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Using Quality Control Charts for Monitoring COVID-19 Daily Cases and Deaths in Türkiye

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Abstract
In this study, since the nationwide partial curfews during the COVID-19 process in Türkiye began on November 18, 2020; especially for the periods between 25.11.2020-31.05.2022, the daily new cases and for the periods between 27.03.2020-31.05.2022, deaths and for the periods between 27.03.2020 to 04.07.2021, fatality rates are monitored by quality control charts. In this research, Run charts, EWMA control charts, and p-control charts are used for monitoring the COVID-19 process in Türkiye. In the periods of nationwide extended curfews (December 1, 2020–February 28, 2021), full lockdown (April 29–May 16, 2021), and gradual normalization (May 17– May 31, 2021), the number of daily cases and deaths show downward trend as it is expected. However, in periods of the local decision-making phase (March 1–29, 2021) and revised local decision-making phase (March 30–April 13, 2021), the number of new daily cases and deaths show an upward trend. In partial lockdown period (April 14-28, 2021), while the number of daily cases shows a downward trend, the number of deaths shows an upward trend. For January 1-May 31, 2022, both the number of daily cases and deaths show an upward trend until February 2022, when they reach a peak for this month then they start to decrease gradually. Fatality rate results show that in the periods of 27.03.2020–17.11.2020, 01.12.2020–28.02.2021, 01.03.2021–29.03.2021, 29.04.2021–16.05.2021 and 01.06.2021-04.07.2021, there are uptrends or downtrends. The daily new cases/deaths and fatality rates due to COVID-19 are monitored rapidly and effectively by control charts. In the future, the risks of this pandemic could be raised again and in that case, the effects of various precautions on the number of cases or deaths could be monitored by using various quality control charts and the process could be managed logically and scientifically for Türkiye.

1. Introduction

The outbreak of COVID-19 rapidly disseminated from China in December 2019, and in March 2020, stated as a pandemic by the World Health Organization. Türkiye reported its first COVID-19 case on 11.03.2020, and since that time, more than 17 million cases and 100000 deaths reported in the country. The surge in the number of new patients, cases, and deaths has posed a significant risk to public health in Türkiye, as in other countries. To mitigate this risk, Türkiye and other nations have implemented measures to contain the spread of the virus, and mitigate the pandemic's negative impact on public health and economies [1].

Statistical Process Control (SPC) methods have significant roles in monitoring hospital performance, for example, fatality rate, pre and post-operative complexities, and number of infections in a hospital, etc. [2, 3]. SPC and the control chart, which is its prime instrument, allow researchers better with communicating and understanding data from

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healthcare advance attempts [4]. Hence, the usage of SPC appears well-fitted for directing the pandemic by carefully observing indicators for the active development of the control plans applied by healthcare practitioners and political authorities.

There are studies on using quality control charts for monitoring COVID-19 data sets for different countries. Some of them listed below [5].

Arafah [6] inspected the usage of Laney p’ control chart and the practice of test rules for evaluating governmental intercessions during the COVID-19 pandemic and understanding how specific actions and circumstances that happened affected the infection proportion. Laney (2002) has warned about the potential for overdispersion when employing the p-control chart, particularly for scenarios with large sample sizes, which could result in control limits too closely spaced. This closeness may lead to identify an excessive number of data points signal particular cause variation inappropriately. Laney introduced the concept of the Laney p’ control chart to mitigate this risk. The infection rate (IR) data for the period of 31.10.2020-19.03.2022 used. IR computed by dividing the number of confirmed cases by the number of PCR (polymerase chain reaction) tests conducted. He used the Laney p’ control chart for monitoring the COVID-19 IR and compared its performance with the exponentially weighted moving average (EWMA) control chart. Moreover, the performance of different test rules in observing IR changes analyzed. Making a comparison of the EWMA control chart with the Laney p’ control chart, the data revealed that in most situations, the Laney p’ control chart could specify the variation of IR faster. Odunayo et al. [7] monitored the analysis of COVID-19 in Africa. The data set was obtained from the Africa Centre for Disease Control (Africa CDC) at 10:00 PM on 24.04.2020, which contains several African countries with a number of deaths, number of discharged/recovered cases, and confirmed cases. Control charts, Pareto analysis, fishbone diagram, pie chart, and bar chart were the quality control methods used in this study. For Pareto analysis to identify the Areas (Countries) where more intervention would be needed, they draw a horizontal line from the 80% mark on the vertical cumulative percentage axis and, where it crosses the line graph, a line down to the horizontal axis also was drawn. The Pareto analysis indicated that 14 countries to the left of this line comprised 80% of the whole of the infected countries and the fishbone diagram described the symptoms for checking out for a patient infected by COVID-19. The trend analysis showed that the spread of the pandemic keeping going on to increase. The pie chart showed that pandemic has been still under control while the death proportion has not been under control. Odunayo et al. [8] used the data retrieved from the Africa CDC at 10:00 PM on 27.05.2020, which consisted of several African countries' COVID-19 data. The number of deaths, a number of recovered cases, and confirmed cases of African countries' were used. In this study monitoring and tracking tools were trend plot, pie chart, Pareto analysis, bar chart, and control chart. The trend plot depicted the trend of the outbreak of the disease. The Pareto analysis indicated that 13 countries (South Africa, Egypt, Algeria, Nigeria, Morocco, Ghana, Cameroon, Sudan, Guinea, Djibouti, Republic of Congo, Gabon, and Somalia) were the most infected African countries. The trend analysis indicated a geometric increase in the spread of the pandemic despite the lockdown, and other measures put in place to curb the pandemic. Finally, from the performance evaluation, it was clear that the spread was likely to be under control from the pie chart. However, the death proportion has already been not under control. Fawzy and Ghalib [9] used the K-Nearest Neighbor Control Chart (K2-chart) and Kernel Principal Component Analysis Control Chart for the analysis. Relying on the daily epidemiological position of the Public Health Department of the Iraqi Ministry of Health, 18 variables representing the governorates of Iraq were used. An average run length metric was employed to assess the effectiveness of the charts. The findings indicated that the spread of infections related to the new coronavirus increased without control. Notably, the K2 chart exhibited superior performance in the short term, while both charts demonstrated relatively equal performance in the medium and long term. Hidayat et al. [10] assessed the data quality for determining the possible errors, which was sourced from the 'COVID-19 Data Repository by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University. They wanted to provide researchers with insights into the data's reliability before usage and then used control charts and acceptance sampling. 30% of the data was detected using a control chart and examined for potential errors. COVID-19 time-series data, 22.07.2020-01.08.2020 was used. The methods used were acceptance sampling and control charts. The Shewhart individual control chart was used. They detected data input errors, confirmed data is lower than recover, decreasing value, confirmed data is lower than death, zero confirm on the first date, not zero recovers on the first date, and not zero death on the first date. Their suggestion to researchers was to check and correct the dataset obtained from this data source before usage. Hidayat et al. [11] used a Tangent Control Chart (t-control chart) to determine countries that have identical positive case data trends with Indonesia. t-control chart and Individual Moving Range Chart (I-MR Chart) showed that 71 countries out of 183 countries affected by the COVID-19 epidemic, have a positive case data trend similar to Indonesia. Irhaif et al. [12] used EWMA and moving average control charts to monitor the number of people infected with COVID-19 for April 2020 and they compared it with the dataset from April 2021. The results showed that there were out-of-control points for both of these two years. However, in 2021 the number of infections became double what it was in 2020 which indicated an increment in the number of patients infected with the virus. Mbaye et al. [5] used p-control chart to monitor the positivity rate, cure rate, and fatality rate for Senegal. The positivity fraction was moving away from the UCL as of 07.06.2020, which indicated that the condition has been yet under control. The progress of the cure fraction exhibited irregularities, followed by an increase, and gradually reached its maximum between 12.04.2020 and 20.04.2020. This period marked the widespread use of chloroquine for the treatment of COVID-19 in Senegal. The fatality fraction was rather low and was closer to the lower limit. But a slight increment had been seen in the latter. The observed phenomenon might be attributed to the rise in the incidence of COVID-19 cases, which in turn increased the number of severe cases and ultimately led to an increment in mortality. Mahmood et al. [13] conducted a comprehensive study to track variations in the number of deaths and classify growth phases, namely pre-growth, growth, and post-growth for Pakistan during the COVID-19 pandemic. To observe these changes, the authors employed c and EWMA control charts, based on secondary data of daily reported deaths in Pakistan owing to the pandemic. As per the c-control chart, Pakistan shifted from the pre-growth phase to the growth phase on 31.03.2020. Meanwhile, the EWMA control chart indicated that Pakistan remained in the growth phase from 31.03.2020 to 17.08.2020, with certain markers suggesting a decline in the number of deaths. The study inferred that Pakistan briefly entered the post-growth phase from 27.07.2020 to 28.07.2020, following which it re-entered the growth phase with an alarm on 31.07.2020. Subsequently, the number of deaths began to decrease in August, implying a probable approximation of the post-growth phase in Pakistan. In their study, Mukhaiyar et al. [14] utilized a p-control chart for monitoring the fraction of positive COVID-19 cases in DKI Jakarta Province. The data used were derived from a sample of COVID-19 tests conducted between April 2020 and January 2021. Notably, the researchers did not statistically control the process of daily new COVID-19 cases, and several mean shifts in the fraction of positive cases were observed at different time intervals. The results of the study revealed a sustained upward trend in the fraction of positive cases, indicating a gradual rise in COVID-19 cases within the region. The study suggested that public behavior in Jakarta could serve as a model for the government in developing policies to contain the spread of COVID-19. The authors inferred that the COVID-19 situation persisted to be unmanageable due to the increased mobility of Jakarta's inhabitants, and the irregularities in the region. Parry et al. [15] devised a hybrid Shewhart control chart that integrates an I-control chart and c-control chart with a log-regression slope to identify four distinct 'epochs' of the COVID-19 epidemic, namely, (i) pre-exponential growth, (ii) exponential growth, (iii) plateau or descent, and (iv) stability after descent. The chart's efficacy was validated using global data from various levels, including national, regional, and local. Local experts in the field were involved in the validation process, which entailed analyzing COVID-19 cases, hospitalizations, and deaths. They observed that the hybrid chart promptly and effectively indicated the onset of each of the four epochs. For instance, in the UK, a signal of the exponential growth of COVID-19 deaths was identified on 17 September, 44 days before the announcement of a comprehensive lockdown. Similarly, in California, USA signals highlighting increases in COVID-19 cases at the county level were noticed in December 2020 before the implementation of statewide stay-at-home orders, with subsequent declines in the weeks that followed. In Ireland, during December 2020, the hybrid chart identified rises in COVID-19 cases, succeeded by increases in hospitalizations, the number of deaths, and intensive care unit admissions. After national restrictions in late December, a parallel sequence of reductions in these measures was identified in January and February 2021. Rashed and Eissa [16] sorted countries in descending order based on their respective residential census. The authors analyzed the top contributing countries, which accounted for approximately 60% of the total COVID-19 cases and deaths. The countries were ranked in decreasing order of cases as follows: USA, Italy, Spain, China and Germany. Similarly, for deaths, the order was Spain, the USA, and France. The authors identified a cubic relationship between the increasing number of cases and daily deaths. CUSUM control charts were utilized to monitor the daily changes in the epidemic disease registers, revealing that the disease's daily fluctuations had been on the rise and statistically out of control by 17.03.2020 and 19.03.2020. Singh et al. [17] employed an X-bar control chart and EWMA control chart to assess the transmission of COVID-19 in several major provinces of India, as well as all of India. Warning and control limits were calculated and analyzed for the average weekly growth. The study indicated that the pandemic cannot be expected to be brought under control shortly, as the average weekly growth index of COVID-19 continues to exceed 0. Yupaporn and Rapin [18] employed the cumulative distribution function of the total number of COVID-19 cases over time to develop a quantile function to determine the levels of COVID-19 alarm. The authors monitored COVID-19 outbreaks using the EWMA control chart, and the control limits were established using both the delta technique, and the sample mean and variance technique. The study focused on selected countries and regions, namely Singapore, Thailand, Hong Kong, and Vietnam, for which the total number of COVID-19 cases from 15.02.2020 to 16.12.2020 exhibited symmetric patterns. To compare the effectiveness of the two techniques, the authors applied them to an EWMA control chart based on the first hitting time to detect COVID-19 outbreaks in the selected regions and countries. The results indicate that the sample mean and variance method outperforms the delta method in detecting the first hitting time. Additionally, the COVID-19 alert levels can be categorized into four stages to effectively monitor the COVID-19 situation. These stages assist authorities in formulating policies for monitoring, controlling, and safeguarding the population against a COVID-19 outbreak. Waqas et al. [19] explored Shewhart (X, R, C) control charts and EWMA control chart for their study. They used the EWMA control chart due to its exceptional capability in detecting shifts and its compatibility with the dataset they employed. Daily deaths have been monitored for the period between March 2020 to February 2023. During the application on COVID-19 deaths, the EWMA control chart accurately depicted mortality dynamics from March 2020 to February 2022, indicating six distinct stages of death. The 3rd and 5th waves had been extremely catastrophic, resulting in a considerable loss of life. Notably, a persistent sixth wave appeared from March 2022 to February 2023. The EWMA map effectively pinpointed the peaks associated with each wave by thoroughly examining the time and amount of deaths, providing vital insights into the pandemic’s progression. The USA entered a seventh phase (6th wave) from March 2022 to February 2023, marked by fewer deaths. They pointed out the ongoing importance of maintaining vaccination campaigns and pandemic control measures. The authors recommended the incorporation of the EWMA control chart for monitoring immunization progress, deaths, and cases.

