

Original Research Article

Monitoring of three-phase variations in the mortality of COVID-19 pandemic using control charts: where does Pakistan stand?

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Abstract

Background: At the end of December 2019, the world in general and Wuhan, the industrial hub of China, in particular, experienced the COVID-19 pandemic. Massive increment of cases and deaths occurred in China and 209 countries in Europe, America, Australia, Asia and Pakistan. Pakistan was first hit by COVID-19 when a case was reported in Karachi on 26 February 2020. Several methods were presented to model the death rate due to the COVID-19 pandemic and to forecast the pinnacle of reported deaths. Still, these methods were not used in identifying the first day when Pakistan enters or exits the early exponential growth phase.

Objective: The present study intends to monitor variations in deaths and identify the growth phases such as pre-growth, growth, and post-growth phases in Pakistan due to the COVID-19 pandemic.

Methods: New approaches are needed that display the death patterns and signal an alarming situation so that corrective actions can be taken before the condition worsens. To meet this purpose, secondary data on daily reported deaths in Pakistan due to the COVID-19 pandemic have been considered. The c and exponentially weighted moving average (EWMA) control charts have been used for monitoring variations.

Results: The c -chart shows that Pakistan switches from the pre-growth to the growth phase on 31 March 2020. The EWMA chart demonstrates that Pakistan remains in the growth phase from 31 March 2020 to 17 August 2020, with some indications signaling a decrease in deaths. It is found that Pakistan moved to a post-growth phase for a brief period from 27 July 2020 to 28 July 2020. Pakistan switches to re-growth phase with an alarm on 31/7/2020, right after the short-term post-growth phase. The number of deaths starts decreasing in August in that Pakistan may approach the post-growth phase shortly.

Conclusion: This amalgamation of control charts illustrates a systematic implementation of the charts for government leaders and forefront medical teams to facilitate the rapid detection of daily reported deaths due to COVID-19. Besides government and public health officials, it is also the public's responsibility to follow the enforced standard operating procedures as a temporary remedy of this pandemic in ensuring public safety while awaiting a suitable vaccine to be discovered.

Key words: c -chart, COVID-19 pandemic, EWMA chart, growth phases, mortality, run chart

Introduction

Viral diseases are prevalent and wide reaching. They range from minor infections to epidemics that alter history. Among the different types of viruses, the coronavirus, first characterized in the 1960s, is responsible for many human and animal diseases. A type of human coronavirus, which causes respiratory infections in humans, has rapidly evolved in this century [1]. At the end of December 2019, an epidemic diagnosed with pneumonia for unknown reasons came into view in Wuhan city of China [2]. Later, this epidemic spread rapidly in almost every part of the world, including Pakistan. The International Committee on Taxonomy of Virus named this new virus as Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2). It is now believed that bats and palm civets are the natural cause of SARS-CoV transmission in humans in Southern China [3]. This virus attacks the respiratory system of humans [4]. On 11 February 2020, the World Health Organization (WHO) named the virus as Coronavirus disease-19 (COVID-19).

China, in the northeast region of Pakistan, initially experienced drastic increase in COVID-19 cases and deaths; Italy in the west has the most number of mortalities due to COVID-19. Furthermore, Iran in the north has the second-highest number of mortalities after Italy [5]. Due to border sharing with China and Iran, Pakistan is also affected by this virus. The first case of COVID-19 was reported on 26 February 2020, in Karachi, while on the same day, a second case was detected in Islamabad [6]. Different precautionary measures have been adopted and suggested by WHO to help control the spread of this pandemic. Few studies also proved these measures to be beneficial. Using the chi-square technique [7] uttered that the use of facemask by healthy people in society could reduce the spread of respiratory viruses and control COVID-19.

As the number of reported deaths fluctuates every day, researchers struggle to recognize meaningful improvement signals in this pandemic if these fluctuations are not considered. Monitoring variation in deaths and identifying the growth phases for COVID-19 infection in Pakistan can help assess the control policies' effectiveness and make evidence-based decisions for further actions.

The Shewhart control charts have been applied successfully to address various problems in different fields, such as healthcare, manufacturing industries, the education sector and human well-being [8]. Understanding the control charts' characteristics can help recognize changes in the disease's levels and, consequently, enable public-health actions to reduce the unnecessary morbidity and mortality rates. However, the application of control charts in epidemics is limited [9].

