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COVID-19 Impact on Public Health in Bangladesh: A Comprehensive Analysis of Morbidity, Mortality and Future Scenarios

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ABSTRACT

To analyze the temporal trends and patterns of COVID-19 cases and deaths in Bangladesh, to identify potential seasonal variations in COVID-19 morbidity and mortality, to visualize the relationship between new cases, new deaths, and time, to prioritize factors or periods based on case and death frequencies and to apply statistical process control charts to monitor the stability and identify significant variations in daily case and death rates. COVID-19, caused by a novel coronavirus, has become a global public health emergency since its emergence in late 2019. Bangladesh, a densely populated and low-resource country, faced many challenges in responding to the pandemic. This study aimed to evaluate the impact of COVID-19 on public health in Bangladesh by analyzing the trends and patterns of morbidity, mortality, and future scenarios which mean the implications of the historical analysis for the potential direction the pandemic might take, while acknowledging the variables and the plan for a dedicated future projection study. The analysis used data from the WHO COVID-19 dashboard, covering 1st January, 2020 to 1st January, 2023. Minitab 17.1.0 was used for analysis and visualization. The data was cleaned and transformed to create new variables like season and case fatality rate. A surface plot was used to show the relationship between new cases, new deaths, and date reported. Trending charts with upper and lower control limits were also created.Results showed an initial surge in cases and deaths peaking in mid-2021, followed by declining death rates. Seasonal variations were observed, with summer and winter having higher cases (summer: 50.3% of total cases; winter: 22.1%) and deaths (summer: 59.1%; spring: 16.8%) compared to spring and autumn. Pareto analysis of cases showed that July 2021 accounted alone for about 16.5% of the total incidents. The study highlights seasonal trends and the critical role of vaccination and healthcare capacity. Public health authorities should prioritize pre-peak-season interventions, enhance real-time monitoring using statistical tools and address systemic vulnerabilities to mitigate future outbreaks.

INTRODUCTION

The coronavirus disease 2019 (COVID-19) pandemic, caused by the novel severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has posed unprecedented challenges to the global health and socio-economic systems. Since its first detection in China in December 2019, the virus has rapidly spread to more than 200 countries and territories, infecting over 300 million people and killing over 6 million as of January 2024 (World Health Organization (WHO), 2024). The pandemic has also disrupted the normal functioning of societies, affecting various aspects such as education, employment, trade, travel, and human rights (Hosseinzadeh et al., 2022).

Bangladesh, a densely populated and low-resource country in South Asia, has been severely affected by the COVID-19 pandemic. The first confirmed case of COVID-19 in Bangladesh was reported on March 8, 2020. Since then, the country has witnessed several waves of infections and deaths, with varying intensity and duration (Saha & Gulshan, 2021). As of January, 2023, Bangladesh has reported 2,046,165 confirmed cases and 29,477 deaths due to COVID-19 (Anonymous, 2023a, 2023b; Lytton & Ghosh, 2024). The country has also administered 361,674,660 doses of COVID-19 vaccines, fully vaccinating 142,193,280 people or 85.6% of its population (UNICEF, 2022).

The COVID-19 situation in Bangladesh is influenced by multiple factors, such as the virus characteristics, the public health interventions, the health system capacity, the socio-economic conditions, and the environmental factors (Hosseinzadeh et al., 2022). Understanding these factors and their interactions is crucial for developing effective strategies to prevent, control, and mitigate the impact of the pandemic. However, there is a challenge to achieve a comprehensive and up-to-date data and analysis on the COVID-19 situation in Bangladesh, which hinders evidence-based decision-making and policy formulation (Anwar et al., 2020; Ferdous et al., 2020; Hasan et al., 2021; Siddika & Islam, 2022).

This work aimed to provide a unique analysis and comprehensive insight interpretation and extrapolation of the future perspective from the graph of COVID-19 in Bangladesh. The graph is a surface plot showing the relationship between new COVID-19 cases and deaths in Bangladesh over three years, from January 2020 to January 2023. This graph was used as a basis to explore the trends and patterns, the possible factors, and the future scenarios of the COVID-19 situation in Bangladesh. Web search results were also used to supplement the analysis with additional information and references. The analysis was intended to contribute to the understanding of the COVID-19 situation in Bangladesh and provide some implications and recommendations for the policymakers and the public. This study aims to analyze temporal trends, seasonal variations, and key determinants of COVID-19 morbidity and mortality in Bangladesh between 2020 and 2023 to inform targeted interventions.

MATERIAL AND METHODS

The data used for this analysis was obtained from the World Health Organization (WHO) COVID-19 dashboard, which provides daily updates on the confirmed cases and deaths due to COVID-19 in Bangladesh and other countries (WHO, 2023a). The data covered the period from 1st January, 2020 to 1st January, 2023 and included the following variables: reporting date, new cases, cumulative cases, new deaths, and cumulative deaths.

The data was downloaded as a comma-separated values (CSV) file and imported into Minitab version 17.1.0, a commercially available Statistical Process Control (SPC) software package for analytical computing and graphics developed by Minitab LLC, State College, Pennsylvania, USA. The data was cleaned to remove any missing or erroneous values and transformed to create new variables, such as season, case fatality rate, and moving average (Alotaibi et al., 2022). Missing or erroneous data (<0.1% of entries) were excluded. Seasons were assigned as Winter (December–February), Spring (March–May), Summer (June–August), and Autumn (September–November).