Control charts contribute to the ability to manage disease outbreaks efficiently, minimize their impact, and inform evidence-based decision-making. They are valuable tools for public health officials, epidemiologists, and policymakers, helping them respond effectively to such crises. After examining the studies on using quality control charts for monitoring COVID-19 data sets for different countries, it is realized that there is no study yet for Türkiye. In this study, COVID-19 data sets for Türkiye considered. The aim of the study is a comprehensive monitoring of daily cases, deaths, and fatality rates in Türkiye, especially considering the periods of restrictions. Hence, the effects of various precautions on the number of cases or deaths could monitored using quality control charts, and the process could be managed logically and scientifically for Türkiye in the future for risks of a pandemic.

The rest part of the study is organized as follows. In Section 2, the COVID-19 process in Türkiye is presented. In section 3, a brief theory for the Run chart, EWMA control chart, and p-control chart are presented. In Section 4, Run charts, EWMA control charts, and p-control charts for the COVID-19 data set of Türkiye are presented, and the comments are presented. Lastly, general comments and a summary of the results are presented in the last section.

2. The Covid-19 Period in Türkiye

On 11.03.2020, the initial COVID-19 cases were reported in Türkiye, leading to a set of limitations imposed from the start of the outbreak until autumn 2020, containing the summer for the year 2020. The measures taken during this period in Türkiye included the suspension of education on March 16, 2020, and the imposition of a curfew on March 20, 2020, for people over the age of 65. Travel between cities was restricted in 31 regions on April 3, 2020, followed by a curfew for those under the age of 20 on April 4, 2020. A weekend curfew was imposed in 31 cities on April 10, 2020. On May 11, 2020, the first phase of the normalization plan was initiated, enabling the reopening of barbershops, marketplaces, shopping malls, cafes, and restaurants. Under certain conditions, hotels and hostels began accepting guests on May 27, 2020. On June 1, 2020, a policy of "new normalization" was instituted, which enabled the resumption of operations at resting areas, public entertainment venues, association clubs, tea gardens, sports halls, and swimming pools. Wedding halls were allowed to reopen with the condition of operating at a maximum capacity of 25%. Restrictions in performance centers, wedding venues, and theaters were lifted on July 1, 2020 [20]. The upsurge in the number of COVID-19 infected patients has been attributed to non-compliance with health guidelines such as wearing masks and avoiding contact with infected individuals in workplaces, markets, or enclosed areas. The continued violation of health protocols in 2021 by some residents is indicative of their disregard for the harm inflicted in 2020. After the end of the normal period in the summer of 2020, nationwide partial curfews were imposed on November 18th in Türkiye. On November 25th, the Republic of Türkiye Ministry of Health reported the first daily number of COVID-19 cases. Several nonpharmaceutical interferences were implemented during the pandemic in Türkiye, which were categorized by İlhan et al [20] based on their characteristics. The authors used circulars from the Ministry of İnternal Affairs to label each period of restrictions. Table 1 provides an overview of the different periods of limitations in Türkiye since 18.11.2020 [20].

Table 1. Periods of limitations in Türkiye since 18.11.2020.

Periods of Restrictions	Implementation Date	Number of Days
Nationwide partial curfews	November 18-30, 2020	13
Nationwide extended curfews	December 1, 2020-February 28, 2021	90
Local decision-making phase	March 1-29, 2021	29
Revised local decision-making phase	March 30–April 13, 2021	15
Partial lockdown	April 14-28, 2021	15
Full lockdown	April 29–May 16, 2021	18
Gradual normalization	May 17–31, 2021	15
2th phase of gradual normalization	June 1, 2021-May 31, 2022	365

Nationwide partial curfews (Starting from November 18th, 2020): Türkiye imposed nationwide partial curfews with weekend curfews, excluding the hours between 10:00 and 20:00. This regulation came into effect from November 21st onwards. During this period, cafes, restaurants, and patisseries were allowed to operate between 10:00 and 20:00 but only provided take-out or pick-up services. Age-specific limitations were imposed, allowing persons aged 65 and over to leave their homes between 10:00 and 13:00, whereas those under the age of 20 were authorized to leave between 13:00 and 16:00. İlhan et al. [20] referred to this period as "nationwide partial curfews," which was the least restrictive measure at the national level, except the final phase (the second phase of gradual normalization). The Republic of Türkiye Ministry of Health used the terms "patient" and "case" with varying definitions for epidemic data reporting. An individual was classified as a patient if they tested positive for the virus through PCR tests, but only if they displayed symptoms. On one hand, a patient was considered as an individual who exhibited symptoms and tested positive with PCR tests. On the other hand, a case was defined as an individual who tested positive with PCR tests, regardless of whether they showed symptoms or not. From November 25th, daily cases began to be reported [20].

