**RESEARCH ARTICLES**

**Estimation and prediction of doubling time for COVID-19 epidemic in Bangladesh: a modelling study of first 14 month’s daily confirmed new cases and deaths**

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**Abstract**

*Background:* The doubling time is a reliable indicator to estimate the rate at which the pandemic is spreading. We evaluated and predicted the doubling time for the daily COVID-19 cases and deaths in Bangladesh.

*Methods:* Publicly available daily data on COVID-19 new cases from 8 March, 2020 to 14 February, 2021 and the daily deaths data from 18 March, 2020 to 14 February, 2021 were used to predict doubling time based on records from seven days prior. Then, short-term predictions for the next 14 days (1 to 14 February, 2021) were performed to validate the accuracy of our prediction. Finally, using the doubling time data up to 14 February, 2021, a two months (15 February- 15 April, 2021) prediction was made for both daily new COVID-19 cases and deaths.

*Results:* The median doubling time for daily new COVID-19 cases and deaths were 90.51 and 86.02 days respectively in the entire period. The doubling period for cases was lowest in the second to third week of March, 2020 [ranged 2.33-8.43 days] and longest in the second week of March, 2021 [ranged 834-2187 days]. Our prediction suggests that the doubling time for daily confirmed new COVID-19 case will be 1310.33 days [95% CI: 854.33 - 1766.32] and deaths will be 683.04 days [556.05 - 810.03] on 15 April, 2021 in Bangladesh.

*Conclusion:*Our prediction is based on current testing strategies. Any changes in daily number of tests or sudden changes of the dynamics of COVID-19 transmission would affect these predictions.

**Keywords:** COVID-19, Doubling Time, Prediction, Bangladesh.

**Introduction**

 Since its first case detection in Wuhan, Hubei Province, China in December 2019, the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) has caused the emergence of the novel coronavirus disease 2019, referred to as COVID-19. On 30 January, 2020, the World Health Organization (WHO) declared COVID-19 a public health emergency of international concern, and then subsequently, a pandemic on 11 March, 2020 [1]. The pandemic has rapidly swept across the globe infecting more than 122 million people, and more than 2.69 million people died as of 20 March, 2021 [2]. Since its rapid spread outside of Mainland China at the beginning of 2020, COVID-19 caused a serious global public health threat [3–5]. At its early phase in China, the number of cases were double at every 7.5 days, indicating a faster transmission of the virus [6]. The rapid spread of COVID-19 has emerged new infections in almost all South-Asian regions, including Bangladesh, from the beginning of March, 2020 [7].

 Understanding the epidemiological changes of COVID-19 pandemic is crucial for the preparation and implementation of policies and strategies aimed towards slowing down the spread of pandemic, and subsequently the flattening of the curve [8]. Several approaches have been made by researchers worldwide to estimate and predict the spread of COVID-19 [9–12]. One of these approaches is estimating the doubling time for COVID-19 cases and deaths figures [13,14], which refer to the time required for the number of cases/deaths to be double from the starting day, based on the rate of cumulative increases in number of cases/deaths. If the pandemic grows exponentially with a constant growth rate, the doubling time remains constant and equal [15]. Doubling time for confirmed cases shows the number of days that have passed since the number of cases were half [13,16]. Similarly, doubling number of deaths shows the number of days that have passed since the number of deaths was half of the current count [14]. Shorter doubling time indicates a faster spread of the virus.

 Bangladesh reported 5.65 million infected and 8,624 confirmed COVID-19 deaths as of 20 March, 2021 [17]. The first case was detected on 8 March, 2020 [18] and since then, Bangladesh reached 100 cases on 9 April, and doubled the cases during the next two days [19]. Moreover, to the best of our knowledge, no research has been published on the speed of COVID-19 transmission for the Bangladeshi population. Findings of such a study can help policy makers at national level to better prepare for the pandemic by adjusting COVID-19 dedicated hospital beds, Intensive Care Unit beds, Personal Protection Equipment (PPE) distributions, and maintaining a steady supply and availability of essential medications for COVID-19 management. The objective of this study was to evaluate and predict the doubling time for daily confirmed new cases and deaths in COVID-19.

