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ORIGINAL RESEARCH

How COVID-19 pandemic influenced the countries? A value at risk based fuzzy TOPSIS approach using IF–THEN rules

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Abstract

COVID-19 pandemic negatively affected healthcare in countries all over the world. When making support decisions related to reducing the pandemic's effects, government agencies should monitor various issues such as cumulative total cases, deaths, newly recorded case numbers, and their interactive effects on public health. The recovery policies used in the countries depend on the sufficient analysis of COVID-19 case-related daily data. The helpful big data sets are provided by the World Health Organization (WHO) day by day. In this paper, instead of using unique performance criteria, an overall performance score is calculated for a selected country in the world using the fuzzy TOPSIS method. We use various attributes to determine which countries are most negatively impacted by the COVID-19 pandemic. We illustrate the applicability of the developed decision support framework in this paper. The fuzzy TOPSIS approach developed in this paper has many primary benefits. For example, we can determine the level of influence of the COVID-19 pandemic for an individual country. Another advantage of the fuzzy TOPSIS approach is that it allows for the comparison of the local, rather than ignoring the population effect, country-wide impact of the COVID-19 pandemic with that of other countries. In the modeling stage, we incorporate the Value at Risk (VaR) integrated IF–Then rules to convert the cognitive evaluation of the criteria weights by the decision maker to the corresponding fuzzy numbers.

Keywords Multi criteria decision making (MCDM) · COVID-19 pandemic · Value at risk · IF–Then rules · Fuzzy TOPSIS

1 Introduction

In human history, viruses entered the sources towards the end of the 1800s. In addition to the discovered species, it is known that there are millions of more unidentified viruses. There are different types of viruses that can spread through plants, insects, and animals. Some viruses are known to cause diseases. The worldwide effects of diseases are called epidemics. In 2019, a virus in the coronavirus family affected the whole world, starting from Wuhan, China. The process that started epidemically in 2020 has been raised to a pandemic epidemic level by the World Health Organization (WHO).

Scientific methodologies can help authorities make quick and valuable decisions that reduce the effects of the COVID-19 pandemic. Health authorities from various countries publish data about the spread of COVID-19. While these data are valuable, it is necessary to evaluate whether they provide enough information to manage the pandemic. The WHO publishes various types of data about the COVID-19 pandemic on its website. These data provide different attributes for the spread of COVID-19. However, a combined overall evaluation result is necessary to combine all data specifications and their preferences for the COVID-19 pandemic in a country. The data available from the WHO changes from one day to another. Therefore, sometimes it is better to use criteria that are increasing from one day to another, while on other days, criteria that show decreasing trends may be more appropriate. During peak cases, the "deaths recorded in the last 24 h" is more crucial, while during stable days of the pandemic, "cumulative total deaths" is more important to determine the influence of the COVID-19 pandemic. Additionally, the diversification of these criteria values from one country to another creates a complex decision-making environment for understanding the COVID-19 impacts in different countries. These types of conflicting structures require multi-criteria decision-making (MCDM)

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methods to model the differentiation of criteria values. MCDM methods are appropriate for incorporating different criteria-related data. MCDM methods can be beneficial in determining the impacts of the COVID-19 pandemic on affected countries because they present a unique combined score that reflects the MCDM problem specification in a better way. There is also the problem of uncertainties in the trend of COVID-19's deployment, which requires the development of fuzzy decision-making models for modeling its impacts on countries. If we analyze published data about the COVID-19 pandemic, we can see that classical fuzzy sets are sufficient for the modeling phase.

The purpose of this study is to use data published by the WHO to develop a multi-criteria decision-making (MCDM) model to monitor the levels of countries affected by the COVID-19 epidemic using the evaluation criteria of cumulative total cases, cases recorded in the last 24 h, cumulative total deaths, and deaths recorded in the last 24 h. The TOPSIS technique, which is one of the MCDM techniques, was chosen for its ease of use and the ease of understanding and interpretation of the results. The evaluation criteria were selected based on criteria in the WHO data. The weights of the evaluation criteria were assigned intuitively. The study was applied as fuzzy TOPSIS (FTOPSIS) by assigning triangular fuzzy number values.