Nationwide extended curfews (Starting from December 1st, 2020): The implementation of the curfew was extended throughout the weekend, beginning at 10:00 p.m. on Friday, and a separate curfew was enforced during weekdays beginning at 9:00 p.m. İlhan et al. [20] identified this period as the "nationwide extended curfews" [20].

Local decision-making phase (Starting from March 1st, 2021): “Local decision-making phase” was implemented in Türkiye to manage the COVID-19 pandemic. The provinces were assessed and classified as "low, medium, high, and very high" according to their level of risk. The categorization was updated every two weeks based on the current status of each province. This phase was called the blue-yellow-orange-red provinces approach. Weekend curfews were lifted in low and medium-risk provinces, while they continued only on Sundays in high and very high-risk provinces. In low and medium-risk provinces, restrictions for those over 65 and under 20 had been lifted, and education at all levels resumed. In high and very high-risk provinces, primary schools, 8th, and 12th grades, and preschool education institutions had been allowed to open. The curfew was still in place for those over 65 and under 20, and it was also extended. Going out on Sunday was allowed only in low and medium-risk provinces. Except in very high-risk provinces, cafes and restaurants began to operate again with a maximum capacity of 50%. The nationwide curfew was from 21:00 to 05:00.

Revised local decision-making phase (Starting from March 30th, 2021): The curfews implemented during weekdays and weekends based on the risk categories have been revised. In high-risk provinces, the weekend curfew had been implemented only on Sundays, while in very high-risk provinces, it was implemented on both Saturdays and Sundays. Public places like restaurants and cafes were allowed to accept customers with a 50% capacity restriction between 07:00 and 19:00. In provinces categorized as low and medium-risk, a maximum of four individuals were permitted to sit together at the same table, whereas in provinces classified as very high-risk and high, only two individuals had been allowed for sitting together. This period has been referred to as the "revised local decision-making phase" by İlhan et al. [20].

Partial lockdown (Starting from April 14th, 2021): On April 14th, 2021, a "partial lockdown" was instituted, which involved updating the hours of the weekday curfew to 7:00 p.m. and 05:00 in the morning. Extra precautions were implemented for Ramadan. A weekend curfew had been imposed in all provinces, and public spaces, for instance, cafes and restaurants, were closed.

Full lockdown (Starting from 29th April 2021): On April 29th, 2021, a comprehensive lockdown was declared in Türkiye. All levels of education were postponed, including exams. In addition, inter-provincial public transport was allowed to operate at only 50% of its normal capacity.

Gradual normalization (Starting from May 17th, 2021): On May 17th, 2021, a phase "gradual normalization" was declared. During weekdays, the curfew enforced from 21:00 to 5:00, curfew covered the entire Saturdays and Sundays in weekends, ending at 05:00 on Mondays. Public establishments, for instance cafes, restaurants, and patisseries, allowed offering only takeaway service.

Second phase of gradual normalization (Starting from June 1st, 2021): The period of "gradual normalization" in Türkiye ended and the period followed by the second phase of gradual normalization from June 1st, 2021. The updated curfew rule mandated individuals to stay indoors between 22:00 and 05:00 on Saturdays and Mondays, while a full-day curfew implemented on Sundays. The Republic of Türkiye Ministry of Healths' Epidemic Management and Working Guide required restaurants, patisseries, cafeterias, and other food and drink establishments following a set of guidelines to ensure public health. Specifically, tables placed 2 meters apart from each other, and chairs placed 60 centimeters apart from each other. These establishments were permitted to serve customers between 7:00 and 24:00 on Sundays and between 21:00 and 24:00 on the other days, exclusively as takeaway services.

3. Material and Methods

Control charts can help in the early detection of outbreaks by monitoring relevant variables such as the number of cases, hospitalizations, or deaths. Sudden shifts or unusual patterns in the data can indicate a potential problem, allowing for a prompt response. Control charts contribute to the ability to manage disease outbreaks efficiently, minimize their impact, and inform evidence-based decision-making. They are valuable tools for public health officials, epidemiologists, and policymakers, helping them respond effectively to such crises. In this study, Run charts, EWMA control charts, and p-control charts used for monitoring the COVID-19 data set of Türkiye.

3.1. Run Chart

A run chart is a basic line graph that displays a measurement over time, featuring a horizontal line representing the median. This line divides the data points, with half of data points located above the median and the other half below it (Figure 1). The primary aim of a run chart is to detect the process improvement or deterioration, which manifests as non-random patterns in the arrangement of data points relative to the median. When the process of interest exhibits purely random variation, the data points will randomly dispersed around the median.

"Random" signifies that we cannot predict whether the next data point will be higher or lower than the median, with each event having a probability of 50% and the data points being unrelated. Independence implies that the location of one data point does not affect on the location of the following data point, indicating an autocorrelation does not exist in the data. When the process undergoes a shift, these conditions cease to hold, and statistical tests may reveal patterns of non-random variation. Hence, run charts are serving as valuable tools for enhancing healthcare processes and identifying process deterioration [21, 22].

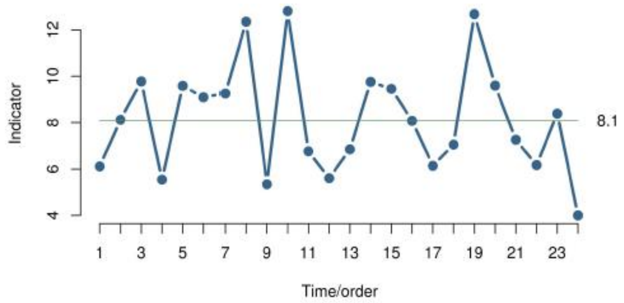


Figure 1. Run Chart.

Variations that are not random can manifest in various ways. When the processing center shifts due to improvement or degradation, we may witness unusually extended sequences of consecutive data points on one side of the median or notice an unusually infrequent crosses the median on the graph [21, 22, 23].

3.2. EWMA Control Chart

An EWMA control chart is a statistical process control chart presented by Roberts [24], a well-established method, namely, employed to identify shifts in process parameters over time. Let a random variable x_i represents the observations, and λ is a smoothing constant and satisfies the expression $0 < \lambda \leq 1$. Then EWMA statistic is defined as follows [13, 19]:

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

Here, Z_{i-1} is the previous EWMA statistic. Hence, the Z_i is a weighted mean of both historical and recent observations, assigning greater importance to more recent observations. To establish the control limits for the control chart, you must first define the initial value μ_0, which represents the in-control process mean. The standard deviation (σ) of the independent random observations (x_i) needs to be calculated. Finally, the control limits' width, denoted as *L* and typically set at 3, needs to be defined. The effectiveness of the EWMA control chart relies on the chosen value of λ, with a smaller λ resulting in faster detection of minor shifts in the mean. When the EWMA statistic Zi exceeds these control limits, it signifies a mean shift. The EWMA control chart is particularly useful for detecting slight mean variations, particularly when λ is small. In our study, the EWMA control chart with smoothing parameter λ=0.25 is used from the values of λ = 0.25, 0.50, 0.75, and 1. Because it was determined to be the most effective for observing patterns and out-of-control situations. The EWMA statistic can be seen as a weighted mean of both historical and recent observations, making it insensitive to the normality assumption. Hence, the EWMA control chart is well-suited for individual observations. The control limits for the EWMA control chart are presented as follows [13, 19]:

$$\begin{aligned} UCL &= \mu_0 + L\sigma\sqrt{\lambda(2-\lambda)^{-1}\left[1-(1-\lambda)^{2i}\right]} \\ CL &= \mu_0 \\ LCL &= \mu_0 - L\sigma\sqrt{\lambda(2-\lambda)^{-1}\left[1-(1-\lambda)^{2i}\right]} \end{aligned} \quad (2)$$

If the i increases to infinity, then the term $\left[1-(1-\lambda)^{2i}\right]$ approaches 1, at which point the time-varying limits transition into asymptotic limits and are defined as follows:

$$\begin{aligned} UCL &= \mu_0 + L\sigma\sqrt{\lambda(2-\lambda)^{-1}} \\ CL &= \mu_0 \\ LCL &= \mu_0 - L\sigma\sqrt{\lambda(2-\lambda)^{-1}} \end{aligned} \quad (3)$$

3.3. p-Control Chart

p-control chart used for monitoring the fraction of nonconforming units, for instance, the proportion nonconforming or proportion of defective, showing the fatality proportion for this study. In this case, it is a proportion of the daily number of patients who died to the daily number of ill people. The centerline (CL) and upper and lower limits (UCL, LCL) of the p-control chart are computed as follows. Here, D_i shows the nonconforming items in sample i, n_i (sample size) is the number of units per sample i, and m shows the number of samples [6].

$$CL = \bar{p} = \frac{\sum_{i=1}^{m} D_i}{\sum_{i=1}^{m} n_i}, \quad LCL = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n_i}}, \quad UCL = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n_i}} \quad (4)$$

3-sigma limits are used as it is a popular choice in literature. The reason is found partially in statistical theory and partially in practicality. Lloyd [25] summarizes the reasons and lists the studies mentioning the reasons for the usage of 3-sigma limits. Shewhart's use of 3 sigma limits (i.e., three above the mean and three below the mean for a total of 6 sigma units) as opposed to any other multiple of sigma did not stem from any specific mathematical computation. Shewhart mentioned that 3 "seems to be an acceptable economic value," and that the choice of 3 was justified by "empirical evidence that it works". A summary of the rationale for using Shewhart's 3-sigma limits mentioned by Provost and Murray (2011) [26] listed below [25]:

- The limits have a basis in statistical theory.
- The limits have proven in practice to distinguish between special and common causes of variation.
- In most cases, the use of the limits will approximately minimize the total cost due to overreaction and underreaction to variation in the process.
- The limits protect the morale of the workers in the process by defining the magnitude of the variations that has been built into the process.
- The combined total risk of type I and type II errors is minimized when 3-sigma limits are used.