**Materials and Methods**

*Study design and data source*

 We collected publicly shared daily data from the website of Directorate General of Health Services (DGHS) Bangladesh [20] and Institute of Epidemiology Disease Control and Research (IEDCR) [21]. The daily data on confirmed COVID-19 new cases from 8 March, 2020 to 14 February, 2021 and the daily data on confirmed COVID-19 deaths from 18 March, 2020 to 14 February, 2021 were used and their doubling times were calculated seven days prior to conducting this study.

*Calculation of doubling time*

 Doubling time was calculated based on records from seven days prior to conducting this study, using the following formula [13,16].

 Here, t1 is the first day from when we start our calculation, t2 is the day we want to calculate the doubling time for, c1 is the cumulative number of cases or deaths for t1, and c2 is the cumulative number of cases or deaths for t2. ln(2) is the natural logarithmic value of 2.

 In Bangladesh, the first COVID-19 positive case was detected on 8 March 2020. A total of 3 cases were detected on that day. On 15 March, 2020, seven days from the first case identification, the total number of cases were 5. So according to the formula, if we calculate the case doubling time for 15 March, our t1 would be 1, t2 would be 8, c1 would be 3, and c2 would be 5.

 So, the doubling time for the daily new cases for



 Using this method, the doubling time for the confirmed COVID-19 cases were calculated and analysed for each day from 15 March, 2020 to 14 February, 2021. Similarly, the doubling time for daily deaths were also calculated. The first confirmed COVID-19 death in Bangladesh was reported on 18 March, 2020. Since we are calculating doubling time based on the data from the last seven days, we started calculating doubling time for deaths from 25 March, 2020. So, the doubling time for daily deaths by COVID-19 was calculated and analysed for each day between the time periods of 25 March, 2020 to 14 February, 2021.

*Model Accuracy and validation*

 To check the accuracy and validity of our prediction model, we performed a short-term 14 days [1 – 14 February, 2021] prediction of the doubling time for daily confirmed COVID-19 cases and deaths. Then, the predicted data with 95% confidence interval for both COVID-19 new cases and deaths were compared with the actual [calculated] doubling time data of the same time frame. ARIMA (1, 1, 1) (0, 0, 0) and ARIMA (0, 1, 0) (0, 0, 0) models were used as the best fitted model for cases and deaths respectively. The prediction models were selected following the time series best model selection criteria [22–24]. Although, the actual death doubling time showed fluctuation with predicted doubling time [Figure 1.b], the predicted doubling time for daily confirmed new cases showed good fit [Figure 1.a], where the actual doubling time falls in the 95% confidence limit of the predicted doubling time which ensures the accuracy and validity of our prediction model [Figure 1].

 Finally, we used data up to 14 February, 2021 and predicted the daily confirmed new cases and deaths for the next two months [15 February to 15 April, 2021]. All the statistical analyses were performed using Excel 2019, R-programming 3.6.1 version and SPSS 20 version for Microsoft Windows.

**Results**

*Trends analysis of doubling time for daily confirmed new COVID-19 cases and deaths*

 Starting on 15 March, 2020, the case doubling time was 9.5 days and later fell to 2.88 days after a week on 22 March, 2020 [Figure 2]. After that, the case doubling time steadily increased and reached to 80.21 days on 5 August, 2020, the highest it has been up until that date. It started to sharply decrease again and hit by 62.77 days on 12 August, and then started to increase gradually again. It reached 1034.32 days on 14 February, 2021. In the case of daily confirmed new COVID-19 deaths, the doubling time was 3.01 days on 25 March, 2020 and two peaks were observed later in that month. Then, it steadily increased until it was hit by another peak on 6 May, 2020 at 36.76 days, followed by decreased trends to 12.38 days on 19 May, 2020. Afterwards, the doubling time for deaths steadily increased with occasional minor drops and reached to 579.39 days on 14 February, 2021, the highest up until that date [Figure 2].