The season variable was created by assigning each date to one of the four seasons: Winter (December to February), spring (March to May), summer (June to August), and autumn (September to November) (Borges do Nascimento et al., 2020). The data was examined using a surface plot, which is a type of plot that shows the relationship between three variables using surfaces.

The data was also analysed using exploratory process-behaviour charts, which are a type of control chart that can help to assess the stability and variation of a process over time (Anonymous, 2024). The charts showed the upper control limits of the new cases and new deaths, which indicate the range of expected variation for the process. Any data point that falls outside the control limits suggests a possible change in the process behaviour.

Statistical Analysis

The statistical analysis of the COVID-19 data from Bangladesh involved the following steps and methods (Gürsakal et al., 2020):

3D Surface Plot

A 3D surface plot was created using the variables date, new cases and new deaths. This showed the relationship between new cases, date and hew deaths over time. The plot revealed that new cases were highest during the summer season (June to August) of 2020 and 2021. Cases started to decline from late 2021 onwards. The surface plot provided a visual understanding of how cases fluctuated with death through the time period of the 3 years.

Pareto Diagram

A Pareto diagram was created to identify the frequency of cases and deaths. The Pareto diagram is a type of bar chart that shows the frequency of different categories in descending order, along with a cumulative percentage line. The Pareto diagram was created using the data from the WHO COVID-19 dashboard.

Median Control Charts

Median control charts were created to monitor the central tendency of new cases and new deaths over time. The median is a measure of location that is less sensitive to outliers than the mean. The median control charts were created using the variables new cases and new deaths, along with the time order. The median control charts showed the upper control limits of the new cases and new deaths, which indicate the range of expected variation for the process. Any data point that falls outside the control limits suggests a possible change in the process behaviour. The control limits were calculated using the average moving range method, which uses the average of the differences between consecutive observations as a measure of variability. The control charts were created for both recorded daily cases and deaths, to compare the seasonal effects on the process. Ethical approval was not required for this study as it utilized anonymized, publicly available data from the WHO COVID-19 dashboard.

RESULTS

The analysis identified the distribution of new COVID-19 cases in Bangladesh over specific months and years using Pareto method. In this case, the Pareto technique shows the new cases of COVID-19 reported in Bangladesh during different time periods, as well as the cumulative percentage of total cases up to that point. The study reveals that July 2021 had the highest number of new cases, accounting for 16.5% of the total cases, followed by August 2021 with 12.3%, and January 2022 with 10.5%. The screening indicates that the new cases of COVID-19 in Bangladesh varied significantly over time, with some months and years having more cases than others.

Figure 1 shows a 3D surface plot of the new deaths versus new cases of COVID-19 reported in Bangladesh over time. The x-axis indicates the reporting date, while the y-axis shows the number of new cases and the z-axis shows the number of new deaths. The color gradient represents the increase in values, ranging from green (low) to blue (high). The figure shows that the new deaths were lower when the new cases were fewer on earlier dates, while the new deaths increased as the new cases rose over time. The figure also shows some peaks indicating spikes in new deaths corresponding with increases in new cases.

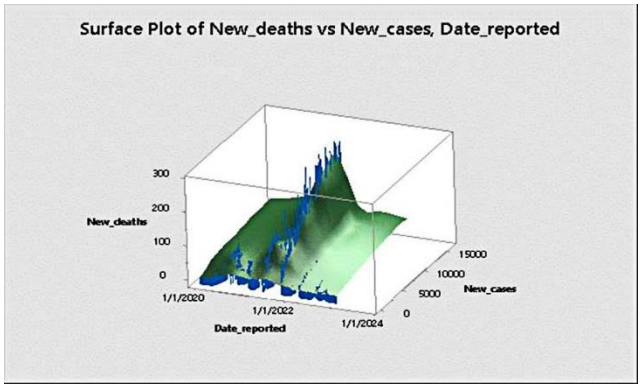

Figure 1. Temporal trends in new cases and deaths of COVID-19 in Bangladesh from January 2020 to January 2023

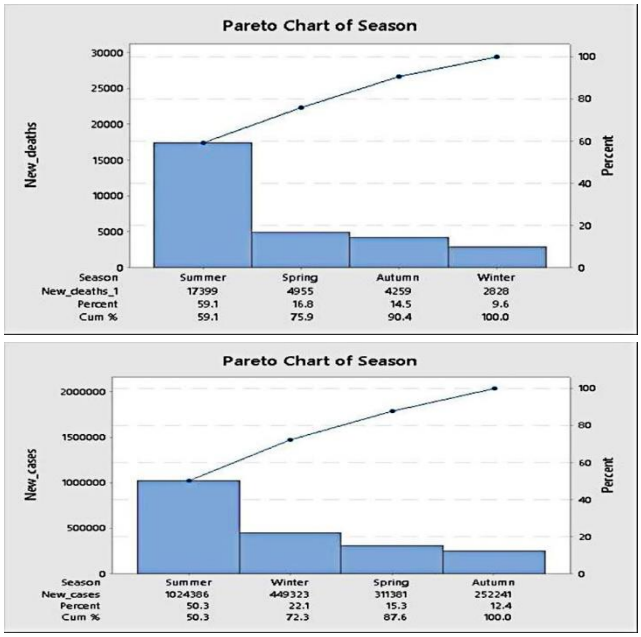

Figure 2. Seasonal variation in new cases and deaths of COVID-19 in Bangladesh from January 2020 to January 2023