The exponentially weighted moving average (EWMA) chart has been used to estimate the expected outcomes and correct counts by controlling the risk factors [10]. According to [11], control charts are used to timely detect outbreaks in public healthcare. Early detection of infected patients and the initial stage of a seasonal disease have been discussed by [12, 13]. The EWMA chart has been used for monitoring the laboratory-confirmed influenza counts to identify the start and end of an influenza spread because rapid and reliable detection of the beginning of an epidemic is needed to support public health measures [14]. The EWMA chart gave an improved graphical statistical tool to observe and improve cardiac surgery [15]. For more details, cf [16, 17].

The c -chart has been used to reduce the time for assembling medical records [18]. The c -chart monitors the pre-growth phase from the first day of reported death(s). Pre-growth is the phase when the daily reported deaths are low and stable in a geographical area

[19]. Implementing a run chart to reduce ventilator-associated pneumonia rates to achieve improved performance in the basic units of care for all ventilated patients has been presented in [20]. Timely investigation on daily reported deaths during a pandemic based on early-warning signals may give health officials life and death implications to improve the situation. This improvement can provide methods to represent and interpret variation, vital for a successful organizational alteration in reaction to COVID-19 [21]. A novel Shewhart chart has been developed to visualize variation in reported deaths due to COVID-19 [22].

Objectives and significance of the study

Research on the existing studies on COVID-19 in general and investigations of the number of deaths, in particular, were conducted across various countries. Yet, the number of deaths in Pakistan is not studied. Therefore, in this research, the intent is to monitor variations in deaths and identify the different growth phases, such as pre-growth, growth, and post-growth phases, using control charts instead of other qualitative and quantitative research methods employed by numerous researchers.

Methods

When a viral disease initially spreads in a region, it does not significantly increase the number of infected people at once; instead, the number of infected people increases gradually, reaching the peak and declining thereafter. This phenomenon consists of three phases: pre-growth, growth and post-growth phases. It has been witnessed that, on average, the growth curve of COVID-19 begins with a pre-growth phase, which is described by a benign growth or a smaller number of deaths. Then it is accelerated by the pandemic, which is called exponential growth [23]. By using expedient trials against the spread of the pandemic, the exponential growth can be slowed down and, at times, can be declined, which is then known as the post-growth phase. Therefore, it is necessary to identify at what phase of growth the infected cases and deaths are.

Study design

This research is based on an observational study. The draft has been written in line with the Reporting of studies Conducted using Observational Routinely collected health Data [24].

Setting

The secondary data for the daily reported deaths in Pakistan due to COVID-19 were considered and taken from the WHO Coronavirus Disease (COVID-19) Dashboard. All the reported deaths from 26 February 2020 to 17 August 2020 were retrieved from <https://covid19.who.int/table> [25]. The data were accessed on 19 August 2020.

Participants

From all COVID-19 cases in Pakistan, the cases resulting in deaths due to COVID-19 infection from 26 February 2020 to 17 August 2020 are considered.

Variables

The quantitative variable 'daily reported deaths' due to COVID-19 only has been considered.

Statistical methods

This study investigates the implementation of control charts in monitoring variations in the number of deaths for different phases of COVID-19 in Pakistan.

Run chart

Growth happens over time, and to determine whether growth is on the way or enduring, it is required to observe patterns over time. The run chart is one of the most effective tools for assessing variation. The run chart is implemented to observe the general pattern of deaths in a region.

c-chart

Walter A. Shewhart proposed the *c*-chart. It is used for monitoring variation in nonconformities or count data. In the present research, the aim is to monitor the variation in deaths; hence, an appropriate chart is the *c*-chart. As the *c*-chart is useful for rare events, the computation of parameters of a *c*-chart depends on the standard error of a Poisson distribution. The 3-sigma upper control limit (*UCL*) and lower control limit (*LCL*), as well as the central line of the *c*-chart are given as follows:

$$UCL = \bar{c} + 3\sqrt{\bar{c}} \quad (1a)$$

$$CL = \bar{c} = \frac{\sum c}{k}, k > 1 \quad (1b)$$

and

$$LCL = \bar{c} - 3\sqrt{\bar{c}} \quad (1c)$$

where \bar{c} is the average number of deaths and the central line of the *c*-chart. Here, k represents the number of samples or subgroups [26].