The paper is organized as follows: Sect. 2 presents a literature survey about COVID19. Section three proposes the techniques used in the study. Section four represents the application. Finally, section five presents the conclusions.

2 Literature review

COVID-19 cases were registered in late December 2019 in Wuhan, China. On January 13, 2020, these cases were defined as New Coronavirus Disease (nCov) (Ministry of Health, 2020). On January 20, 2020, a case was detected in the Republic of Korea for the first time outside China (World Health Organization 2020a, b, c, d, e, f, g, h, i, j, k, l, m). The first case was recorded in the United States on January 23, 2020 (World Health Organization 2020a, b, c, d, e, f, g, h, i, j, k, l, m). The number of cases recorded worldwide was 2798, and 37 of these cases were detected in 11 countries outside of China (World Health Organization 2020a, b, c, d, e, f, g, h, i, j, k, l, m). With the total number of cases exceeding six thousand worldwide, the "Pandemic Supply Chain Network" has been established with the cooperation between WHO and the World Economic Forum (WEF). WEF is a platform that provides data sharing, market visibility, operational coordination, and connectivity (World Health Organization 2020a, b, c, d, e, f, g, h, i, j, k, l, m). WHO has worked with technical experts to develop diagnostic kits. Costing, procurement, and assembly issues are identified as priority issues for the future (World Health Organization 2020a, b, c, d, e, f, g, h, i, j, k, l, m).

As a global strategic preparedness and response plan outlining public health measures, the global pandemic preparedness and response plan was developed by WHO and partners. The plan aims to stop the spread of the disease in all countries (World Health Organization 2020a, b, c, d, e, f, g, h, i, j, k, l, m). WHO has worked with the international network of statistics and mathematical modelers to determine the epidemiological parameters of COVID-19, such as the incubation period (time between infection and symptom), case fatality rate, and serial interval (time between symptom onset of primary and secondary cases) (World Health Organization 2020a, b, c, d, e, f, g, h, i, j, k, l, m). WHO updated its assessment of spreading risk and impact risk on February 28. From this date, regional and global levels have been added to China, which is in the high-risk class (World Health Organization 2020a, b, c, d, e, f, g, h, i, j, k, l, m). While the COVID-19 pandemic is at a high level, World Health Organization has provided online resources in various languages for effective preparedness and response (World Health Organization 2020a, b, c, d, e, f, g, h, i, j, k, l, m). These resources are crucial guides for healthcare professionals, decision-makers, and the public. On March 11, 2020, WHO classified the COVID-19 virus as a pandemic, taking into account past cases and the speed of its spread worldwide (World Health Organization 2020a, b, c, d, e, f, g, h, i, j, k, l, m).

Although the COVID-19 outbreak is a new issue, numerous academic studies have been included in the literature. For example, Majumder, Biswas, and Majumder (2020) presented an approach to examine deaths from COVID-19 and identify important risk factors. They created a model for analyzing deaths from COVID-19 using Technique for Order Preferences by Similarity to Ideal Solution (TOPSIS) techniques and compared it with the existing model. This new model is more accurate and consistent compared to existing regression models. Since there is no weight given to factors in the new model obtained, it has been possible to evaluate the cases originating from COVID-19 (Majumder et al. 2020). Grida et al. (2020) have created a study to prevent COVID-19 impacts under uncertainty in supply, demand, and logistics, which determined to chain supply. They used the Best Worst Method (BWM) and TOPSIS methods based on the pathogenic cluster. While BWM weighs the policies that prevent the spread of the virus, TOPSIS has listed the supply chain aspects for the food, electronics, pharmaceutical, and textile industries (Grida et al. 2020). Alqahtani and Rajkhan (2020) conducted a study on the education sector, one of the sectors affected by the COVID-19 era, to determine the critical success factors of online learning using the Analytic Hierarchy Process (AHP) and TOPSIS methods.