*Monthly comparison of doubling time for daily COVID-19 confirm new cases and deaths*

 The monthly distribution of doubling time for daily new COVID-19 cases and deaths in Bangladesh indicates a Sine curve of doubling time [Figure 3]. Overall, the median doubling time for the daily new COVID-19 cases and deaths were 90.51 and 86.02 days respectively. The lowest median doubling time for cases was 4.74 days in March, 2020 with a lower variation (lowest value was 2.33), and the longest median doubling time for new case was 447.72 days in January, 2021 [maximum: 774.97], experiencing a larger variation. The doubling period for daily confirmed deaths in COVID-19 was 5.30 days in March [minimum: 3.01] and 298.74 days in January, 2021 [maximum: 376.73]. A significant Sine trend in median doubling time for both COVID-19 confirmed cases and deaths were observed during the whole period. The median doubling times for both daily new cases and deaths were lower in March, 2020. After that, it increased gradually and reached its highest in June, 2020 [Figure 3].

*Prediction of doubling time for daily confirmed new COVID-19 cases and deaths*

 The doubling time for daily confirmed new COVID-19 cases and deaths was forecasted for the 15 February to 15 April, 2021, obtained by the best fitted ARIMA (1, 1, 1) (0, 0, 0) and ARIMA (0, 1, 0) (0, 0, 0) models respectively [Table 1, Figure 4]. Our prediction model suggested increased trends of doubling times for both daily new cases and deaths. It was predicted that the doubling time for daily confirmed new COVID-19 case will be 1310.33 days [95% CI: 854.33 - 1766.32] and deaths will be 683.04 days [556.05 - 810.03] on 15 April, 2021 in Bangladesh [Table 1 & Figure 4].

**Discussion**

 In Bangladesh, on the date when the first positive case of COVID-19 was detected (8 March), the doubling period was 9.5 days. The daily deaths was first doubled within 3.01 days on 25 March, 2020. Our trend analysis of daily confirmed new cases and deaths showed a consistently increasing trend of doubling time. This finding is consistent with the report from the World Health Organization [25]. The case doubling time increased up to four times from 15 March, 2020, while the doubling time for deaths had increased up to 14 times during the study period. As the pandemic progressed, it took longer for the cumulative incidence cases to double in Bangladesh, which indicated an overall sub-exponential growth pattern. A consistent increase in the doubling time coincided with other preventive measures, including the use of face masks, area-based lockdowns, isolation, quarantine of suspected cases, and physical distancing where possible [13].

 The increase in doubling time for new cases indicates a gradual decrease in the pace at which the virus is spreading [26]. Doubling time would remain the same if the pandemic is growing exponentially [13]. Yet, the slow but steady increase in doubling time for new cases in Bangladesh points towards a lower rate of new infection. Preventive measures are taken by the government, including area-based lockdowns, restrictions on public transport, limited opening of restaurants and shops, suspending conventional on-campus classes in all the educational institutes [27] and opting instead for online classes, keeping all non-essential services and offices closed, working alternate days, and introducing awareness programs for face mask use. Maintaining social distancing and hand washing, along with testing for COVID-19, seemed to have a positive impact in reducing the spread of the pandemic [28,29].

**Figure 1**. Comparison between actual and predicted doubling times to validate the accuracy of the prediction model for COVID-19 positive new cases and deaths in Bangladesh.

**Figure 2.** Trends of doubling time for daily confirmed new COVID-19 cases from 15, March, 2020 to 14 February, 2021 and deaths from 25 March, 2020 to 14 February, 2021 in Bangladesh.

**Figure 3.** The boxplot for monthly doubling time for daily confirmed new COVID-19 cases and deaths from March, 2020 to February, 2021 in Bangladesh. The bottom and top of the box indicate the first and third quartiles value; the band inside the box is the median days.



**Figure 4.** Two months (15 February to 15 April, 2021) prediction of doubling time for daily confirmed new COVID-19 cases and deaths in Bangladesh.