Calculations for the *c*-chart

The following steps were adopted to plot the *c*-chart on the lines of [22].

1. Start with the date when the first death occurs in Pakistan. Plot the number of deaths against each day.
2. Calculate the control limits and central line of the *c*-chart using Equations (1a)–(1c) when at least eight total deaths have been reported by considering all reported deaths from 19 March 2020 to 26 March 2020. Noting that the rule of at least eight total deaths is based on the study [22].
3. Plot the points on the *c*-chart based on the limits computed in Step 2 and update control limits every day. Then look for a point that indicates that the number of deaths has exceeded the *UCL*, signaling an alarm to the country and healthcare department. According to [22], if 20 points fall within control limits, freeze the central line and upper control limit and extend the limits into the future. Besides, a point plotting above the *UCL* indicates the beginning of the growth phase, and then stop monitoring with the *c*-chart and switch to the growth chart.

EWMA chart

The EWMA chart was first introduced by Roberts in 1959 [27]. If x_i represents the number of deaths per day, then the EWMA statistic is defined as

$$Z_i = \lambda x_i + (1 - \lambda) Z_{i-1}, \text{ for } i = 1, 2, 3, \dots \quad (2)$$

where $0 < \lambda \leq 1$ is a smoothing constant. The initial value Z_0 is the process target so that $Z_0 = \mu_0$ but sometimes, the average of preliminary data may be considered as the starting value, i.e. $Z_0 = \bar{x}$. The EWMA chart depends on the selected value of λ , where a smaller value of λ leads to quicker detection of small shifts. The EWMA statistic can be regarded as a weighted average of all past and recent observations, so it is insensitive to the normality assumption. Therefore, the EWMA chart is ideal to use with individual observations [26]. The EWMA chart can be constructed by plotting Z_i with respect to time. The control limits and central line of the EWMA chart are given by

$$UCL = \mu_0 + L\sigma \sqrt{\frac{\lambda}{2-\lambda} (1 - (1-\lambda)^{2i})} \quad (3a)$$

$$CL = \mu_0 \quad (3b)$$

and

$$LCL = \mu_0 - L\sigma \sqrt{\frac{\lambda}{2-\lambda} (1 - (1-\lambda)^{2i})} \quad (3c)$$

where σ is the standard deviation of the independent random observations x_i . The term $(1 - (1 - \lambda)^{2i})$ approaches unity as i tends to infinity. Thus, the steady-state control limits are given by

$$UCL = \mu_0 + L\sigma \sqrt{\frac{\lambda}{2-\lambda}} \quad (4a)$$

$$CL = \mu_0 \quad (4b)$$

and

$$LCL = \mu_0 - L\sigma \sqrt{\frac{\lambda}{2-\lambda}} \quad (4c)$$

The factor L is the width of the control limits and is often set as 3 [28]. Simultaneously, a small value of λ , say $\lambda = 0.2$, is usually considered to enable the EWMA chart to be effective in detecting small process shifts [26].

Calculations for the EWMA chart

Calculate the control limits and central line of the EWMA chart (growth phase) using Equations (4a)–(4c) when the *c*-chart (pre-growth phase) indicates the beginning of the growth phase. Plot the EWMA statistic computed using Equation (2) on the EWMA chart and look for possible signals.

Results

Participants

There were 289 215 reported coronavirus positive cases in Pakistan from 26 February 2020 to 17 August 2020. Among these cases, a total of 6175 deaths occurred and have been used in developing a run chart and the control charts.

Figure 1 shows that deaths occurred in an increasing trend and reached the apex before decreasing thereafter, giving an illustration of the three different growth phases. A sketch of the beginnings and ends of the pre-growth, growth, and post-growth phases is shown in Figure 1, based on the definitions defined in [22].