Interested readers could access detailed information on why 3-sigma limits are used popularly and the article titles on this issue from Lloyd [25].

4. Results and Discussion

Control charts are statistical tools for monitoring and maintaining the stability of processes or situations. Control charts play crucial role in tracking and managing the outbreak for COVID-19. They help public health officials monitor important indicators, identify unusual patterns or trends, and assess the effectiveness of interventions. Control charts also enable data-driven decision-making. For COVID-19, a situation is considered "under control" when the disease spreads within acceptable limits, and the number of cases and deaths, fatality rate, and other relevant indicators remain relatively stable. It means that outbreak is not experiencing sudden, unexplained surges or declines. Achieving control may involve maintaining certain thresholds for significant parameters, such as the number of new cases per day. After examining the literature review over quality control charts implementations on COVID-19 datasets for different countries, in this study, Türkiye considered, and the dataset of the number of daily COVID-19 cases and deaths, fatality rates of Türkiye are used. The data was obtained from the website of the Republic of Türkiye Ministry of Health. The Ministry of Health employed distinct definitions for the terms "patient" and "case" when presenting information about the epidemic. As of 25.11.2020, the number of daily cases started to be declared [27]. The analyses were performed using R software.

4.1. Monitoring the Daily Cases

The General Coronavirus Chart dataset of the Republic of Türkiye Ministry of Health is used as the data source. When we monitor the daily cases with Run charts as given in Figure 2, it is clear that for the period of **25.11.2020–30.11.2020**, there is an upward trend, and then it stabilizes, and again the upward trend starts. For the period of **01.12.2020–28.02.2021**, there is a downward trend. For the period **01.03.2021–29.03.2021**, an upward trend starts, and for the period **30.03.2021–13.04.2021**, this trend continues. For the period **14.04.2021–28.04.2021**, a downward trend starts and continues until **01.06.2021**. For the period of **01.06.2021-31.12.2021** (last 7 months of 2021), the number of daily cases begins increasing at the end of July and then shows small waves until the last days of December as it starts upward trend again. For the period of **01.01.2022-31.05.2022** (first 5 months of 2022), the number of daily cases shows an upward trend until February 2022 when it reaches a peak on this month then it starts to decrease gradually.

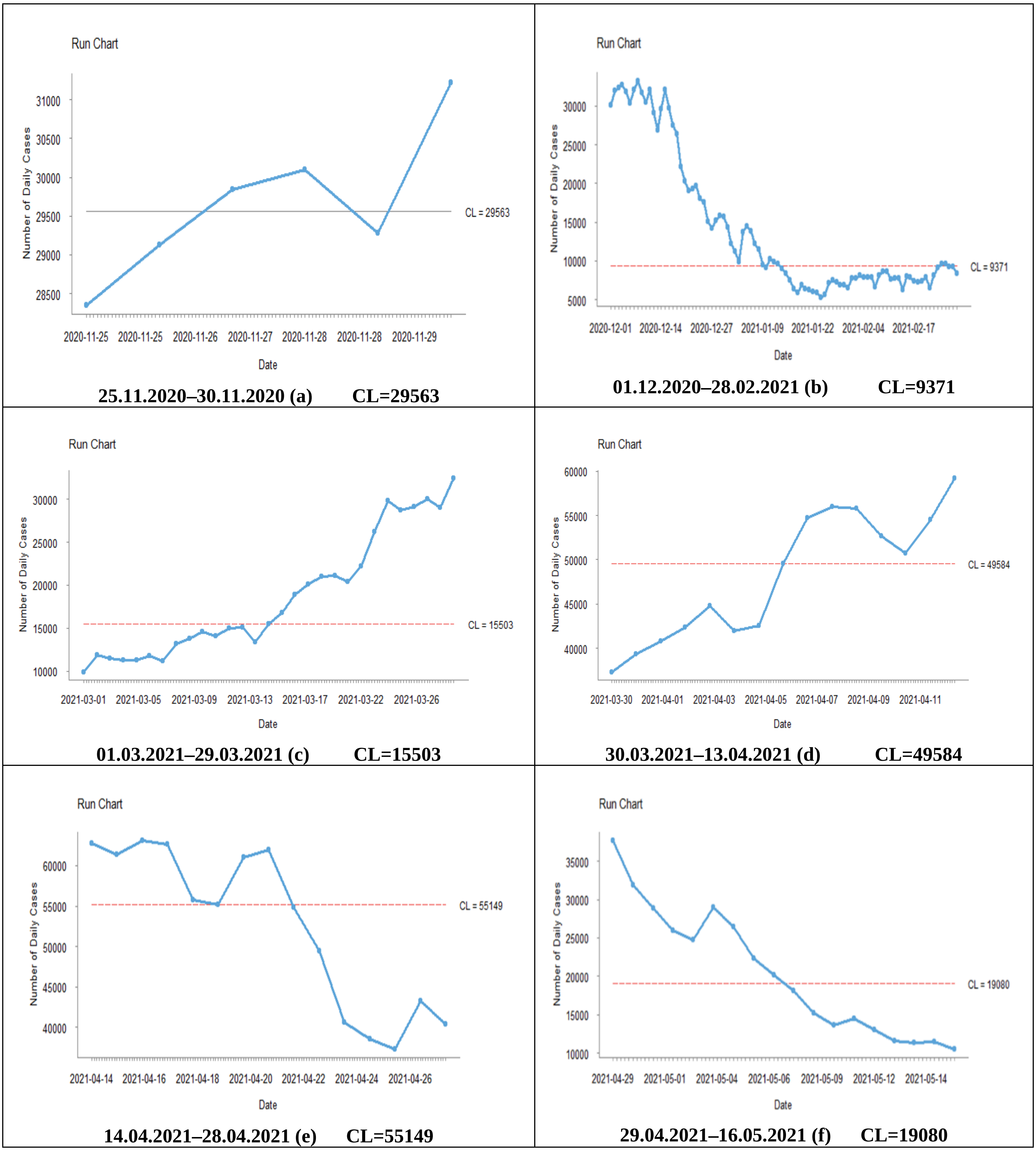
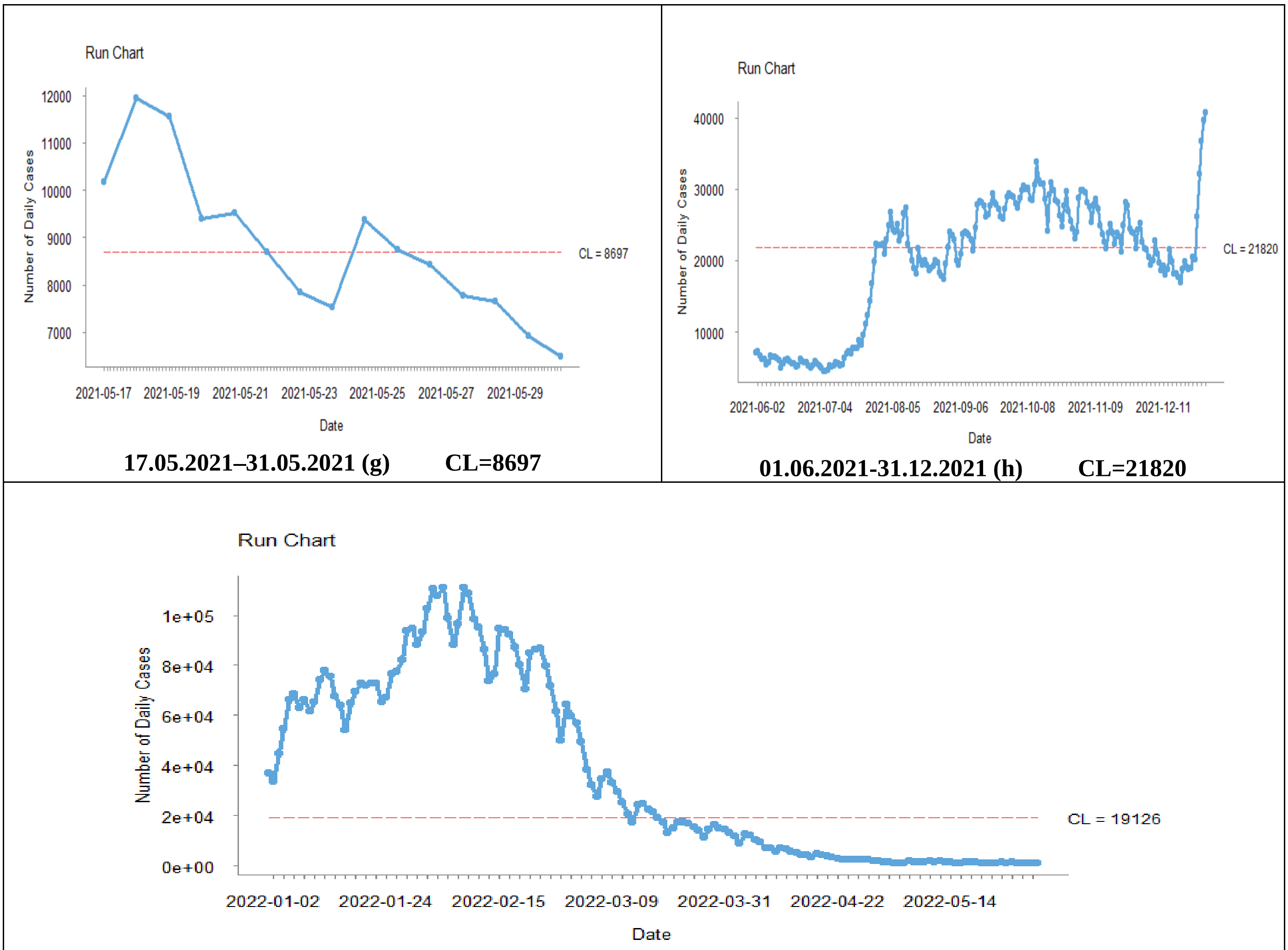


Figure 2. Run charts for number of daily cases.