**Table 1.** Two months (15 February – 15 April, 2020) prediction of doubling time for daily confirmed new COVID-19 cases and daily confirmed COVID-19 deaths with 95% confidence interval.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Date** | **Daily Predicted New Cases with 95% confidence** | **Daily Predicted Deaths with 95% confidence** | **Date** | **Daily Predicted New Cases with 95% confidence** | **Daily Predicted Deaths with 95% confidence** |
| 15/Feb | 1041.52 (1030.98 - 1052.05) | 578.56 (561.60 - 595.52) | 17/Mar | 1202.46 (956.33 - 1448.59) | 631.94 (540.63 - 723.26) |
| 16/Feb | 1048.55 (1031.42 - 1065.67) | 580.99 (557.51 - 604.47) | 18/Mar | 1206.64 (952.56 - 1460.73) | 633.71 (540.93 - 726.48) |
| 17/Feb | 1055.41 (1031.74 - 1079.09) | 582.58 (553.92 - 611.23) | 19/Mar | 1210.78 (948.78 - 1472.78) | 635.47 (541.25 - 729.68) |
| 18/Feb | 1062.13 (1031.73 - 1092.52) | 584.38 (551.38 - 617.39) | 20/Mar | 1214.87 (945.01 - 1484.73) | 637.23 (541.60 - 732.86) |
| 19/Feb | 1068.69 (1031.35 - 1106.03) | 586.13 (549.28 - 622.98) | 21/Mar | 1218.92 (941.24 - 1496.60) | 638.99 (541.97 - 736.01) |
| 20/Feb | 1075.10 (1030.61 - 1119.59) | 587.90 (547.57 - 628.23) | 22/Mar | 1222.93 (937.49 - 1508.38) | 640.75 (542.36 - 739.15) |
| 21/Feb | 1081.38 (1029.55 - 1133.21) | 589.66 (546.13 - 633.19) | 23/Mar | 1226.90 (933.74 - 1520.06) | 642.52 (542.76 - 742.27) |
| 22/Feb | 1087.53 (1028.19 - 1146.87) | 591.42 (544.91 - 637.93) | 24/Mar | 1230.83 (930.00 - 1531.66) | 644.28 (543.19 - 745.36) |
| 23/Feb | 1093.55 (1026.55 - 1160.55) | 593.18 (543.87 - 642.50) | 25/Mar | 1234.73 (926.29 - 1543.17) | 646.04 (543.63 - 748.45) |
| 24/Feb | 1099.45 (1024.66 - 1174.24) | 594.95 (542.98 - 646.91) | 26/Mar | 1238.59 (922.59 - 1554.59) | 647.80 (544.09 - 751.51) |
| 25/Feb | 1105.23 (1022.54 - 1187.91) | 596.71 (542.22 - 651.20) | 27/Mar | 1242.42 (918.91 - 1565.92) | 649.56 (544.57 - 754.56) |
| 26/Feb | 1110.90 (1020.23 - 1201.57) | 598.47 (541.57 - 655.37) | 28/Mar | 1246.21 (915.25 - 1577.17) | 651.32 (545.06 - 757.59) |
| 27/Feb | 1116.46 (1017.72 - 1215.20) | 600.23 (541.02 - 659.44) | 29/Mar | 1249.98 (911.61 - 1588.34) | 653.09 (545.56 - 760.61) |
| 28/Feb | 1121.92 (1015.06 - 1228.78) | 601.99 (540.56 - 663.43) | 30/Mar | 1253.71 (908.00 - 1599.42) | 654.85 (546.08 - 763.61) |
| 1/Mar | 1127.28 (1012.24 - 1242.32) | 603.75 (540.17 - 667.34) | 31/Mar | 1257.42 (904.41 - 1610.42) | 656.61 (546.62 - 766.60) |
| 2/Mar | 1132.55 (1009.29 - 1255.80) | 605.52 (539.85 - 671.18) | 1/Apr | 1261.10 (900.85 - 1621.34) | 658.37 (547.17 - 769.58) |
| 3/Mar | 1137.72 (1006.22 - 1269.22) | 607.28 (539.60 - 674.95) | 2/Apr | 1264.75 (897.32 - 1632.18) | 660.13 (547.73 - 772.54) |
| 4/Mar | 1142.81 (1003.05 - 1282.57) | 609.04 (539.41 - 678.67) | 3/Apr | 1268.38 (893.82 - 1642.94) | 661.90 (548.30 - 775.49) |
| 5/Mar | 1147.81 (999.78 - 1295.85) | 610.80 (539.27 - 682.34) | 4/Apr | 1271.99 (890.35 - 1653.62) | 663.66 (548.89 - 778.43) |
| 6/Mar | 1152.74 (996.42 - 1309.05) | 612.56 (539.18 - 685.95) | 5/Apr | 1275.57 (886.91 - 1664.23) | 665.42 (549.48 - 781.35) |
| 7/Mar | 1157.58 (992.99 - 1322.17) | 614.33 (539.13 - 689.52) | 6/Apr | 1279.13 (883.50 - 1674.76) | 667.18 (550.09 - 784.27) |
| 8/Mar | 1162.36 (989.50 - 1335.21) | 616.09 (539.13 - 693.05) | 7/Apr | 1282.67 (880.13 - 1685.21) | 668.94 (550.72 - 787.17) |
| 9/Mar | 1167.06 (985.95 - 1348.17) | 617.85 (539.17 - 696.53) | 8/Apr | 1286.19 (876.78 - 1695.60) | 670.70 (551.35 - 790.06) |
| 10/Mar | 1171.69 (982.35 - 1361.04) | 619.61 (539.24 - 699.98) | 9/Apr | 1289.69 (873.47 - 1705.91) | 672.47 (551.99 - 792.94) |
| 11/Mar | 1176.26 (978.71 - 1373.82) | 621.37 (539.35 - 703.40) | 10/Apr | 1293.17 (870.20 - 1716.15) | 674.23 (552.64 - 795.82) |
| 12/Mar | 1180.77 (975.04 - 1386.51) | 623.14 (539.49 - 706.78) | 11/Apr | 1296.64 (866.96 - 1726.32) | 675.99 (553.30 - 798.68) |
| 13/Mar | 1185.22 (971.33 - 1399.11) | 624.90 (539.66 - 710.13) | 12/Apr | 1300.08 (863.75 - 1736.42) | 677.75 (553.98 - 801.53) |
| 14/Mar | 1189.61 (967.60 - 1411.62) | 626.66 (539.86 - 713.46) | 13/Apr | 1303.51 (860.58 - 1746.45) | 679.51 (554.66 - 804.37) |
| 15/Mar | 1193.95 (963.86 - 1424.03) | 628.42 (540.09 - 716.75) | 14/Apr | 1306.93 (857.44 - 1756.42) | 681.28 (555.35 - 807.20) |
| 16/Mar | 1198.23 (960.10 - 1436.36) | 630.18 (540.35 - 720.02) | 15/Apr | 1310.33 (854.33 - 1766.32) | 683.04 (556.05 - 810.03) |