Ic (2021) proposed a forecasting model to predict a potential reactivated COVID19 patient. His paper aims to explore the applicability of a modified TOPSIS integrated Design of Experiment (DoE) method to predict a potential reactivated COVID19 patient in real-time clinical or laboratory applications. Mohammed et al. (2020) presented a benchmarking methodology for the selection of an optimal COVID19 diagnostic model based on entropy and TOPSIS Methods. Their integrated MCDM approach is proposed where TOPSIS applied for the benchmarking and ranking purpose while Entropy is used to calculate the weights of criteria. Hezer et al. (2021) purposed a study to evaluate the safety levels of 100 regions in the world in terms of COVID19 using TOPSIS, VIKOR, and COPRAS methods. Mohammed et al. (2021) proposed a novel convalescent plasma transfusion intelligent framework for rescuing COVID19 patients across centralized/decentralized telemedicine hospitals based on the matching component process to provide an efficient CP from eligible donors to the most critical patients using the TOPSIS method. Gupta et al. (2021) presented a CRITIC-TOPSIS approach to stress intensity in the urban areas of India during the COVID19 pandemic. Ecer and Pamucar (2021) aimed to identify insurance companies' priority ranking in terms of healthcare services in Turkey during the COVID19 outbreak through an MCDM model. They proposed a Measurement of Alternatives and Ranking according to the Compromise Solution model under an intuitionistic fuzzy environment to rank insurance companies.

We referred to a flow chart to select the most appropriate MCDM methodology to apply in our study. Figure 1 shows a flow chart to determine the suitable method for our problem. According to Fig. 1, the green illustration proposes the TOPSIS method as the most appropriate MCDM method for this study. As a result, the TOPSIS method is selected as a multi-criteria decision-making method to rate the COVID-19 pandemic-influenced countries. Also, we provide a sub-flow chart to illustrate the proposed methodology that incorporates the Value at Risk (VaR), fuzzy TOPSIS, and IF–Then rules.

In this paper, instead of using a traditional crisp multi-criteria decision-making model, we calculate an overall performance score for a selected country in the world using the fuzzy TOPSIS method. We use various criteria to determine which countries are most negatively affected by the COVID-19 pandemic. We also demonstrate the applicability of the developed decision support framework in this paper.