17.05.2021–31.05.2021 (g) CL=8697

01.06.2021-31.12.2021 (h) CL=21820

01.01.2022-31.05.2022 (i) CL=19126

Figure 2. Run charts for number of daily cases (continued).

The EWMA control chart offers a versatile method for modeling the number of cases, as it can customize by altering the smoothing parameter. This adjustment enables you to have greater or lesser responsiveness to changes in the dataset, providing flexibility in the modeling approach.

This study aims to monitor the changes in daily cases; hence, after conducting a thorough literature review, an ideal chart is the EWMA control chart. Because it provides rapid detection of minor shifts. Figure 3 shows that during these periods, the daily cases are out of control for all periods except **25.11.2020–30.11.2020**, as only 5 days were monitored. However, for all of the periods, there are upward or downward trends or wavy trends. Figure 3 (a) depicts that no point falls beyond the control limits, meaning that Türkiye’s COVID-19 pandemic is at the start of the growth phase. It is evident from Figure 3 (b) that Türkiye has sustained the growth phase until the middle of December 2020. Starting from January 14, 2021, the number of daily cases stays below 14110 daily cases on average per day, and it shows a downward trend. From Figure 3 (c), it is clear that for the period of **1.03.2021–29.03.2021**, the EWMA control chart monitored 18585 daily cases on average per day, until March 18, 2021, the downward trend continued, after this date upward trends started. A sudden rise (exponential growth) was identified when 26182 daily cases were reported in a day in March 2021, and March 2021 remained higher in daily cases. As seen from Figures 3 (d) and 3 (e) the number of daily cases is increasing even further starting from April 9, 2021. The number of daily cases started to decrease on April 23, 2021, the last days of April 2021, the number of daily cases remains in lower values. As the spring period starts Figure 3 (f) shows that the number of daily cases is decreasing, even further starting from May 10, 2021, the daily cases less than average. Figure (g) shows that for the second half of May, 7 days of 14 days are out of control and there is a sudden downward trend. Figure 3 (h) shows that in June and until the last days of July 2021, the number of daily cases remained lower than the central limit, however, after July 2021 it started to get higher. For the latest period of **01.01.2022-31.05.2022**, for the year 2022, during the winter season of January and February, the number of daily cases touched a peak, such as the number of daily cases reached 111157 on February 4, 2022. From March 2022, a downward trend starts gradually.

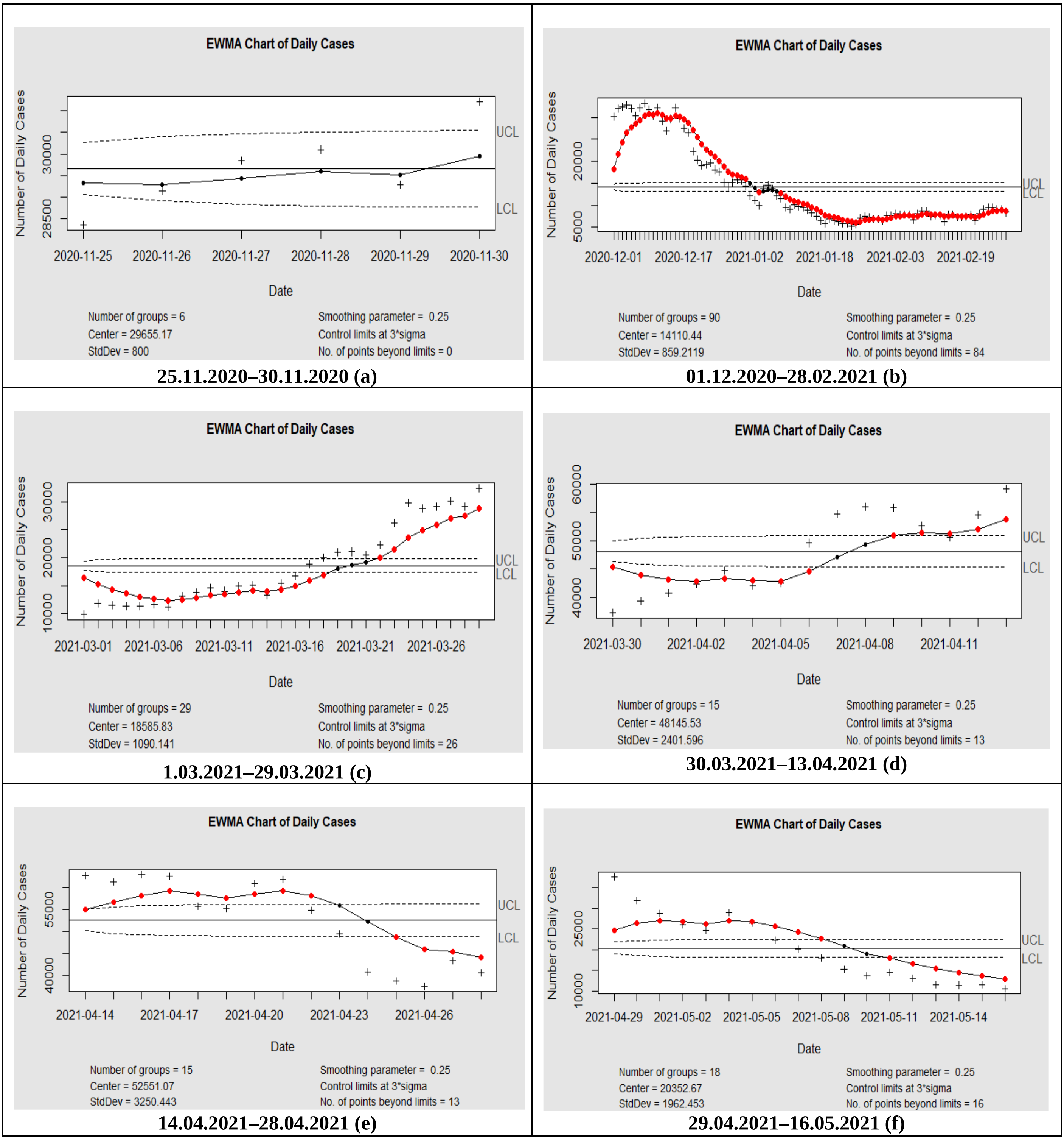


Figure 3. EWMA control charts for number of daily cases.