Figure 2 shows a Pareto chart of the new cases of COVID-19 reported in Bangladesh by season. The x-axis indicates the season, while the y-axis on the left shows the number of new cases and the y-axis on the right shows the cumulative percentage of new cases. The bars represent the new cases in each season, while the line graph shows the cumulative percentage of new cases for each season. The figure shows that summer accounted for more than half of the total new cases, followed by winter, spring, and autumn, respectively. Summer recorded the highest cases (50.3%) and deaths (59.1%), followed by winter (22.1% cases; 9.6% deaths). Spring and autumn accounted for 16.8% and 14.5% of deaths, respectively. In terms of cases, they showed 15.3% and 12.4%, respectively. The table below the chart summarizes the new cases and percentages for each season.

Figure 2 shows a Pareto chart of the new deaths from COVID-19 reported in Bangladesh by season. The x-axis indicates the season, while the y-axis on the left shows the number of new deaths and the y-axis on the right shows the cumulative percentage of new deaths. The bars represent the new deaths in each season, while the line graph shows the cumulative percentage of new deaths for each season. The figure shows that summer accounted for more than half of the total new deaths, followed by spring, autumn, and winter, respectively.

Figures 3 and 4 shows a trending chart of the new cases and deaths per day of COVID-19 reported in Bangladesh over time. The y-axis indicates the number of cases per day, while the x-axis shows the date and season. The horizontal lines represent the upper control limit (UCL), the mean (X-bar), and the lower control limit (LCL) (Eissa, 2022; Essam Eissa, 2023; Eissa & Rashed, 2023). The data points are marked by black crosses connected by a line. The figure shows that the new cases fluctuated around the mean.

According to the WHO COVID-19 dashboard, as of 4 January 2024, Bangladesh has reported 2,046,165 confirmed cases and 29,477 deaths due to COVID-19. The country has also administered 361,674,660 doses of COVID-19 vaccines, fully vaccinating 142,193,280 people or 85.6% of its population (WHO, 2024). However, the country is still facing challenges such as the emergence of new variants, the waning of vaccine immunity, and the relaxation of preventive behaviors (Anonymous, 2024). Therefore, it is important to continue to follow the public health guidelines and to monitor the situation closely.

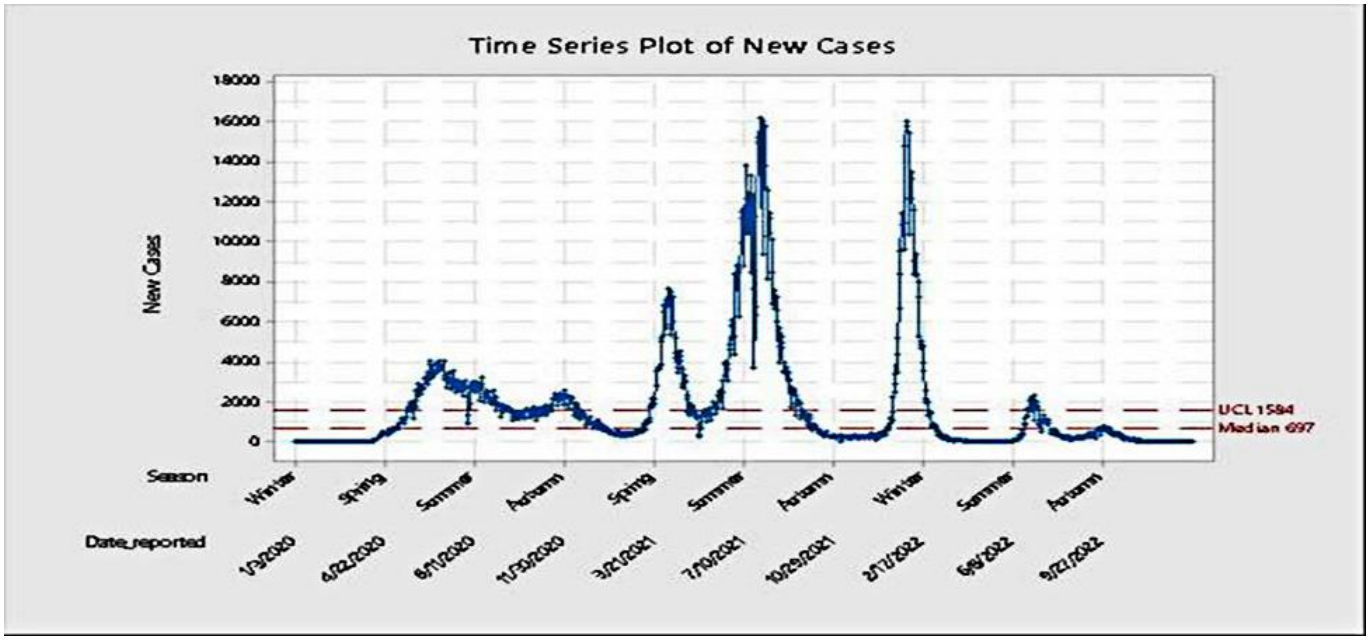

Figure 3. Seasonal trends in new cases of COVID-19 in Bangladesh from January 2020 to January 2023