 A higher value of actual doubling time for the daily new cases than the predicted values indicates that the pandemic not only stopped growing at an exponential rate but also slowed down more than anticipated in Bangladesh, considering the number of daily tests as fixed. While the pandemic is slowing down in its spread among the Bangladeshi population, a lower doubling time for deaths than the predicted values indicate towards an increased rate of case fatality from COVID-19 among existing cases [25]. The doubling time for the daily deaths kept increasing at a steady rate up until 15 July, 2020, but after that it remained almost the same up until 26 July, and then started increasing sharply, indicating an exponential increase in the number of deaths as well as case fatalities from COVID-19 during the middle of the month of July. While the ARIMA model was able to reliably predict the change in doubling time for new cases, it could not predict the doubling time for deaths very accurately for first 11 days of the prediction and this could be due to a multitude of different reasons. Late in case reporting, inability to identify the danger signs of the COVID-19 by the patients or the family members, delay in hospitalization, insufficiency of required infrastructure necessary for proper management of COVID-19 at hospitals, and shortage of trained and skilled health care professional for infection management at every level of healthcare services could contribute to this pattern of COVID-19 case fatality in Bangladesh [30]. As a unique initiative, our evaluation of the doubling time of daily new COVID-19 confirmed cases and deaths observed increasing trends of epidemic doubling time of COVID-19 infection in Bangladesh.