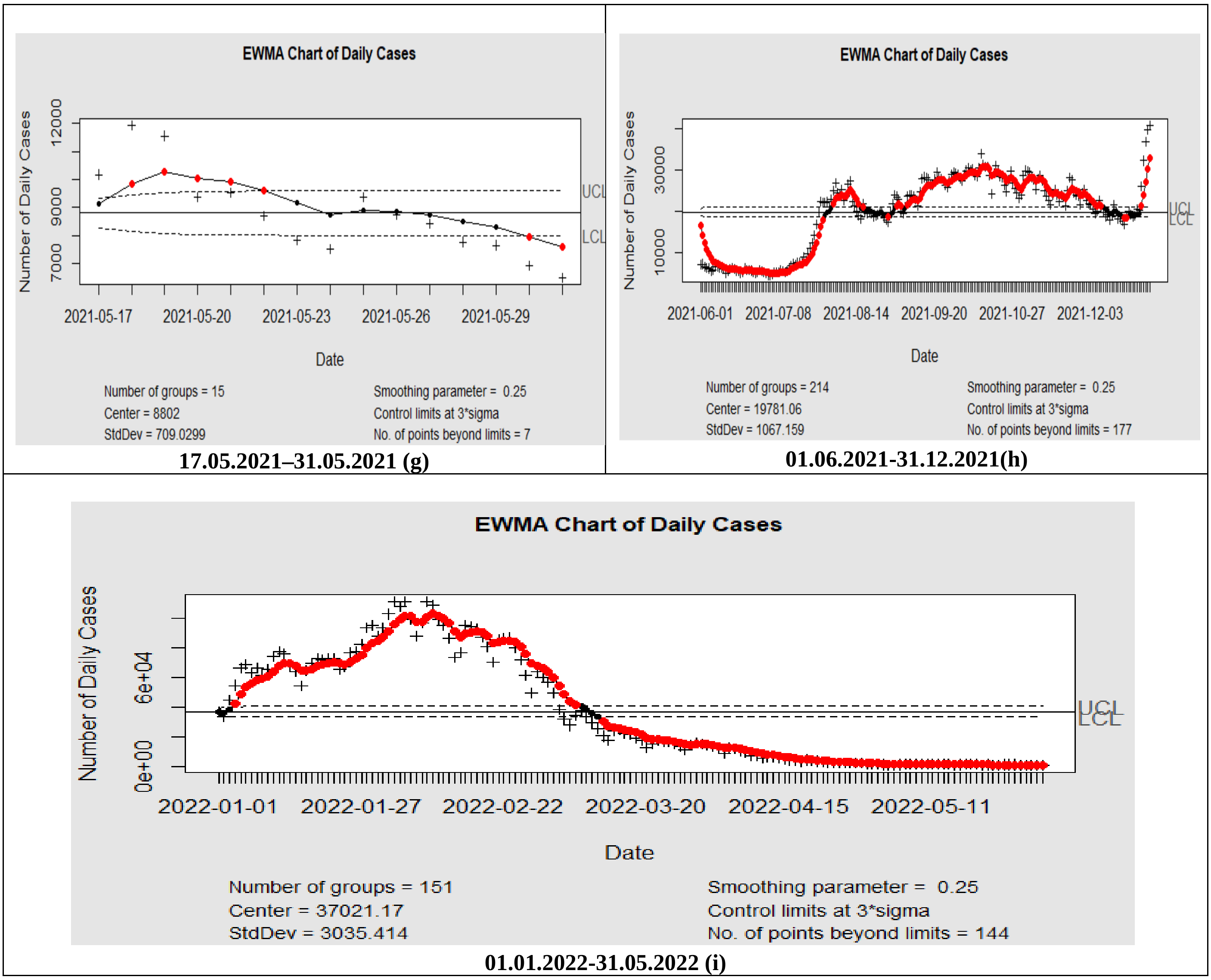


Figure 3. EWMA control charts for number of daily cases (continued).

4.2. Monitoring the Deaths

When we monitor Run charts for the deaths as given in Figure 4, it is clear that for the period of **27.03.2020–17.11.2020**, there is an upward trend, and then a sudden decrease and stabilizes between May and August, and again upward trend starts in September. For the period of **18.11.2020–30.11.2020**, there is an upward trend. For the period of **01.12.2020–28.02.2021**, there is a downward trend. For the period **01.03.2021–29.03.2021** an upward trend starts again and for the **30.03.2021–13.04.2021** and **14.04.2021–28.04.2021** periods this upward trend continues. For the period **29.04.2021–16.05.2021**, a downward trend starts, and this trend continues until the **01.06.2021** period. In the period of **01.06.2021-31.12.2021** (the last 7 months of 2021) the number of deaths starts to increase in August 2021 and peaks in September 2021 then starts to decrease gradually. For the period of **01.01.2022-31.05.2022** (first 5 months of 2022), the number of deaths shows an upward trend until February 2022 when it reaches a peak in this month then it starts to decrease gradually.

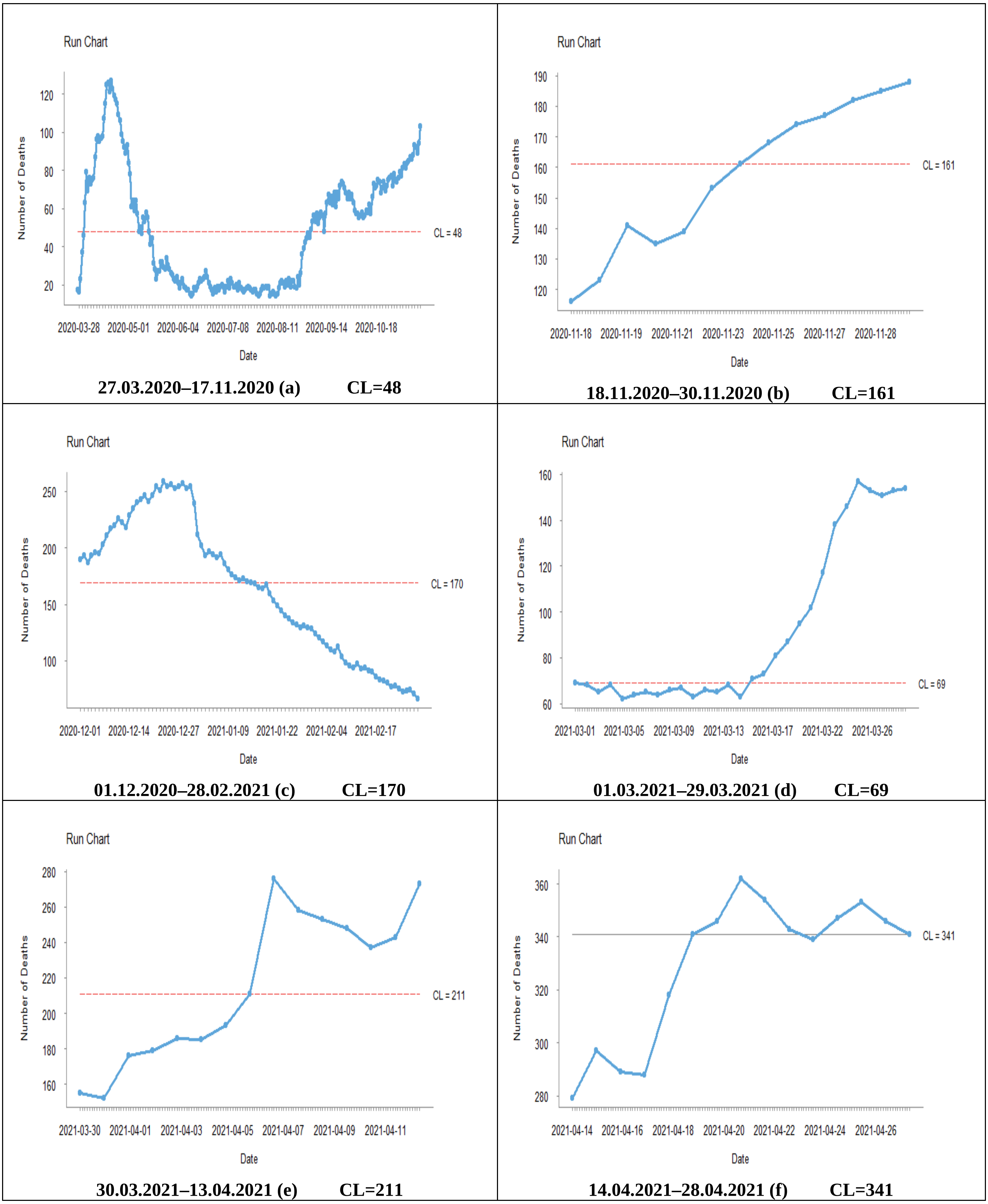


Figure 4. Run charts for number of deaths.