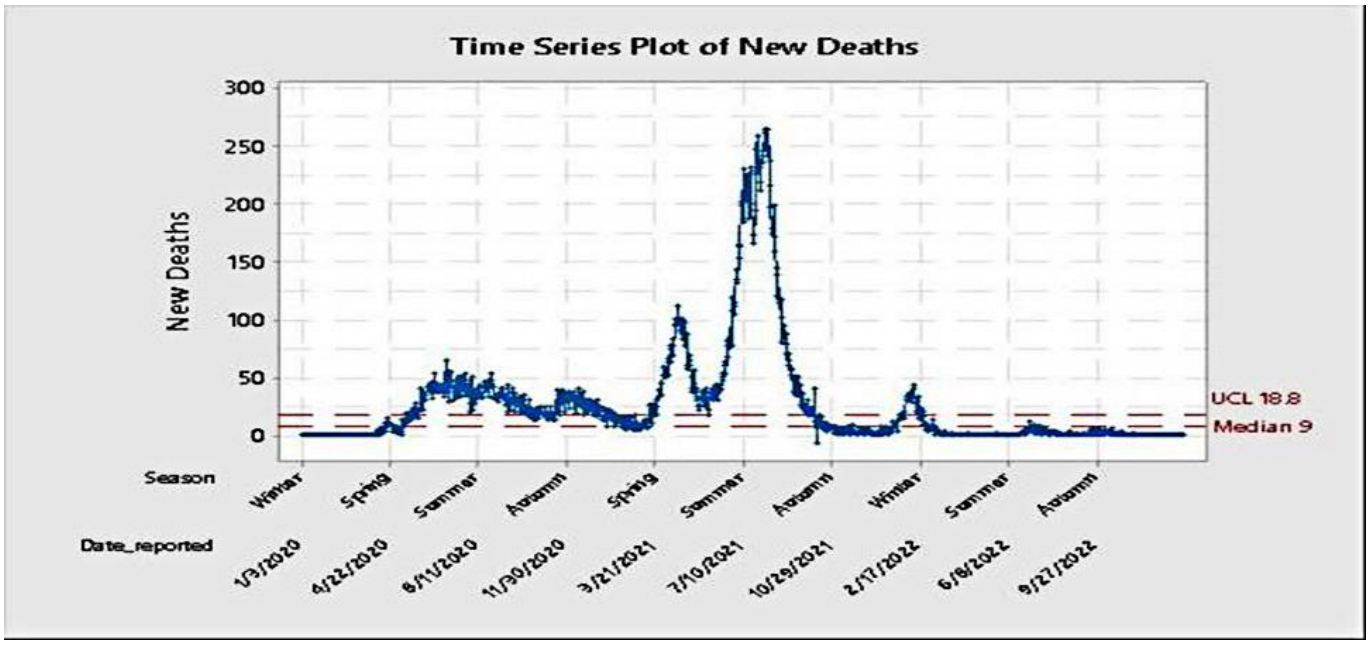

Figure 4. Seasonal trends in mortality rates of COVID-19 in Bangladesh from January 2020 to January 2023

DISCUSSION

The results of 3D visualization show a clear seasonal pattern of new COVID-19 cases in Bangladesh, with spikes during the summer and winter seasons. This suggests that the virus transmission is influenced by environmental factors such as temperature, humidity, and sunlight, as well as human behavior such as indoor activities and travel patterns (Saha & Gulshan, 2021; Kochańczyk & Lipniacki, 2021; Cegolon et al., 2023; WHO, 2023b). The results also show a remarkable peak and decline in both new cases and deaths in the summer of 2021, reaching almost 300 deaths per day at its highest point and dropping below 50 deaths per day by the end of the season (Anonymous, 2021). This could be attributed to several factors, such as the emergence of a new variant, the relaxation or tightening of public health measures, the increase or decrease of testing and reporting, or the effect of vaccination campaigns. The results also show a significant spike in both new cases and deaths around early 2022, coinciding with

the emergence of the highly contagious Delta variant in neighboring India and its spread to Bangladesh (WHO, 2023b). This highlights the need for timely and effective response to the emergence and spread of new variants, and the importance of regional and global cooperation and coordination to contain the virus.

The results also show a decline in both new cases and deaths in late 2022 and early 2023, indicating a reduction in transmission and mortality. This demonstrates the impact and benefits of implementing strict lockdown measures, ramping up testing and tracing, improving healthcare facilities, and rolling out vaccination campaigns, and the necessity of sustaining and scaling up these efforts (Saha & Gulshan, 2021; WHO, 2023b). To predict the future trends of the pandemic, it is essential to consider various factors, such as the vaccination rates, the public health measures, the virus variants, and the socio-economic impacts (Saha & Gulshan, 2021). According to the WHO, as of 4 January 2024, Bangladesh has fully vaccinated 142.2 million people, or 86.4% of its population (Anonymous, 2021). This is a remarkable achievement that could help prevent severe cases and deaths (Anonymous, 2024). However, there are still challenges and uncertainties, such as the emergence of new variants, the waning of vaccine immunity, the relaxation of preventive behaviors, and the inequity of vaccine access. Therefore, it is crucial to maintain vigilance and preparedness, and to adopt a holistic and adaptive approach to end the pandemic.