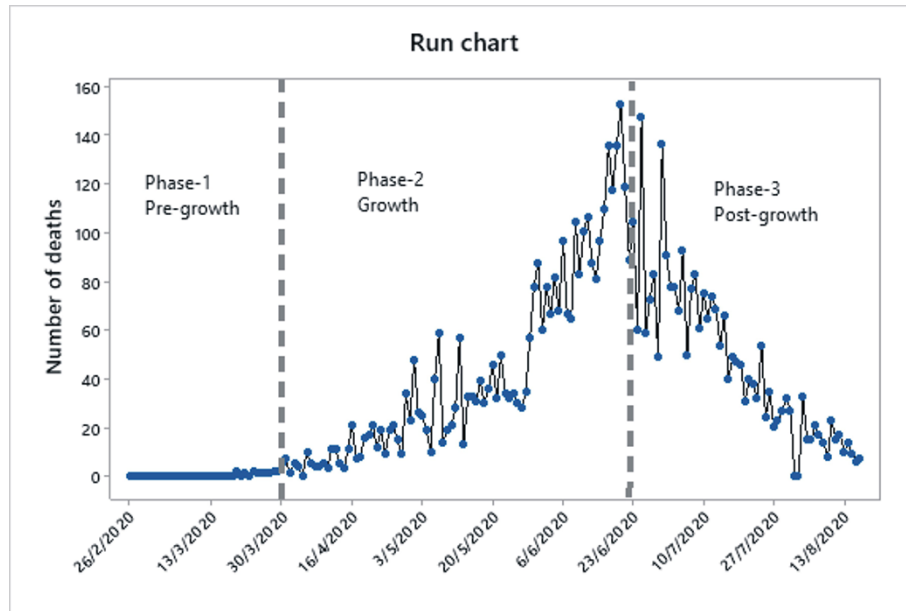


Figure 1 Run Chart of deaths from COVID-19.

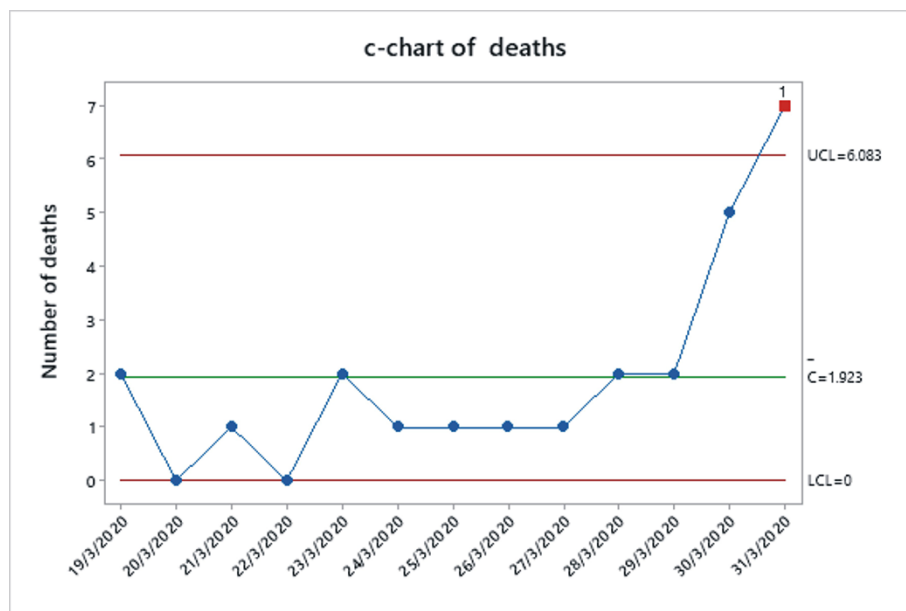


Figure 2 *c*-chart of deaths from COVID-19.

Pre-growth phase

The first stage, when deaths in a region are less and stable, is known as the pre-growth phase, and the chart used for this phase is the *c*-chart for count data [22]. The pre-growth phase encompasses the day when the first death was reported in Pakistan on 19 March 2020. The focus of the analysis at this stage is to study the pattern of reported deaths in determining whether the pandemic has shifted to the growth phase.

The *c*-chart in Figure 2 shows that the first point falls above the *UCL* on 31 March 2020, and this signals the first alarm to the healthcare officials and government. Hence, the pre-growth phase

switched to the growth phase on 31 March 2020. The *c*-chart issued a signal right after the 12th day since the first death was reported (see Figure 2).

