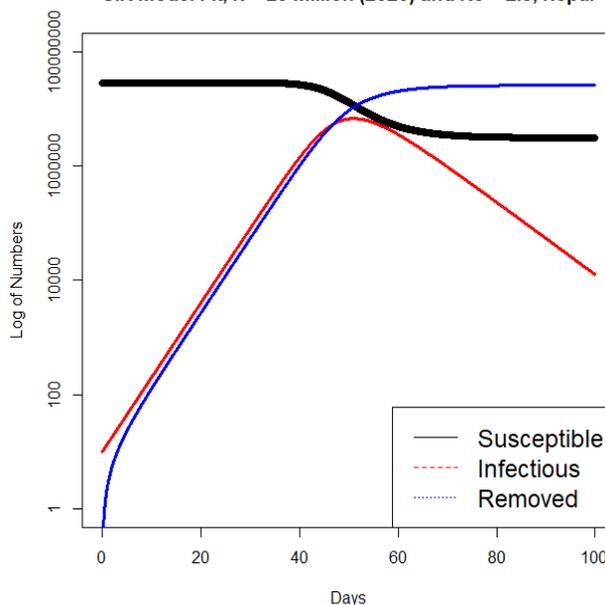**Fig. 6. SIR model with β = 0.5 and γ = 0.2 for N=29,000,000 of Nepal which gave basic reproduction number Ro = 2.5**

Mathematical modelling of COVID-19 cases of Nepal

Scenario 1

Beta = 1/2 = 0.5 per person; Beta = 0.5/29,000,000 = 1.72 x 10^{-8} for Nepal and Gamma = 1/5 = 0.2 (reciprocal of

This SIR model shows that 6770893 persons will be infected around 60 days whereas 38,560 persons will be infected at 100 days since the first case appeared in Nepal.

Scenario 2

Beta= 1/5 = 0.2 per person; Beta= 0.2/29,000,000 = 6.689 x 10^{-9} for Nepal and Gamma= 1/5 = 0.2 (reciprocal of average incubation period of COVID-19 cases) (Fig. 7). This gives basic reproduction number (Ro) as 0.2/0.2= 1.

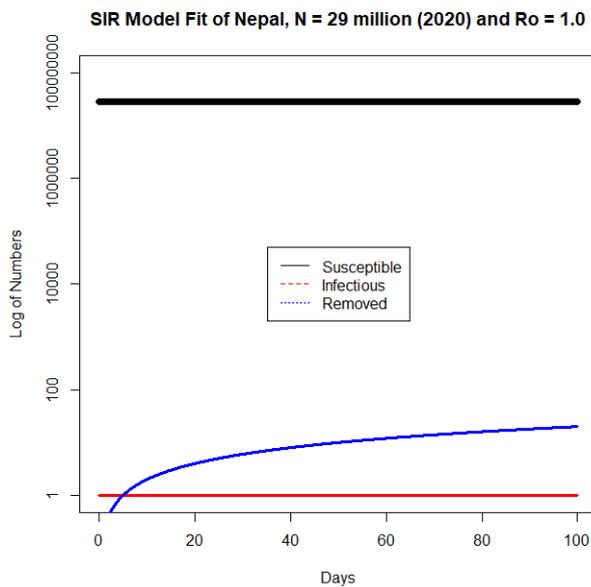**Fig. 7. SIR model with β= 0.5 and γ= 0.5 for N=29,000,000 of Nepal giving basic reproduction number Ro=1**

This SIR model shows that only 1 person will be infected each day as the basic reproduction number is 1.

Scenario 3

We used estimated β = 0.5197019 and γ = 0.4802873 obtained for official cases between 23rd January and 30th April 2020 using LM-BFGS optimization in R software giving Ro = β/γ = 1.08. This SIR model revealed that there will be a maximum of 532,627 cases if it continues with this Ro. (Fig. 8).

Estimated β and γ obtained using LM-BFGS optimization in R software for official cases reported between 22nd March and 30th April 2020 were 0.5553948 and 0.4446052 respectively giving Ro = beta/gamma = 1.25. This SIR model revealed that there will be a maximum of 6197014 if it continues with this Ro.