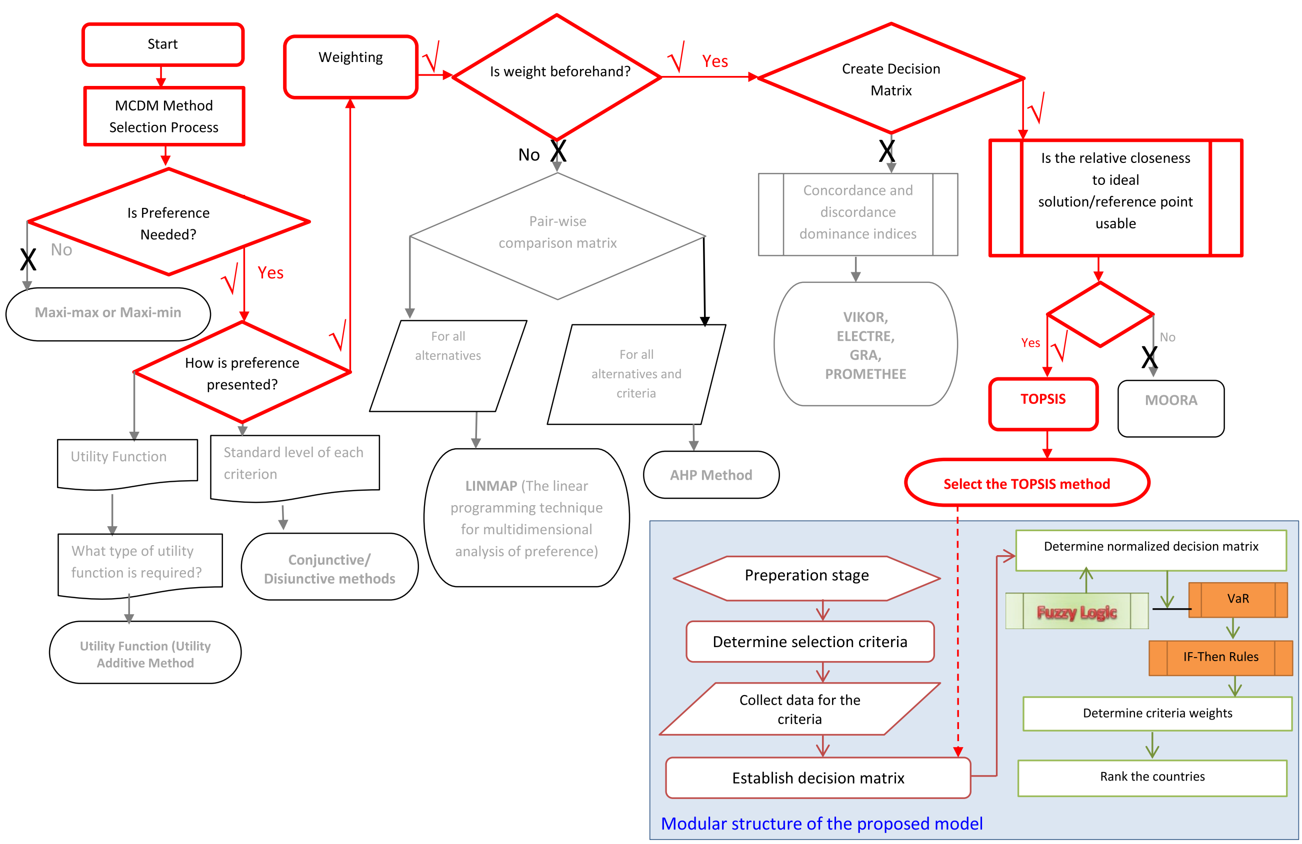

Fig. 1 MCDM model selection flow chart (adapted from Koçak et al. 2021; Ic and Simsek 2019; Sen and Yang 1998; Yorulmaz and Ic 2022)

3 Methodology

3.1 TOPSIS method

In Multi-Criteria Decision Making (MCDM) problems, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method is commonly used as a guide for decision-makers as it deals with the distances to the ideal solution. It is widely applied in various studies in literature due to its practical interpretability of the results. For example, İç and Yurdakul (2020) presented a paper that examined the development of manufacturing companies and provided sectoral rankings using the integrated TOPSIS and fuzzy AHP methods. In another study, Zhang, Zhang, Sun, Zou, and Chen (2018) presented a TOPSIS approach that evaluated public transport performance levels in Wuhan.

3.2 Fuzzy logic and fuzzy set theory

Fuzzy logic has been widely used in various research areas such as renewable energy, computer security, and robotic systems (Cobos-Guzman et al. 2020; Barai and Nonami 2008; Seraji and Howard 2002; Fateh 2010). The popularity of fuzzy logic is due to its ability to approximate reasoning under uncertainty simply and suitably for modeling purposes. When building a fuzzy system, the information from real-world systems takes precedence over decision-making approaches. Since obtaining accurate information from different criteria of COVID-19 spread considering the data structure is not easy and there are no clear categories of the involved criteria, we have developed a fuzzy decision-making model to rate the countries. The design of the fuzzy decision-making system includes the following tasks:

- Selection of the membership functions for the data and criteria weights.
- Establishing the fuzzy rules base.
- Development of the MCDM model's structure.

- Selection of the defuzzification approach that converts the fuzzy output into a crisp one.