Growth phase

The growth phase starts when the reported death curve due to the COVID-19 pandemic stops being stable and starts increasing exponentially. The growth phase begins on the day when the *c*-chart exposes the first special cause, signaling on 31 March 2020 when a point falls above the *UCL*. The EWMA chart is used to investigate

the growth phase. The following steps were used to construct the EWMA chart:

1. Switch monitoring from the c -chart (pre-growth phase) to the EWMA chart (growth phase) and compute the control limits using the number of deaths for 20 days, that is, from 31 March 2020 to 19 April 2020. The EWMA chart issues a signal when a point falls above the UCL or below the LCL . Figure 3a depicts that no point falls beyond the control limits, meaning that Pakistan's COVID-19 pandemic is in the growth phase.
2. Compute new control limits for the number of deaths of the next 20 days from 20 April 2020 to 9 May 2020 and check whether any point falls below the LCL , signaling that the growth phase has ended. In Figure 3b, there is no point falling beyond the control limits, meaning that the number of deaths is static in the growth segment. The same scenario is observed in Figure 3c.
3. Figure 3d shows a decrease and then an increasing trend in the number of deaths for the next 20 days (30 May 2020 to 18 June 2020). It reveals that the number of deaths is still in the growth phase, where deaths increased alarmingly on 18 June 2020 when a point falls above the UCL .
4. Figure 3e displays the trend for the subsequent 20 days (19 June 2020 to 8 July 2020). It exhibits that the COVID-19 situation in Pakistan is still in the growth phase with 4922 cumulative deaths and 237 489 reported cases since the first day when Pakistan was affected by the pandemic.
5. It is evident from Figure 3f that Pakistan has sustained in the growth phase from 9 July 2020 to 28 July 2020. The growth curve takes a shrill growing trend forming an upward run of four consecutive days of increased deaths from 10 July 2020 to 13 July 2020. Also, the number of fatalities between 10 July 2020 to 16 July 2020 falls above the UCL , which is alarming.
6. It can be viewed in Figure 3g that after a decrease in the number of deaths, at some point, newly infected cases outburst in Pakistan, and a re-growth phase emerged. It is evident from Figure 3g that the growth phase still prevails in Pakistan, and during this time, the number of deaths and the number of cases are decreasing gradually, which might signal that the growth phase is about to end soon.

Post-growth phase

The post-growth phase may begin on the day(s) when the EWMA chart signals some points falling below the LCL (see Figure 3f). The points from 27 July 2020 to 28 July 2020 lie below the LCL , signifying that the number of deaths is decreasing, and the COVID-19 pandemic may have shifted to the post-growth phase.

Discussion

Statement of principal findings

Pakistan faces all three phases due to variations in deaths and among the phases, the growth phase is the longest, in terms of time, followed by the pre-growth and post-growth phases. The growth phase agonizes Pakistan for almost four and a half months. In between, a short-term post-growth phase appears between 27 July 2020 and 28 July 2020. A re-growth phase emanates after two days, which is the most crucial phase in the death cases' growth curve [31].

Strengths and limitations

Healthcare officials and the government will remain informed, vigilant and active after monitoring the variation with control charts. This study highlights the feeble aspects of the government, health sector, state authorities and public. It will facilitate a better understanding of the phases of growth of the coronavirus pandemic, hence, preparing for better and proper handling should the same type of pandemic happens again.

This study is limited to monitoring the variation in the number of deaths due to the coronavirus pandemic. No comparison is made among the control charts. The efficiency of control charts can be compared based on the speed of the charts in the detection of alarming deaths due to COVID-19. The findings are limited to the accuracy of the reported data. The more accurate the reported data are, the better will be the findings.

Interpretation

Pre-growth phase

The c -chart indicates that something may be going vilest soon, although, at the start, the government remained saying, 'no need to panic' [6]. A timely signal was generated, but it was ignored. A reliable, timely signal might have issued a warning about the pandemic situation [22]. Early signals might have given healthcare officials life and death implications to improve the condition [21]. The number of deaths started increasing in the last couple of days in March 2020. This might be due to the pilgrims travelling back from Iran even though stranded pilgrims from the virus-hit areas in Iran were quarantined at the Taftan border. The first two cases had a travel history to Iran, and around 8000 pilgrims had already travelled to Pakistan before the institution of quarantine [29]. This could be the cause of the spread of COVID-19 cases in Pakistan and later deaths that were signaled on 31 March 2020, consequently starting the growth phase.