The Pareto results show a clear seasonal variation in the number of new COVID-19 cases in Bangladesh, with summer and winter having the highest peaks and autumn having the lowest trough. This suggests that the virus transmission is influenced by environmental factors such as temperature, humidity, and sunlight, as well as human behavior such as indoor activities and travel patterns (Saha & Gulshan, 2021). This is consistent with previous studies that have reported seasonal patterns of COVID-19 in different regions of the world (Anwar et al., 2020). The results also show that summer had the most severe outbreak of COVID-19 in Bangladesh, with over one million new cases accounting for more than half of the total cases. This could be due to several reasons, such as the relaxation of lockdown measures, the emergence of new variants, the low vaccination coverage, and the lack of public awareness – which is a major problem in many countries around the globe - and compliance with preventive measures. This highlights the need for timely and effective interventions to control the spread of the virus and protect the population, especially during the high-risk seasons. The results also show that winter had the second-highest peak of COVID-19 in Bangladesh, with nearly 450,000 new cases contributing to 22.1% of the total cases. This could be due to the increased susceptibility of people to respiratory infections in cold and dry weather, the reduced effectiveness of the immune system, the increased indoor gatherings and social events, and the reduced ventilation and air quality (Tuli et al., 2020; Hossain et al., 2021; Anonymous, 2024; WHO, 2024). This indicates the importance of strengthening the health system and enhancing the testing and tracing capacity, as well as promoting preventive behaviors and measures among the public, especially during the winter season.

The graph shows that there is a clear seasonal variation in the number of new COVID-19 deaths in Bangladesh, with summer and spring having the highest peaks and winter having the lowest trough. This suggests that the virus fatality is influenced by environmental factors such as temperature, humidity, and sunlight, as well as human behavior such as indoor activities and travel patterns. This is consistent with the previous discussion on new cases, which also showed a seasonal pattern.

The graph shows that summer had the most severe impact of COVID-19 in Bangladesh, with over 17,000 new deaths accounting for 59.1% of the total deaths. This aligns with the previous discussion on new cases, which also showed that summer had the most severe outbreak of COVID-19 in Bangladesh. The summer 2021 peak aligns with the Delta variant's emergence and relaxed mobility measures (Anonymous, 2021; Saha & Gulshan, 2021; WHO, 2023b). Seasonal trends mirror studies from India and Brazil, where heat and humidity influenced transmission (Tuli et al., 2020; Saha & Gulshan, 2021; Hossain et al., 2021; Anonymous, 2021, 2024; Essam Eissa, 2023; Eissa & Rashed, 2023; WHO, 2023b, 2024).

The graph shows that spring had the second-highest peak of COVID-19 in Bangladesh, with nearly 5,000 new deaths contributing to 16.8% of the total deaths. This is different from the previous discussion on new cases, which showed that winter had the second-highest peak of COVID-19 in Bangladesh. This could be due to the delayed effect of the virus on the mortality rate, as well as the increased strain on the health system and the limited availability of medical resources and treatments.

The graph shows that autumn had a decline in the number of new COVID-19 deaths in Bangladesh, with around 4,000 new deaths contributing to 14.5% of the total deaths (Tuli et al., 2020; Hossain et al., 2021; Anonymous, 2024; WHO, 2024). This is similar to the previous discussion on new cases, which also showed that autumn had a decline in the number of new COVID-19 cases in Bangladesh. This could be due to the improved public health measures or the environmental conditions that might have started showing positive effects. While cases peaked in summer and winter, deaths were highest in summer and spring, likely due to delayed mortality reporting and healthcare strain during overlapping waves

The graph shows that winter had the lowest impact of COVID-19 in Bangladesh, with around 2,800 new deaths contributing to 9.6% of the total deaths. This is different from the previous discussion on new cases, which showed that winter had a resurgence of COVID-19 in Bangladesh. This could be due to the improved public health measures or the adaptation to the environmental conditions that might have been conducive to virus transmission. Integrating the data on new deaths with the previous discussion on new cases provides comprehensive insights into both the infection rate and the fatality rate of COVID-19 across different seasons in Bangladesh. The graph shows that summer and spring were the most critical periods for COVID-19 in Bangladesh, while autumn and winter were relatively less affected (Tuli et al., 2020; Hossain et al., 2021; Anonymous, 2024; WHO, 2024). Therefore, it is important to continue to implement and enforce effective public health measures, such as wearing masks, social distancing, testing, tracing, and isolating, as well as to accelerate the vaccination campaign and monitor the emergence and spread of new variants.

Based on the graph, it is possible to project the future trend of COVID-19 in Bangladesh, assuming that the current situation and interventions remain unchanged. The graph indicates that spring and autumn have lower numbers of new cases than summer and winter, but still higher than the global average (WHO, 2024). The order seems different for daily recorded deaths. Therefore, it is important to stress again to continue to implement and enforce effective public health measures, such as wearing masks, social distancing, testing, tracing, and isolating, as well as to accelerate the vaccination campaign and monitor the emergence and spread of new variants.