A fuzzy set is a class of objects expressed in degrees of membership with continuity. The values of the elements in the membership function take membership values between 0 and 1 (Zadeh 1965). Fuzzy numbers are shown as a triangle, and trapezoids are widely used in research and practice. Triangular fuzzy numbers are represented as (*a*, m, b). Figure 2 illustrates that *a* is the smallest value on the left, m is the most appropriate value, and b is the largest value (Cheng 2004). Functions of triangle fuzzy numbers;

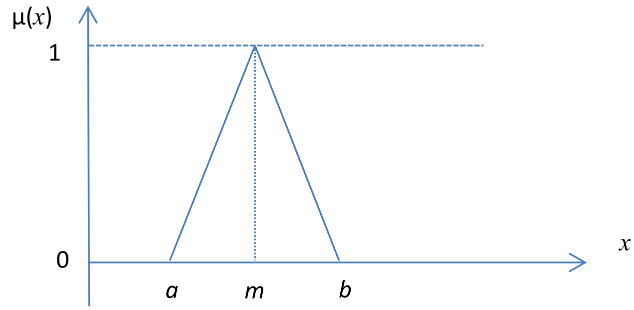

Fig. 2 Membership function of triangular fuzzy numbers (*a*, m, b)

$$t(x;a,m,b)=\begin{cases}1-\frac{m-x}{m-a}, & a\le x\le m,\\ 1-\frac{x-m}{b-m}, & m\le x\le b,\\ 0, & elsewhere.\end{cases} \quad (1)$$

As with normal clusters, operations can be performed on fuzzy clusters as well. For example, let $F_1=(a_1, m_1, b_2)$ and $F_2=(a_2, m_2, b_2)$ be two triangular fuzzy numbers:

$$F_1+F_2=(a_1+a_2, m_1+m_2, b_1+b_2) \quad (2)$$

$$kF_1=\left(ka_1, km_1, kb_2\right) \quad k\ge 0 \quad (3)$$

3.3 Fuzzy TOPSIS

$\widetilde{D}$ Represents the fuzzy decision matrix and criteria weights can assign with fuzzy weight vector (İç et al. 2017):

Step 1: Decision matrix is constructed:

$$\widetilde{D}=\begin{bmatrix}\widetilde{x_{11}} & \cdots & \widetilde{x_{1n}}\\ \vdots & \ddots & \vdots\\ \widetilde{x_{m1}} & \cdots & \widetilde{x_{mn}}\end{bmatrix} \quad (4)$$

$$where, \quad \widetilde{x_{ij}}; i=1,2,\ldots m alternatives,$$
$$and \quad j=1,2,\ldots n, criteria$$

Step 2: Determination of the normalized decision matrix:

A normalized decision matrix is obtained using the Eqs. (5) and (6) for B and C being high-affected and low-affected clusters.

$$\widetilde{r}_{ij}=\widetilde{x}_{ij}(\div)\widetilde{x}_j^*=\left(\frac{a_{ij}}{c_j^*},\frac{m_{ij}}{b_j^*},\frac{b_{ij}}{a_j^*}\right), \quad j\epsilon B \quad (5)$$

$$\widetilde{r}_{ij}=\widetilde{x}_j^-(\div)\widetilde{x}_{ij}=\left(\frac{a_j^-}{b_{ij}},\frac{b_j^-}{m_{ij}},\frac{c_j^-}{a_{ij}}\right), \quad j\epsilon C \quad (6)$$

$$\left(a_j^*, b_j^*, c_j^*\right) = max_i\left(a_{ij}, m_{ij}, b_{ij}\right)\ if\ j\,\epsilon B \tag{7}$$

$$\left(a_j^-, b_j^-, c_j^-\right) = min_i\left(a_{ij}, m_{ij}, b_{ij}\right)\ if\ j\,\epsilon C \tag{8}$$

$where, \widetilde{x}_{ij} = (a_{ij}, m_{ij}, b_{ij})$ and $\widetilde{x}_j^* = (a_j^*, b_j^*, c_j^*)$.