Growth phase

The COVID-19 cases and deaths surged across Pakistan exponentially when the government removed the lockdown before Eid-ul-Fitr (Holy day) celebration between 24 May 2020 and 26 May 2020. People showed sheer negligence by ignoring wearing facemasks, mobilizing, handshaking, visiting, and even embracing each other, compromising fatalities. The use of facemask among healthy people in society could reduce respiratory viruses and control the spread of COVID-19 [7]. The risk of death can be reduced by practicing self-isolation, proper hand washing and immobilizing, and therefore, the entire community can be protected [30].

The exponential growth offers people two primary choices, i.e. to act before time or be overwhelmed. Even after experiencing this terrible situation, the government and the public again exhibit absolute carelessness in the first 15 days of July 2020, when healthcare officials' directives have been disregarded. Consequently, seven consecutive signals have been generated (see Figure 3f). After every media reporting on increasing deaths and government negligence, the government took mitigation measures by imposing fines and made announcements through print and electronic media. It made announcements on wearing face masks, practicing social distancing, using hand sanitizers and staying at home. This resulted in a decrease in the number of deaths and shifted the spread arc from the growth phase to the post-growth phase in the last two weeks of July 2020 (see Figure 3f). If government and healthcare officials understand the disease levels, they can reduce mortality due to COVID-19 [9].

