**Methods:**

**Time series model to predict the trend**

We performed three time-series model including SES, ARIMA and Prophet models to identify the trend of deaths for COVID-19. We selected all these time series models as the outcome variable (daily deaths) are dependent on the previous records and all these three models can take this into account. Using the time series models with the reported COVID-19 data, we forecasted trends for the prospective 10-days and visualizing in the figure. SES was used as a benchmark to compare the performance of the ARIMA model.

**Simple Exponential Smoothing:**

Simple exponential smoothing is one of the familiar methods for forecasting procedures. The SES is a short-term forecasting model that assumes data fluctuates around a relatively stable mean. For infectious diseases in general, this method has been shown to be reasonably accurate and reliable. It considers the more recent observations and exponentially reduces the weights of older observations. The SES model for this study had been carried out using R package ‘fpp2’.

**Auto-Regressive Integrated Moving Average (ARIMA):**

We performed an ARIMA model to forecast the trend of daily deaths. The ARIMA model is an exploratory, data-oriented method that allows the user to fit an appropriate model adapted from the structure of the data itself. This model assumes that the time series values are linearly related and intends to extract local patterns by eliminating high-frequency noise from the data.

The benefit of ARIMA models is the ability to adjust to dynamically oriented system which evolve over time by updating the model to forecast the system's future state based on recent events. The ARIMA model for this study had been carried out using R package ‘forecast’.

**Automatic Forecasting time-series model (Prophet):**

We also performed a decomposable automatic forecasting time-series model called ‘Prophet’ using R package “prophet” to predict the 10-days fatality rate and compared with deaths. The Prophet model ignores the temporal dependence of the data. Moreover, the irregular observations are allowed in the data set and the model fits very quickly. It is also robust for missing data and generally manages outliers well.

**Empirical evaluation**

The ARIMA and Prophet models are empirically assessed by comparing their results to benchmarks in predicting the deaths. This benchmark permitted us to assess the performance gains made by their counterparts. The SES also allows the most appropriate non-seasonal model for each series, allowing for any kind of error or trend component. Then, we analyse and compare the performance of the studied time series models with some of the commonly used measures to evaluate the prediction significance including coefficient of determination (R2), root mean square error (RMSE), and mean absolute error (MAE).

**COVID-19 Data**

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**Outcome variable**

In this study, COVID-19 deaths were taken as the main outcome variable.

**Predictor variables**

Three variables were included in the model as predictors: number of tests, number of infection and number of recovered.

**Statistical analysis**

As the outcome variable was count data, we used negative binomial (NB) regression models to investigate the association between deaths and the possible explanatory variables of Bangladesh. NB refers to regression models in which the dependent variable is assumed to have a NB distribution. NB regression models are used in situations where the variable of interest is continuous and counted frequently and is related to other variables through a regression structure.

For the NB regression, we reported incidence rate ratios (IRRs) adjusted for number of tests, number of infection and number of recovered, with 95% confidence intervals (CIs). All analyses were done using the R (statistical package).

Results:

Table 1: Factors associated with reported death of COVID-19 using negative binomial regression (NBR) model during XX to YY.

|  |  |  |
| --- | --- | --- |
|  | RR (95% CI) | P-value |
| Number of tests | 0.99 (0.99 – 1.00) | 0.075 |
| Number of infected | 1.01 (1.01 – 1.02) | <0.001 |
| Number of recovered | 1.01 (1.01 – 1.02) | <0.001 |

In the NBR model, the estimated effect of each variable is presented in relative risk (RR) and its significance is shown by its p-value. The number of test (0.99 [0.99–1.00]) was negatively associated with the COVID-19 deaths. The number of infected (1.01 [1.01–1.02]), and number of recovered (1.01 [1.01–1.02]) was positively and significantly associated with the COVID-19 deaths, indicating that infected and recovered person are contributed to increase of deaths of COVID-19.

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Table 2. The summary of Simple Exponential Smoothing (SES), Auto-Regressive Integrated Moving Average (ARIMA), and Automatic forecasting time-series model (Prophet). The SES, ARIMA and Prophet models used daily COVID-19 deaths data.

|  |  |  |  |
| --- | --- | --- | --- |
| Method & Period | R2 | RMSE | MAE |
| *Simple Exponential Smoothing* | | | |
| Overall | 39.24% | 1.85 | 1.22 |
|  |  |  |  |
| *Auto-Regressive Integrated Moving Average* | | | |
| Overall ARIMA (1,1,2) | 41.92% | 1.70 | 1.07 |
|  |  |  |  |
| *Automatic Forecasting time-series model* | | | |
| Overall | 13.67% | 2.07 | 1.56 |

*RMSE: Root Mean Square Error; MAE: Mean Absolute Error*

In the SES model, we found a strong declining trend of deaths of COVID-19 between observed and predictive deaths of COVID-19 with an *R2*, RMSE, and MAE value of 39.24%, 1.85, and 1.22. In the ARIMA and Prophet Model, we found a strong declining trend of deaths of COVID-19 between observed and predictive deaths of COVID-19 with an *R2*, RMSE, and MAE value of 41.92% and 13.67%, 1.70 and 2.07, and 1.07 and 1.56, respectively (Table 2). In terms of accuracy, the ARIMA model performed better over Prophet and SES model (with better *R2*, RMSE, and MAE value). The coefficient of determination of the ARIMA model was larger and errors are lower than Prophet and SES model. According to the forecast in both models, the ratio of COVID-19 deaths is expected to decrease considerably in the coming 30 days (Fig 1).