The graph shows a clear seasonal pattern of new COVID-19 cases in Bangladesh, with spikes during the winter and summer seasons (Saha & Gulshan, 2020). This suggests that the virus may be more transmissible or virulent in colder or hotter weather, or that people's behavior and mobility may change with the seasons, affecting the spread of the virus (Tuli et al., 2020; Hossain et al., 2021; Anonymous, 2024; WHO, 2024). This is consistent with previous studies that have reported seasonal patterns of COVID-19 in different regions of the world.

The graph also shows the upper control limit (UCL) of the number of cases, which are calculated based on the average and standard deviation of the data. There is no lower control limit (LCL) as this type of data is one-sided inspection characteristic.

These limits indicate the range of variation that is expected or normal for the process. Any data point that falls outside the control limits is considered an outlier or a signal of a special cause of variation, such as a change in policy, testing, or intervention (Eissa et al., 2016; Essam Eissa & Refaat Rashed, 2020). This can help to identify and address the factors that affect the process performance and quality.

To extrapolate the future perspective of the COVID-19 situation in Bangladesh, one might anticipate similar patterns of case increases during the winter and summer seasons, unless significant interventions or changes occur, such as widespread

vaccination, implementation of stricter health protocols, or emergence of new variants (Eissa, 2024). The control limits can also be used to monitor the process and detect any abnormal or unexpected changes in the number of cases. This can help to evaluate the effectiveness of the interventions and adjust the response accordingly.

Figure 4 show that the mortality rate of COVID-19 in Bangladesh has varied over time, with a peak and decline in the summer of 2021 and a seasonal trend across the years. This section will discuss the possible explanations and implications of these findings, as well as the limitations and recommendations for future research.

The remarkable peak and decline in the summer of 2021 could be attributed to several factors, such as the emergence of a new variant, the relaxation or tightening of public health measures, the increase or decrease of testing and reporting, or the effect of vaccination campaigns. However, the exact causes and contributions of these factors are difficult to determine, as they may interact and vary across regions and populations (Tuli et al., 2020). Further studies are needed to investigate the epidemiological and behavioral dynamics of this period and to evaluate the impact and effectiveness of the interventions implemented.

The seasonal pattern observed in the graph suggests that the virus may be more transmissible or virulent in hot and humid conditions, or that people may have lower immunity or more exposure to the virus during the summer. This is consistent with some previous studies that have found a correlation between temperature, humidity, and COVID-19 transmission (Saha & Gulshan, 2020). However, other studies have challenged this hypothesis, arguing that other factors, such as population density, mobility, social mixing, and indoor ventilation, may play a more important role in determining the seasonality of the virus (Anwar et al., 2020). Moreover, the seasonal variation may also reflect the variation in testing and reporting, as well as the lag between infection and death (Johnsen et al., 2022). Therefore, more research is needed to understand the environmental and social factors that influence the seasonality of COVID-19 and to develop appropriate strategies to prevent and control the spread of the virus in different seasons.

Based on the graph, one might expect the death rates to remain low or stable in the upcoming winter season, and possibly rise again in the next summer season (Hossain et al., 2021). However, this projection is subject to many uncertainties and assumptions, and should not be taken as a definitive forecast (Tuli et al., 2020). The future course of the pandemic will depend on many factors, such as the evolution of the virus, the availability and effectiveness of vaccines and treatments, the adherence and enforcement of public health guidelines, and the behavior and awareness of the population. Therefore, it is important to monitor the situation closely and adjust the response accordingly.

One of the main limitations of this study is that it relies on the official data reported by the government and the WHO, which may not reflect the true extent and severity of the pandemic in Bangladesh. There may be underreporting or misreporting of cases and deaths due to various reasons, such as lack of testing, stigma, or political pressure (Siddika & Islam, 2022). Moreover, the data may not capture the differences and disparities among different regions, groups, and settings within the country (Hasan et al., 2021). Therefore, the results of this study should be interpreted with caution and validated by other sources of data, such as serological surveys, mortality registries, or hospital records (WHO, 2023a).

Another aspect that should be considered as a future extension of this study is that other factors should be considered, such as the hospitalization rate, the recovery rate, the excess mortality, and the quality of life (Alotaibi et al., 2022). Unfortunately, comprehensive and holistic data of these kinds are not always available. Moreover, the pandemic has also caused significant social, economic, and psychological consequences, such as poverty, unemployment, inequality, violence, and mental health problems, which may affect the health and well-being of the population in the long term (Borges do Nascimento et al., 2020). Therefore, future studies should adopt a more comprehensive and holistic approach to

measure and evaluate the impact of COVID-19 in Bangladesh and other countries.

CONCLUSION

In conclusion, this study has shown that the morbidity and mortality rates of COVID-19 in Bangladesh has varied over time, with a peak and decline in the summer of 2021 and a seasonal trend across the years. The possible explanations and implications of these findings have been discussed, as well as the limitations and recommendations for future research using special and unique statistical techniques. The study highlights the need for continuous monitoring and evaluation of the situation, as well as the development and implementation of effective and equitable strategies to prevent and control the spread of the virus and to mitigate its adverse effects. Assessing the future projection will be covered in extended study by monitoring periods after January 2023 and analyzing morbidities and mortalities till January 2026. A comparative examination will be conducted to evaluate the kinetics of the outbreak.