Step 3: Computation of the weighted normalized matrix in which fuzzy weights are calculated as $\widetilde{w}_j = (\alpha_j, \beta_j, \gamma_j)$:

$$\widetilde{v} = \left[\widetilde{v}_{ij}\right]_{mxn} i = 1, 2, 3, \dots, m,\ j = 1, 2, 3, ..., n \tag{9}$$

$$\widetilde{v}_{ij} = \widetilde{r}_{ij} \otimes \widetilde{w}_j. \tag{10}$$

where the weight α_j is the smallest value on the left, β_j is the most appropriate value, and γ_j is the largest value of the triangular fuzzy weight number of $\widetilde{w}_j$.

Step 4: Defuzzification: Fuzzy performance values are converted to crisp values by calculating the means of the fuzzy numbers (Ic et al. 2013; Chen and Hwang 1992):

$$\bar{x}(\tilde{A}) = \frac{\int x\mu_{\tilde{A}}(x)dx}{\int \mu_{\tilde{A}}(x)dx} \tag{11}$$

Since the criteria values used in this study are crisp values, they will be expressed as (m; m; m) using the center of the fuzzy number to perform mathematical operations. For this reason, crisp values are identified in triangular fuzzy number format to multiplying by the fuzzy triangular numbers. Within the scope of the study, the averages of the crisp values multiplied by the weight values without dividing by the value of 3 and, the clarified values will be calculated as in the following Eq. (12):

$$\bar{x}(\tilde{A}) = \frac{(m + m + m)}{3} = (m + m + m) \tag{12}$$

The fuzzy *weighted normalized* values ($\tilde{v}_{ij}$) provided in Eq. (10) is defuzzified using Eq. (12) and the crisp *weighted normalized* values (v_{ij}) is obtained.

Step 5: Identify positive ideal and negative ideal solutions: The A^* and $A-$ are defined in terms of the weighted normalized values, as shown in Eqs. (13) and (14):

$$A^* = \left\{ (\max_i v_{ij} \middle| i \in I), (\min_i v_{ij} \middle| i \in I' \right\} \tag{13}$$

$$A^- = \left\{ (\min_i v_{ij} \middle| i \in I), (\max_i v_{ij} \middle| i \in I' \right\} \tag{14}$$

where I is the set of benefit type criteria and I′ is the set of cost type criteria.

Step 6: Calculation of separation measures:

$$d_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2} \tag{15}$$

$$d_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \tag{16}$$

where, v*i** is the positive-ideal value for *i*th criteria, and v*i*- is the negative-ideal value for the *i*th criteria.

Step 7: Calculation of ranking scores:

$$C_i^* = \frac{d_i^-}{d_i^- + d_i^+} \quad i = 1, \dots m. \tag{17}$$

3.4 Value at risk (VaR)

We apply the value at risk (VaR) approach for historical data and applied the "historical simulation" methodology for the problem. First of all, we calculated the "return values" indicated that the daily log-return, Rt + 1, using the daily value K_i, t + 1:

$$R_{t+1} \equiv \ln\left(\frac{K_{i,t+1}}{K_{i,t}}\right) \tag{18}$$

In the financial engineering literature, the term "return" indicates the revenue. However, criteria using the COVID19 pandemics reflects the "minimum value is better" type (cost type) evaluation. So, we used the calculated VaR value within a contrary perspective that "maximum VaR is better" perspectives. We can now directly model the volatility of the COVID19 portfolio return, $R_{PF,t+1}$, call it $K_{PF,t+1,}$ and then calculate the VaR for the portfolio.

Given a confidence interval of p ∈ [0,1] and assumed the time index of t and t + 1, we can find the volatility of the portfolio of the ΔV(α) over the period. Let $F_\alpha(x)$ be the cumulative distiribution function of ΔV(α). Considering the hold of a short position with a period α with probability p, and the position ΔV(α) ≥ 0, the VaR is defined as

$$p = \mathbb{P}[\Delta V(\alpha) \geq VaR] = 1 - \mathbb{P}[\Delta V(\alpha) \leq VaR] = 1 - F\alpha(VaR) \tag{19}$$

We can define the p-quantile of $F_\alpha(x)$ and the given confidence level of p ∈ [0,1] (0.05 for 95% confidence level) is

$$VaR_p = x_p = inf\{(x|F\alpha(x) \geq p)\} \tag{20}$$

where, *inf* is the smallest real number. Hence, the tail behavior of the cumulative distribution function of $F_\alpha(x)$ or its quantile is condition necessary for approaching VaR calculation (Tsay 2005).