When Ro=1 was considered for the official data on 30th April 2020 then maximum cases will be 58.5462 and the COVID-19 epidemic will be over by June 2020 at this Ro in Nepal (Fig. 9).

SIR model based on official data revealed that COVID-19 cases will increase in Nepal with Ro of 1.08 and the epidemic will be over only by December 2020 with a peak of cases on August 2020 for this Ro. On the other hand, the COVID-19 epidemic will only be over around one year time if Ro continues as 1.25.

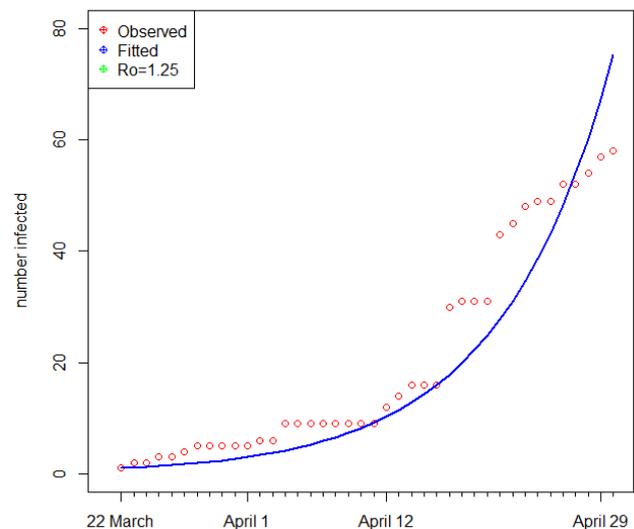**Fig. 8. SIR model with official cumulative COVID-19 cases of Nepal if Ro=1.25**
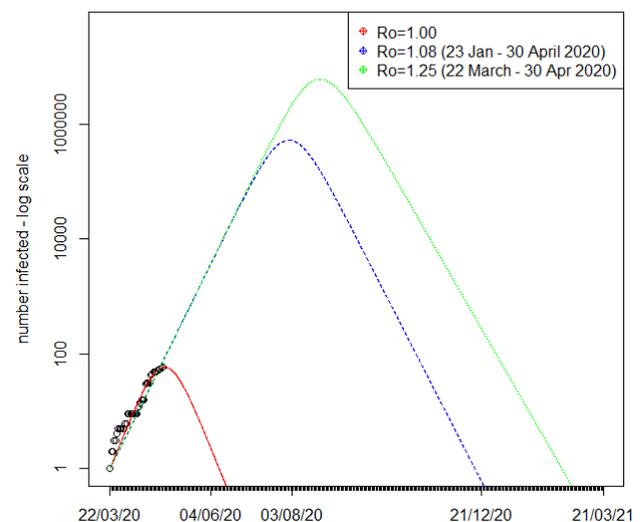

Fig. 9. Data-driven SIR model fit with three Ro values (1, 1.08, and 1.25) for Nepal

SIR model based on official data revealed that COVID-19 cases will increase in Nepal with Ro of 1.08 and the epidemic will be over only by December 2020 with a peak of cases on August 2020 for this Ro. On the other hand, the COVID-19 epidemic will only be over around one year time if Ro continues as 1.25.

DISCUSSION

The analysis of COVID-19 cases in Nepal provided an insight into the situation till the implementation of the first phase of lockdown and prediction of the expected

scenario thereafter. The data of the cases were based on the results of the test confirmed by RT-PCR. From the trend graph of cases as percent of RT-PCR tests, the percent of cases have rapidly decreased as the number of tests increased in the month of February and has remained more or less constant between 0.2 to 0.5 % thereafter. This is an indication of an absence of a significant rise in COVID-19 cases despite the increase in the tests substantially in the months of March-April in Nepal, although the number of tests may still not be sufficient to cover a large proportion of the population in Nepal. The overall growth of COVID-19 cases in Nepal is not high, which can be taken positively and credited to the lockdown implemented by the Nepal Government and awareness of the diseases through media along with the preventive measures. The doubling time of COVID-19 cases along with the incubation period of the coronavirus are important variables in the spread of the epidemic. The incubation period of the virus has been reported with a certain amount of variability (2-14 days) with the median average hovering around 5 days with possible outliers up to 27 days (Worldometer, 2020).