Critical periods for COVID-19 intervention and prevention in Bangladesh were identified and prioritized using the Pareto method. The relationship between new cases, new deaths, and reporting date was visualized using a surface plot, and the patterns and trends of the COVID-19 situation in Bangladesh were revealed. A timely and effective response to new variants was needed, and regional and global cooperation and coordination were required to contain the virus. Lockdown measures, testing and tracing, healthcare facilities, and vaccination campaigns were sustained and scaled up to reduce transmission and mortality. Vigilance and preparedness were maintained, and a holistic and adaptive approach was adopted to end the pandemic. Moreover, the Pareto chart of new COVID-19 deaths in Bangladesh by season reveals a clear seasonal variation, with summer and spring being the most fatal and winter being the least. This is partly consistent with the chart of new cases, which also showed a seasonal pattern, except for winter. The reasons for the seasonal variation could be related to environmental and behavioral factors, as well as the virus characteristics and the health system capacity. The findings suggest that preventive measures and vaccination programs should be tailored to the seasonal trends and the local context to effectively control the pandemic. The process-behavior charts of new COVID-19 cases and deaths in Bangladesh confirmed the seasonal pattern with aberrant waves emerging above the UCL suggesting out-of-control episodes of the outbreak. To effectively manage future public health crises, it's recommended that pre-emptive vaccination drives be conducted before anticipated summer and winter peaks in disease transmission. Furthermore, resource allocation to hospitals should be strategically increased during these high-risk seasons to ensure adequate capacity. Finally, public awareness campaigns are crucial to target and mitigate behavioral risks, such as increased indoor gatherings during winter, that can contribute to viral spread.

Compliance with Ethical Standards

Conflict of Interest

The author declares that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

Funding

Not applicable.

Data Availability

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

AI Disclosure

The author confirms that no generative AI was used in writing this manuscript or creating images, tables, or graphics.

REFERENCES

Alotaibi, N., Al-Dayel, I., Elbatal, I., Ezzeldin, M. R., Elgarhy, M., & Al-karawi, K. A. (2022). Statistical analysis of the COVID-19 epidemic in Saudi Arabia. *Advances and Applications in Statistics, 74*, 107-118. https://doi.org/10.17654/0972361722020

Anonymous. (2023a). *John Hopkins Coronavirus Resource Center*. Retrieved on March 10, 2023, from https://coronavirus.jhu.edu/data

Anonymous. (2023b). *Bangladesh Directorate General of Health Services, Ministry of Health and Family Welfare Coronavirus COVID-19 Dashboard*. Retrieved on June 1, 2023, from http://103.247.238.92/webportal/pages/covid19.php

Anonymous. (2021). *Covid-19: Crowds flee Dhaka ahead of strict Bangladesh lockdown*. BBC News. Retrieved on January 1, 2023, from https://www.bbc.com/news/world-asia-57624557

Anonymous. (2024). *COVID-19 vaccination in Bangladesh*. Retrieved on October 1, 2024, from https://dashboard.dghs.gov.bd/pages/covid19-vaccination-update.php

Anwar, S., Nasrullah, M., & Hosen, M. J. (2020). COVID-19 and Bangladesh: Challenges and how to address them. *Frontiers in Public Health*, *8*, 154. https://doi.org/10.3389/fpubh.2020.00154

Borges do Nascimento, I. J., Cacic, N., Abdulazeem, H. M., von Groote, T. C., Jayarajah, U., Weerasekara, I., Esfahani, M. A., Civile, V. T., Marusic, A., Jeroncic, A., Carvas Junior, N., Pericic, T. P., Zakarija-Grkovic, I., Meirelles Guimarães, S. M., Luigi Bragazzi, N., Bjorklund, M., Sofi-Mahmudi, A., Altujjar, M., Tian, M., Arcani, D. M. C., … Marcolino, M. S. (2020). Novel coronavirus infection (COVID-19) in humans: A scoping review and meta-analysis. *Journal of Clinical Medicine*, *9*(4), 941. https://doi.org/10.3390/jcm9040941

Cegolon, L., Magnano, G., Negro, C., Larese Filon, F., & ORCHESTRA Working Group (2023). SARS-CoV-2 Reinfections in Health-Care Workers, 1 March 2020-31 January 2023. *Viruses*, *15*(7), 1551. https://doi.org/10.3390/v15071551

Eissa M. (2024). Bioburden analysis and microbiological stability of municipal distribution system through examination of transformed total microbial count dataset. *Frontiers in Scientific Research and Technology*, *8*, 57-70. https://doi.org/10.21608/fsrt.2023.251967.1115

Eissa, M. (2022). Modeling of COVID-19 major outbreak wave through statistical software: Quantitative risk evaluation and description analysis. *ESTUDAM Public Health Journal*, *7*(1), 145-161. https://doi.org/10.35232/estudamhsd.1024129

Eissa, M. E., & Rashed, E. R. (2023). Analysis and modeling of morbidity and mortality from coronavirus outbreak in Brazil: A case study of public health challenge using unique statistical tools. *Journal of Health Science Research*, *8*, 57–61. https://doi.org/10.25259/JHSR_3_2023

Eissa, M. E., Mahmoud, A. M., & Nouby, A. S. (2016). Control chart in microbiological cleaning efficacy of pharmaceutical facility. *Dhaka University Journal of Pharmaceutical Sciences, 14*(2), 133-138.