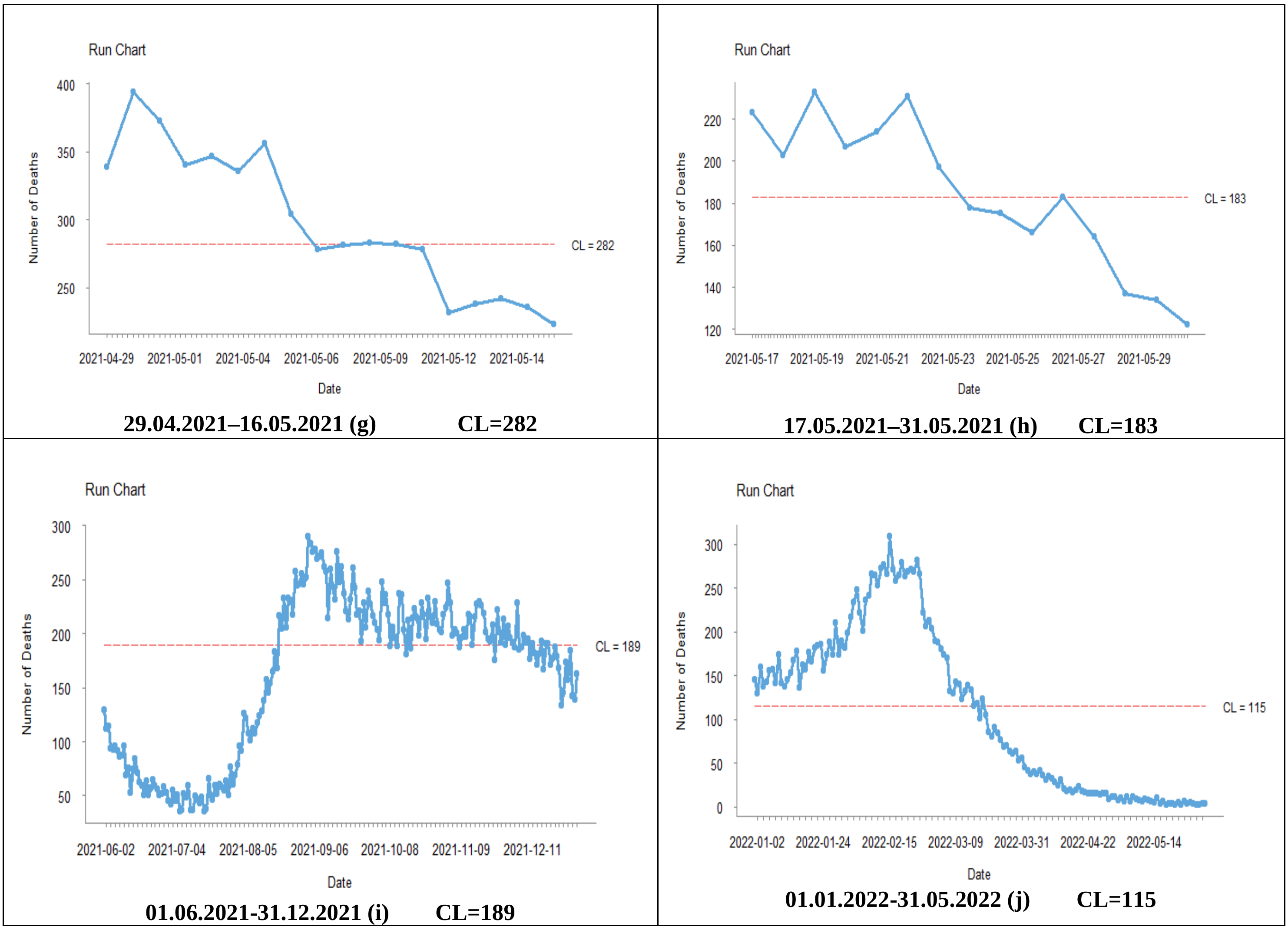
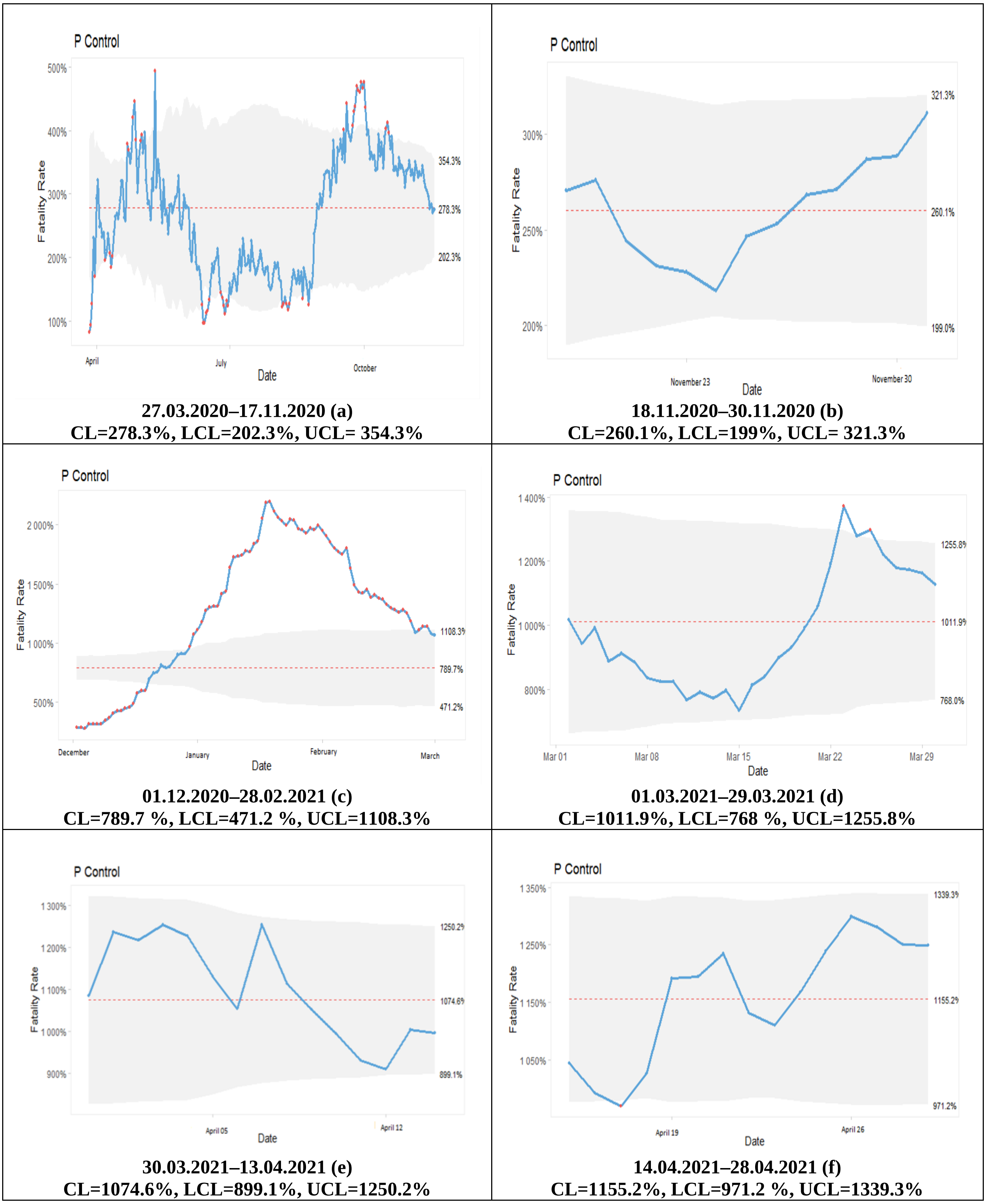


Figure 4. Run charts for number of deaths (continued).

4.3.Monitoring the Fatality Rate

The fatality rate, defined as the daily number of deaths per daily number of patients, was calculated over a period from **27.03.2020** to **04.07.2021**. Since the sample size of daily number of patients varies, a p-control chart with a variable sample is the most suitable control chart for analyzing the data.

Figure 5 shows the trend of the fatality rate over time. The grey region on the charts shows the control area that the points out of this area are out of control and that they fall outside the LCL or UCL values. Fatality rate was under control during specific periods, namely from **18.11.2020–30.11.2020**, **30.03.2021–13.04.2021,** and **17.05.2021–31.05.2021**. A sequence of 6 consecutive points, whether all increasing or all decreasing, is commonly referred to as the "trend rule." This test encompasses two scenarios. A gradual shift of data points towards a control limit defined as a "trend." Conversely, when there are 6 consecutive points either all increasing or all decreasing, it's known as a "run-up" or "run-down." 6 consecutive decreasing points show an improvement, demonstrating that the fatality rate is under control and affirming that the measures are taken yielding results. However, if there are 6 consecutive increasing points, it serves as an alert, indicating that the virus is spreading and the death toll is rising, signifying the need for immediate action. Upward or downward trends suggest changes in the process. Hence, from Figure 5 (a) it is clear that trends moving up and down that summer season there is a downward trend. Figure 5 (c) shows that in the winter season fatality rate causes an alarm that an upward trend is observed, moreover, it is out of control. Figure 5 (d) shows that during March 2021 trends moved from down to up. Figure 5 (g) shows that after May 11, 2021, there is an alarming upward trend in the fatality rate. Figure 5 (i) indicates an improvement and shows that the fatality rate is out of control, that in this period the fatality rate decreased.



27.03.2020–17.11.2020 (a)
CL=278.3%, LCL=202.3%, UCL= 354.3%

18.11.2020–30.11.2020 (b)
CL=260.1%, LCL=199%, UCL= 321.3%

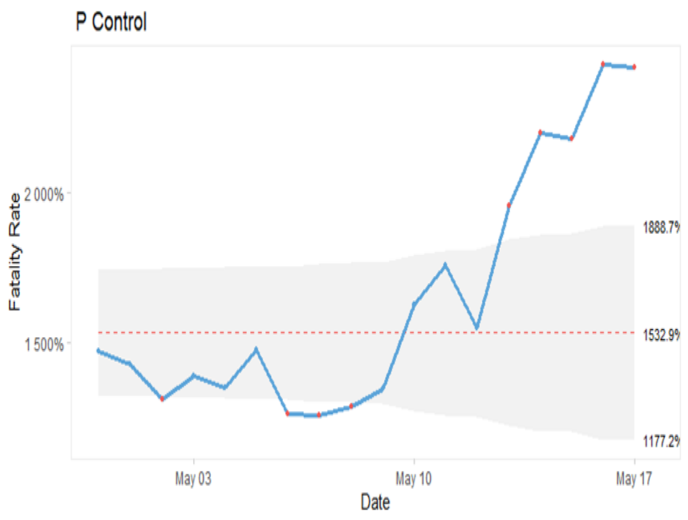
01.12.2020–28.02.2021 (c)
CL=789.7 %, LCL=471.2 %, UCL=1108.3%