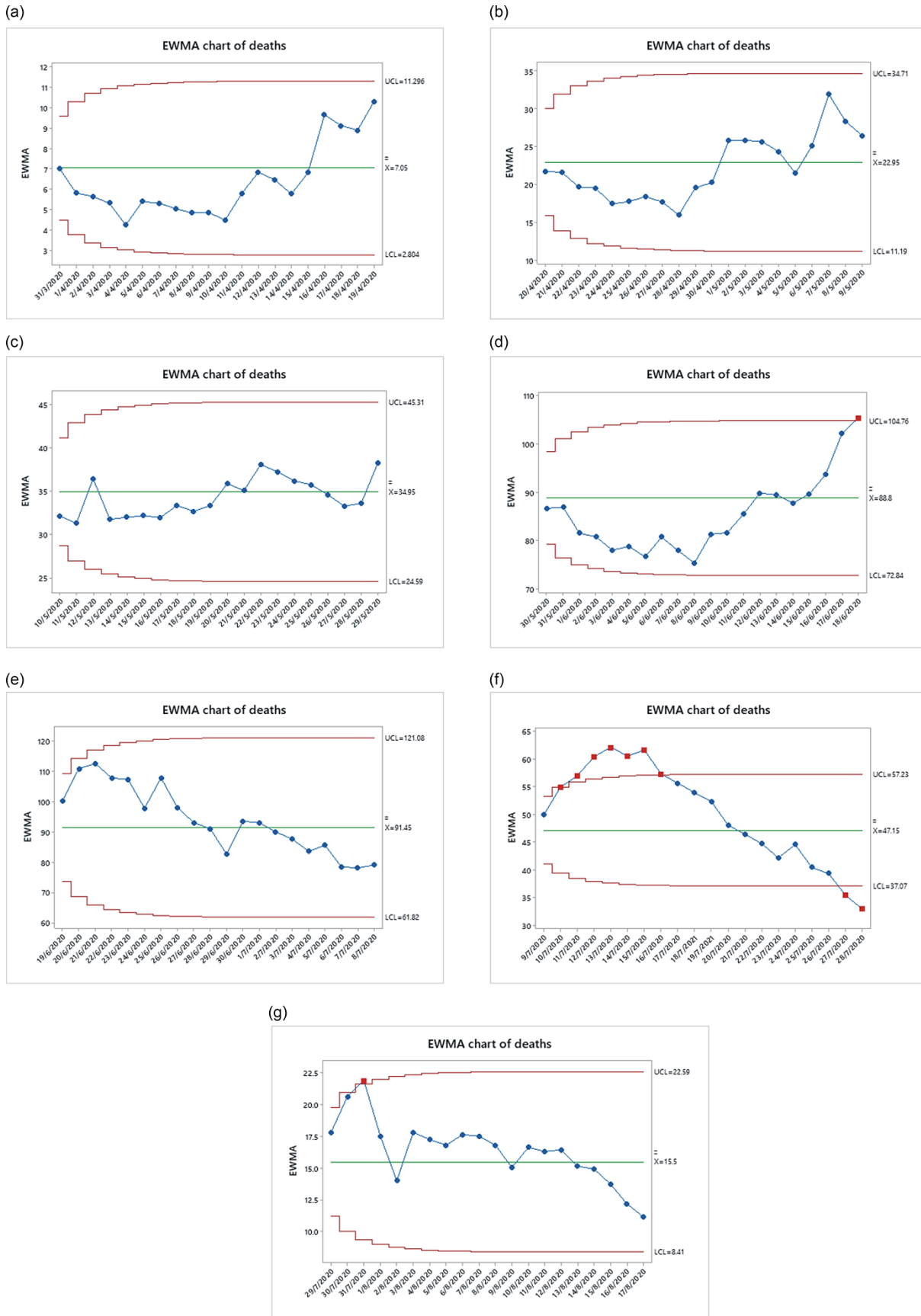


Figure 3 EWMA chart of deaths from COVID-19 (31 March 2020 to 17 August 2020).

Another reason contributing to the COVID-19 cases and deaths in Pakistan is that its citizen initially assumed no coronavirus disease in the country. They thought that the media was creating sensation through fake reporting of the trajectory of COVID-19 cases and deaths in the world, in general, and Pakistan, in particular [22].

The re-growth phase indicates an alarming situation (See Figure 3g) and the most dreadful phase in the death cases' growth curve [31]. It was the time when the government completely lifted the lockdown, except for educational institutions. Unfortunately, mitigation measures could not be implemented effectively and enforced for a long and indefinite period in the country, primarily due to religious occasions, like Eid-ul-Azhaa (Holy Day), celebrated a day after a point lies above the UCL on 31 July 2020. Certainly, loosening the mitigation measures during the growth phase will lead to the beginning of a terrible re-growth phase.

Post-growth phase

Preventive measures against this pandemic may influence the growth curve so that the growth curve either remains stable or shifts to the post-growth phase depending on the practical implementation of the seemingly measures.

Implications on policy, practice and research

Monitoring variation in the number of deaths and identifying the growth phases of COVID-19 infection in Pakistan can help assess the control policies' effectiveness and make evidence-based decisions for the future. Healthcare officials can safeguard humanity by practicing the knowledge gained in coping with this pandemic. The public has to practice the directives issued by the government and healthcare officials. The government and research institutes should help world organizations overcome this pandemic by exploring the causes and sharing the latest research findings.

Conclusions

The c and EWMA charts have been successfully employed to monitor the number of deaths by signaling alarms and identifying pre-growth, growth and post-growth phases. The run chart (26 February 2020 to 17 August 2020) shows a general pattern of the number of deaths due to COVID-19 in terms of the growth phases. The c -chart depicts that the pre-growth phase of deaths due to the COVID-19 pandemic had started in Pakistan on 19 March 2020 when the first death was reported, and this phase ended on 31 March 2020. Pakistan's COVID-19 situation switched from the pre-growth to the growth phase on 31 March 2020 and remained in the growth phase until 17 August 2020 (almost four and a half months). The EWMA chart has indicated that Pakistan's COVID-19 situation moved to the post-growth phase between 27 July 2020 and 28 July 2020.

The COVID-19 pandemic in Pakistan entered a re-growth phase after this short-term post-growth phase, and this may be due to relaxation in the implementation of the suggested growth-phase-based mitigation measures and negligence among the public. Figure 3f and 3g displays a trend of diminishing deaths, but this can only be sustained if precautionary measures are adopted.

Supplementary material

Supplementary material is available at *International Journal for Quality in Health Care* online.

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Contributorship

Y.M. Conceptualization, Formal analysis, Data curation, Visualization, Writing - original draft. S.I. Software, Data curation, Visualization, Writing - original draft. M.B.C.K. Statistical Analysis, Validation, Writing - review & editing. S.Y.T. Methodology, Statistical Analysis, Writing - review & editing. H.K. Validation, Writing - review & editing.

Data availability

The data underlying this article are available in [WHO Coronavirus Disease (COVID-19) Dashboard] at [<https://covid19.who.int/table>] and can be accessed with [accession number, 32429679].

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