Essam Eissa, M, & Refaat Rashed, E. (2020). Unique descriptive analysis approach of Ebola Outbreak from WHO database using statistical process control. *Singapore Journal of Scientific Research*, *10*(3), 336-341.

Essam Eissa, M. (2023). Studies on morbidities and mortalities from COVID-19: Novel public health practice during pandemic periods. *Asian Journal of Applied Sciences*, *16*, 84-94. https://doi.org/10.3923/ajaps.2023.84.94

Ferdous, M. Z., Islam, M. S., Sikder, M. T., Mosaddek, A. S. M., Zegarra-Valdivia, J. A., & Gozal, D. (2020). Knowledge, attitude, and practice regarding COVID-19 outbreak in Bangladesh: An online-based cross-sectional study. *PLoS One*, *15*(10), e0239254. https://doi.org/10.1371/journal.pone.0239254

Gürsakal, N., Batmaz, B., & Aktuna, G. (2020). Drawing transmission graphs for COVID-19 in the perspective of network science. *Epidemiology and Infection*, *148*, e269. https://doi.org/10.1017/S0950268820002654

Hasan, S. M., Das, S., Hanifi, S. M. A., Shafique, S., Rasheed, S., & Reidpath, D. D. (2021). A place-

based analysis of COVID-19 risk factors in Bangladesh urban slums: A secondary analysis of World Bank microdata. *BMC Public Health*, *21*, 502. https://doi.org/10.1186/s12889-021-10230-z

Hossain, M. B., Alam, M. Z., Islam, M. S., Sultan, S., Faysal, M. M., Rima, S., Hossain, M. A., & Mamun, A. A. (2021). COVID-19 vaccine hesitancy among the adult population in Bangladesh: A nationwide cross-sectional survey. *PLoS One*, *16*(12), e0260821. https://doi.org/10.1371/journal.pone.0260821

Hosseinzadeh, P., Zareipour, M., Baljani, E., & Moradali, M. R. (2022). Social consequences of the COVID-19 pandemic. A systematic review. *Investigacion y Educacion en Enfermeria*, *40*(1), e10. https://doi.org/10.17533/udea.iee.v40n1e10

Johnsen, M. G., Christiansen, L. E., & Græsbøll, K. (2022). Seasonal variation in the transmission rate of covid-19 in a temperate climate can be implemented in epidemic population models by using daily average temperature as a proxy for seasonal changes in transmission rate. *Microbial Risk Analysis*, *22*, 100235. https://doi.org/10.1016/j.mran.2022.100235

Kochańczyk, M., & Lipniacki, T. (2021). Pareto-based evaluation of national responses to COVID-19 pandemic shows that saving lives and protecting economy are non-trade-off objectives. *Scientific Reports*, *11*(1), 2425. https://doi.org/10.1038/s41598-021-81869-2

Lytton, S. D., & Ghosh, A. K. (2024). SARS-CoV-2 variants and COVID-19 in Bangladesh—Lessons learned. *Viruses*, *16*(7), 1077. https://doi.org/10.3390/v16071077

Saha, P., & Gulshan, J. (2021). Systematic assessment of COVID-19 pandemic in Bangladesh: Effectiveness of preparedness in the first wave. *Frontiers in Public Health*, *9*, 628931. https://doi.org/10.3389/fpubh.2021.628931

Siddika, A., & Islam, D. (2022). Covid-19 and Bangladesh: A study of the public perception on the measures taken by the government. *The Dhaka University Studies Journal of The Faculty of Arts*, *79*(1-2), 113-128. https://doi.org/10.62296/DUS202212008

Tuli, S., Tuli, S., Tuli, R., & Gill, S. S. (2020). Predicting the growth and trend of COVID-19 pandemic using machine learning and cloud computing. *Internet of Things*, *11*, 100222. https://doi.org/10.1016/j.iot.2020.100222

UNICEF. (2022). *UNICEF: 190 million COVID-19 vaccines delivered under COVAX*. Retrieved on October 1, 2024, from https://www.unicef.org/rosa/press-releases/unicef-190-million-covid-19-vaccines-delivered-under-covax

World Health Organization (WHO). (2023a). *WHO COVID-19 dashboard*. Retrieved on January 1, 2023, from https://data.who.int/dashboards/covid19/

World Health Organization (WHO). (2023b). *COVID-19 dashboard, COVID-19 Cases, World*. Retrieved on January 1, 2023, from https://data.who.int/dashboards/covid19/cases

World Health Organization (WHO). (2024). *07 December 2020 Morbidity Mortality Weekly Update (MMWU) No.41*. Retrieved on January 16, 2024, from https://cdn.who.int/media/docs/default-source/searo/bangladesh/covid-19-who-bangladesh-situation-reports/who_covid-19-update_41_20201207.pdf?sfvrsn=d21baace_7