3.5 Linguistic summarization using type 1 fuzzy set

We define a set of M objects $\mathbb{Y} = \{y_1, y_2, \ldots, y_M\}$ and a set of N criteria $\mathbb{V} = \{v_1, v_2, \ldots, v_N\}$.Let $\mathbb{X}_n (n = 1, 2, \ldots, N)$ be the domain of v_n.Then $v_n(y_m) \equiv v_n^m \in \mathbb{X}_n$ is the value of the nth object (m = 1,2,…,M) (Wu et al. 2010). Hence the data set $\mathbb{D}$, which collects information about elements from $\mathbb{Y}$, is in the form of

$$\mathbb{D} = \{< v_1^1, v_2^1, v_N^1 >, \ldots, < v_1^M, v_2^M, \ldots, v_N^M >\} \equiv \{d_1, d_2, \ldots, d_M\} \quad (21)$$

where $d_m =< v_1^m, v_2^m, \ldots, v_N^m >$ is a complete record about object y_m.

Only single-antecedent single-consequent rules are considered in this subsection. Because we are interested in generating IF–THEN rules from a dataset, our canonical form for LS using type 1 fuzzy sets is:

IF $\mathbb{X}_1$ is/has S_1, THEN $\mathbb{X}_2$ is Has S_2.

where S_1 and S_2 are words modeled by type 1 fuzzy sets (Wu et al. 2010).

4 Application

The study aims to evaluate and interpret countries' levels of exposure to the COVID-19 outbreak based on cumulative total cases, cases recorded in the last 24 h, and cumulative total deaths, deaths recorded in the last 24 h. In the application part of the study, data collection is to be used, as the weighting method and the application steps of the TOPSIS method, which is one of the MCDM techniques, to the blurred environment. On the other hand, the TOPSIS method is a very useful method for evaluating the criteria values (data). The figures related to the COVID-19 pandemic are very dependent on the size of the country. We certainly trust that the data standardization process considers the population size effects. The data normalization step (vector normalization in Eqs. (5–8)) in the fuzzy TOPSIS method is suitable for the standardization of the collected values. WHO systematically publishes reports throughout the COVID-19 outbreak. These reports numerically show the cumulative daily total cases of countries, cases recorded in the last 24 h, cumulative total deaths, and deaths recorded in the last 24 h. In the study, 11 countries were selected depending on the density of cases between March 2, 2020, and August 16, 2020, and these countries are Germany, the United States of America, Argentina, Brazil, India, England, Spain, Italy, Colombia, Russia, and Turkey, respectively.

To calculate the criteria weights for the TOPSIS the collected data are arranged within the date range selected based on criteria. The edited data were plotted graphically (Figs. 3, 4, 5, 6) and received linguistic expressions based on expert opinion. The decision-makers can use fuzzy triangular numbers when attempting to predict the weight of the criteria. The center value of the fuzzy triangular number is the closest number to the crisp equivalent. Therefore, the lower and upper values of the fuzzy number are one unit apart. Triantaphyllou and Lin (1996) offer a fuzzy scale that appropriates Saaty's scale (Table 1). Fuzzy number equivalents of the linguistic expressions in the graphics above are shown in Table 1.