The overall picture shows that there has been ups and downs in the doubling time of the COVID-19 cases in Nepal and is currently around 11 days (Fig. 1) which is just above 10 days doubling time of COVID-19 cases in India as reported by different news channels of India though the total cases in Nepal are still negligible compared to that of India. Bhandary (2020) has stated that with implementation of lockdown the doubling time increased from 5 days to 15 days.

Statistical modelling showed that COVID-19 cases may continue to increase exponentially in Nepal. Forecasts from the best ARIMA model (MAPE = 4.18) are found to be more precise than the ETS exponential smoothing model (MAPE = 4.55). Forecasts from the best ARIMA model will be a valid estimate if clusters with more than 10 cases will be found there in the future too. This has already happened once between 18th April and 1st May 2020 in Nepal and thus requires particular attention of the concerned administrators and policymakers. However, it will not be valid if the cases will be increased at higher rates in the country. ETS and ARIMA models produced estimated values of COVID-19 cases for Nepal based upon the currently available official data. Despite the possibility of questions on whether sufficient tests have been conducted for such modelling, COVID-19 cases in Nepal have not risen sharply in high numbers and the total cases in Nepal are still below 100 but expected to rise in coming days.

Compartmental SIR model on the other hand reveals that nearly seven million Nepalese population might be infected with an average global basic reproduction number of 2.5 for COVID-19 cases and maximum cases would have reached within 60 days of the first case, which

fortunately did not happen in the country. The total number of cases would have been only 1 if the basic reproduction number remained at one in Nepal, which also did not happen as 30 cases were reported by 17th April 2020 and 58 in 30th April 2020.

The basic reproduction number of Nepal was computed as 1.08 for 23rd Jan – 30th April 2020 period, which means lockdown was working well to maintain a low level of basic reproduction number in the country. Further, it also revealed that COVID-19 will only be over by December 2020 with peak cases in August 2020 with Ro of 1.08. On the other hand, basic reproduction number of 1.25 was computed for total cases reported from 22nd March to 30th April 2020 period, which means that COVID-19 did not increase exponentially but it will remain for at least a year in the country. Thus, these results suggest to continue the lockdown in the hotspots (heavily affected areas), and slowly open the lockdown on the least affected areas with social/physical distancing and personal hygiene maintenance in Nepal.

This analysis we performed have been restricted to the lockdown implemented from 24th March 2020 till the end of April 2020 and not a final assessment yet considering that the spread of disease could still be at the early stage in Nepal and calls for re-assessments periodically in future as well till the pandemic phases out.

CONCLUSIONS

The data-based trends for the COVID-19 epidemic in Nepal have been analyzed followed by the assessment of the outbreak impacts in comparison with existing models. The outcomes of the research can be summarized as follows:

1. The total COVID-19 cases are increasing by following the logistic curve. However, there has been a variation in the doubling time during the analysis period, which can be attributed to the effect of lockdown imposed by the Government. The forecasts from the best ARIMA model may provide more precise and valid estimates if clusters with more than 10 cases are found in the future.

2. As in the compartmental SIR model, nearly 7 million people might get infected. With an average global basic reproduction number of 2.5 for COVID-19 cases, maximum cases would have reached within 65 days, which fortunately did not happen in the country. The basic reproduction number in Nepal being maintained at a low level of 1.08 for the period between 23rd January and 30th April 2020 is an indication of the effectiveness of the lockdown in containing the COVID-19 spread.

3. Further, the model has suggested that the COVID-19 will extend to December 2020 with the peak cases in

August 2020. On the other hand, basic reproduction number of 1.25 was computed for total cases reported for the 22nd March – 30th April 2020 period, which implies that COVID-19 may persist at least for a year in the country.

Thus, the results so far obtained clearly recommend continuing the lockdown in the hotspots (heavily affected areas) and gradually easing the lockdown in the least affected areas with strict social/physical distancing and personal hygiene maintenance.

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