01.03.2021–29.03.2021 (d)
CL=1011.9%, LCL=768 %, UCL=1255.8%

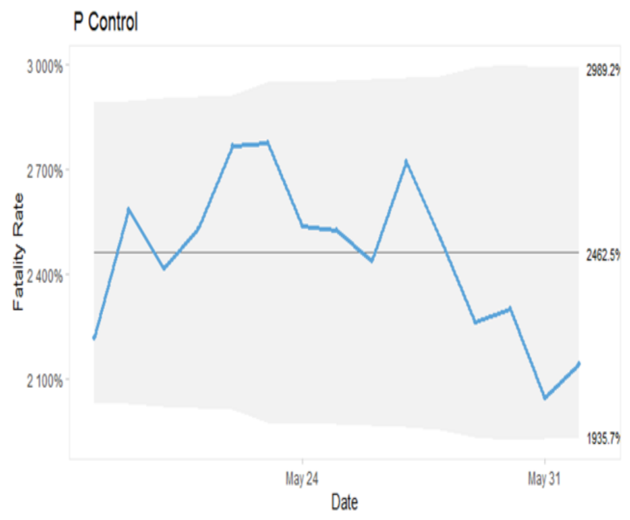
30.03.2021–13.04.2021 (e)
CL=1074.6%, LCL=899.1%, UCL=1250.2%

14.04.2021–28.04.2021 (f)
CL=1155.2%, LCL=971.2 %, UCL=1339.3%

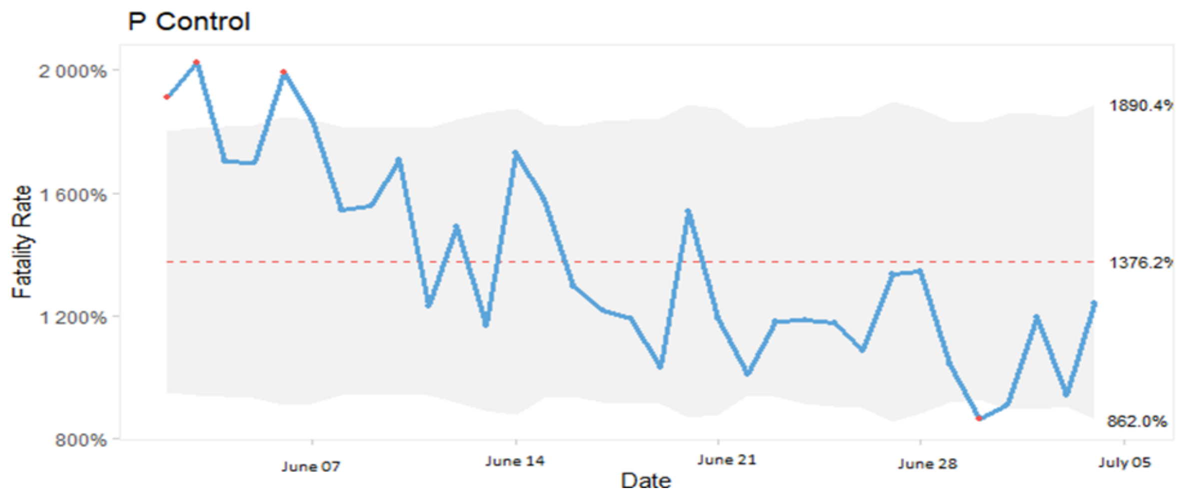
Figure 5. p-control charts for fatality rate.



29.04.2021–16.05.2021 (g)
CL=1532.9 %, LCL=1177.2 %, UCL=1888.7 %



17.05.2021–31.05.2021 (h)
CL=2462.5 %, LCL=1935.7 %, UCL=2989.2 %



1.06.2021-04.07.2021 (i)
CL=1376.2 %, LCL= 862 %, UCL=1890.4 %

Figure 5. p-control charts for fatality rate (continued).

5.Conclusion and Discussion

As a result of Run charts, in the periods of nationwide extended curfews (December 1, 2020–February 28, 2021), full lockdown (April 29–May 16, 2021), and gradual normalization (May 17–31, 2021) the number of deaths and daily cases show downward trend as expected. However, in the periods of nationwide partial curfews (November 18-30, 2020), local decision-making phase (March 1–29, 2021), and revised local decision-making phase (March 30–April 13, 2021), the number of deaths and daily cases show an upward trend. In these periods, since provinces in low-risk status lost the restrictions, the cases, therefore, deaths may have started to increase again. In the partial lockdown period (April 14-28, 2021), while the number of daily cases shows a downward trend, the number of deaths shows an upward trend. For January 1- May 31, 2022, both the daily cases and deaths show an upward trend until February 2022, in this month, when they reach a peak then they start to decrease gradually.

Detailed monitoring for the COVID-19 period was performed by EWMA control charts and p-control charts. The growth, peak, wavy, and decline periods for the number of daily cases detected by EWMA control charts. In nationwide partial curfews (November 25-30, 2020), the COVID-19 pandemic is at the start of the growth phase. Nationwide extended curfews period (December 1, 2020- February 28, 2021), the growth phase of a number of daily cases continues until the middle of December 2020. The downward trend starts from January 14, 2021. For the period of the local decision-making phase (March 1, 2021- March 29, 2021), it is clear that the downward trend continues until March 18, 2021, after this date upward trend starts. Overall, in March 2021 the number of daily cases continues to rise. The revised local decision-making phase (March 30, 2021- April 13, 2021) and partial lockdown (April 14-28, 2021) are the periods in which the number of daily cases is increasing even further starting from April 9, 2021. The number of daily cases started to decrease on April 23, 2021, the last days of April 2021, the number of daily cases remains in lower values. When the spring period starts, in the full lockdown period (April 29, 2021- May 16, 2021), the number of daily cases is decreasing even further than beginning from May 10, 2021. It could be declared that a full lockdown could be also effective in this decrease. In the gradual normalization period (May 17–31, 2021), there is a sudden downward trend. After the 2nd phase of gradual normalization in June 2021 and until the last days of July 2021, the number of daily cases remained lower, though after July 2021 started to increase even further. For 2022 during the winter season in January and February, the number of daily cases touched the peak. From March 2022, a downward trend starts gradually for a number of cases. Overall, EWMA quality control charts reveal that the COVID-19 pandemic is experiencing sudden or non-sudden surges, increases, or declines due to seasonal changes and restrictions or other factors that must be examined.

After drawing the p-control charts for the fatality rate for the periods between March 27, 2020-July 4, 2021 it is seen that this ratio is out of control, especially for the periods March 27–November 17, 2020 (nearly after the start of the pandemic March 11, 2020) and December 1, 2020-February 28, 2021 (nationwide extended curfews). For these periods, fatality rate did not remain relatively stable. It means that the outbreak was experiencing sudden, unexplained surges, rises, or declines. For the period of 27.03.2020-17.11.2020, it is clear that trends moving up and down that summer season there is a downward trend. For the nationwide extended curfews period (December 1, 2020–February 28, 2021), the fatality rate caused an alarm that upward trend was observed. After the 2nd phase of gradual normalization for June 1, 2021-July 4, 2021 the impact of the pandemic is diminishing the fatality rate in low proportions.

The escalation in the number of individuals contracting the virus could be reflection of non-adherence to health protocols, which include mask-wearing and avoidance of contact with infected individuals in work, market, or enclosed environments or because of seasonal changes. The rapid spread of infection is attributed to non-compliance with the urbanization directives imposed by the health crisis cell. A considerable number of infections identified in the early stages of the epidemic had been recent, and consequently, some eventually led to fatalities. Therefore, in the early stages of the pandemic, an increase in the fatality rate was inevitable. Moreover, due to sporadic testing for the virus, many infections have gone undetected in the early stage and numerous mild cases of the disease have not been observed. Many studies indicate that the respiratory system is adversely affected by exposure to air pollutants, leading to the production of free radicals in the body and a reduction in resistance to viral and bacterial infections. Moreover, it was found in the literature that there is a direct correlation between COVID-19-related fatalities and socioeconomic status. It has been observed that individuals with lower incomes are more susceptible to diseases and have a higher mortality rate. Therefore, the factors of changes in the number of cases/deaths or mortality rates can be examined in more detail in future studies.

Quality control charts are widely used in healthcare quality monitoring. After the COVID-19 pandemic, control charts were also utilized for monitoring COVID-19 datasets from various countries all around the world. Using the control charts is valuable for monitoring COVID-19 data, especially in assessing the impact of different measures such as curfews, lockdowns, and risk categorizations on the number of cases/deaths, fatality rates, etc. Each study that uses quality control charts for monitoring the COVID-19 process provides unique insights into the specific dataset (deaths, discharged/recovered cases, confirmed cases, positivity rate, cure rate, fatality rate, infection rate), period, and country it examines. Literature on monitoring COVID-19 data with quality control charts highlights the diversity of methods used globally to monitor and analyze the COVID-19 pandemic. EWMA control charts seem efficient in capturing sudden variations and are one of the most popular ones in the literature. The contribution of our study to the literature is comprehensive monitoring of daily cases, deaths, and fatality rates in Türkiye, especially for considering the periods of restrictions. Since Türkiye is known to be one of the countries that efficiently fought against the pandemic, this study contributes to evaluating this process. In future studies, quality control charts, regression models, and other statistical techniques could be used with various variables and factors together for a detailed review of the pandemic process for Türkiye or other countries. More detailed data can be obtained and examined, especially for cities such as İstanbul, Ankara, and İzmir, where the population is densest. Thus, more detailed comments can be made about Türkiye in general. In the future, the risks of this pandemic could be raised again. In this situation, the effects of various precautions on the number of cases, deaths, etc., could monitored by using quality control charts so that the process could managed logically and scientifically for Türkiye. Hence, this study and future studies could help political authorities and healthcare practitioners develop active control plans for a pandemic in the future.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics

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