 The new cases and deaths have declined in Bangladesh since July 1, 2020. Overall, Bangladesh experienced a relatively milder effect of the pandemic compared to countries in Europe and North America [31]. Countries with similar economy and demographic profiles in South and South East Asia and Sub-Saharan African were mildly affected by the COVID-19 pandemic. One possible explanation is that the younger demographics helped dilute the impact of COVID-19 in Bangladesh, as this has been seen in many other Asian and Sub-Saharan African countries [32]. Bangladesh has a relatively younger population with a median age of 27.9 years [33]. Another explanation is T-cell mediated immunity acquired through previous human coronavirus infection that could cross react with previous human coronavirus infection [32]. People living in tropical climate experience infectious diseases throughout the year compared to winter surge in temperate countries. However, the exact reason for why some countries were mildly affected by COVID-19 pandemic is still unknown. After an initial surge of the epidemic in April–June, Bangladesh experienced relatively slower spread rate which is explained through our doubling time prediction.

 One of the major limitations of this study is considering daily sample test as a constant. The doubling time is correlated on the number of samples tested and we assumed that the testing number would not change significantly. However, our study found a moderate correlation between daily sample test data and confirmed cases and deaths (Pearson correlation value between daily tests and cases was r=0.525, and between daily tests and deaths was r=0.474). Bangladesh admittedly has a severe shortage of testing kits, PPE, masks, and infrared thermometers. Moreover, the lack of diagnostic facilities particularly in sub-districts, limited number of the healthcare workers, and a lack of understanding in rural areas are the causes of limited sample testing [27]. From 8 March, 2020 to date, the government of Bangladesh is administering on average between 12 000 and 15 000 tests per day for a population of 168 million [34]. Furthermore, Bangladesh was affected by cyclone ‘Amphan’ on 20 and 21 May, 2020 [35] and experienced Eid festivals in the month of May. Along with occasional delayed reporting, backlog, communications gaps with hard to reach areas, it is possible that all of the data used in this analysis is not 100% accurate [36,37]. Further, the speed of disease transmission has been linked with adopted control measures, human behavior and emergence of new SARS-CoV-2 variants as seen in Europe and North America [38,39]. Thus, the change of control measures, and the emergence and spread of new variants which can change the dynamics of transmission within a short span of time might affect our estimation.

**Conclusion**

 The median doubling time for new COVID-19 cases and deaths were 90.51 and 86.02 days respectively over the whole period. The lowest median value for doubling new COVID-19 cases was 2.00 days in March 2020 and that of deaths was 3.01 days in March, 2020. There is an increasing trend for doubling period for daily new cases and recorded deaths. However, the daily cases and deaths toll had a shorter doubling time in the month of October with a mean value of 185.63 and 184.43 days respectively. Our estimation was based on the number of daily samples tested in the first 11 months that averagely ranges interquartile range (IQR): 10261-14774.5. However, these doubling times would not be changed over the predicted period if the daily sample testing would not change suddenly. Bangladesh experienced a mild effect of the pandemic compared to countries in Europe and North America. While the exact reason why Bangladesh was mildly affected by COVID-19 pandemic is still unknown, our predicted doubling period explains the slow spread rate of the virus in the country.

**Abbreviations**

COVID-19 - Coronavirus disease; DT- Doubling Time; UCL- Upper Confidence Limit; LCL- Lower Confidence Limit; ARIMA - Autoregressive Integrated Moving Average; DGHS - Directorate General of Health Services, Bangladesh; IEDCR - Institute of Epidemiology, Disease Control and Research

**Conflict of Interest**

The authors have no competing interests to declare.

**Author’s contribution**

MMR conceptualized, supervised, analysed and drafted the study. MFH analysed and drafted the study. SMA, EA, SM helped with the preparation and editing of the draft. GKP updated and edited the new drafted. NH helped in supervision, analysis and editing of the draft. All authors critically checked the manuscript and approved the version to be submitted.

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