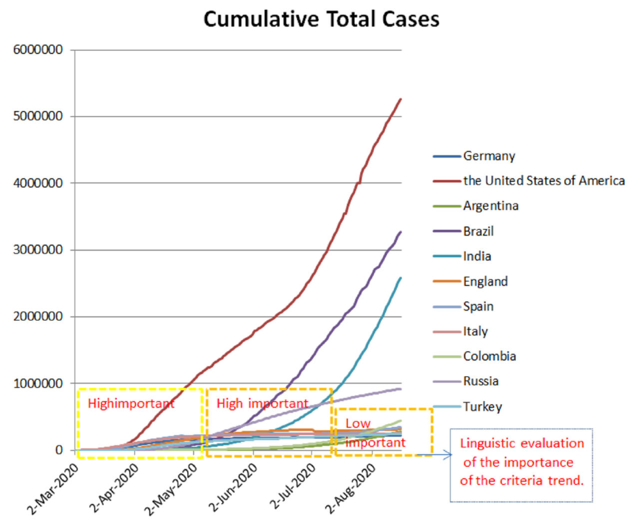

Fig. 3 Cumulative total cases

The evaluation criteria, along with the abbreviations used, are shown in Table 2. They include the cumulative total cases, cases recorded in the last 24 h, the total number of cumulative deaths, and the number of deaths recorded in the last 24 h. These four criteria are all published by the World Health Organization (WHO) on their website and are all cost-type. We use the distances between the ideal and negative-ideal solutions to be calculated based on these cost criteria. The minimum value of the criterion represents the positive ideal solution value, while the maximum criteria values represent the negative-ideal solution for the TOPSIS model.

The display of evaluation criteria graphs with linguistic expressions was shown verbally in Table 3 by creating a decision matrix, which was then transformed into numerical values using fuzzy number equivalents. The linguistic expressions were obtained with the help of a physician who is an intensive care specialist at a hospital in Turkey, as shown in Table 3. The time series was observed and evaluated with linguistic expressions according to the time series in the graphs given in Figs. 3, 4, 5, 6, respectively; (high important, high important, low important), (very high important, high important, low important), (very low important, medium important, high important), and (medium important, very high important, high important). To obtain the normalized fuzzy matrix, the geometric means were first calculated. However, we also provide a discussion on

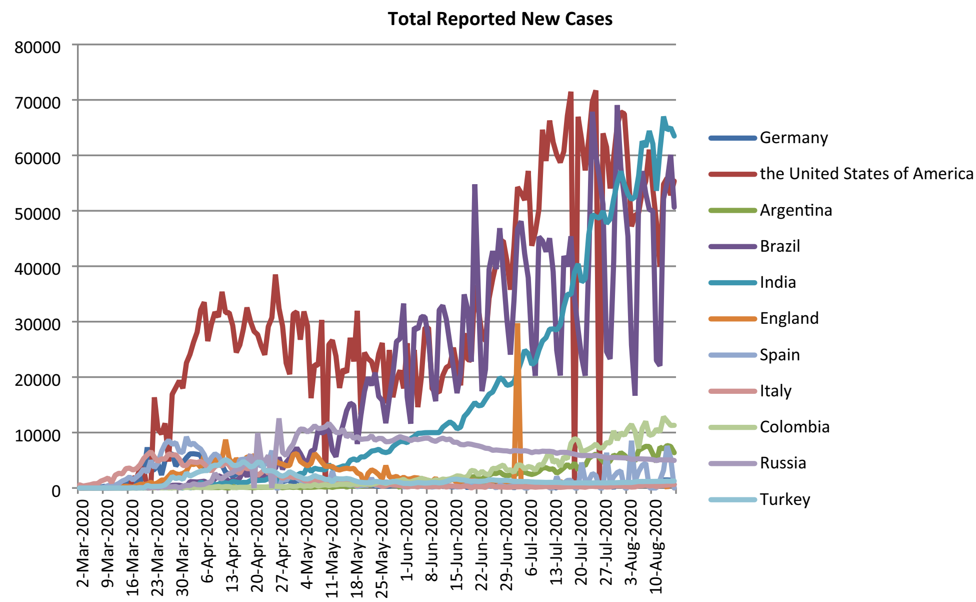

Fig. 4 Total reported new cases

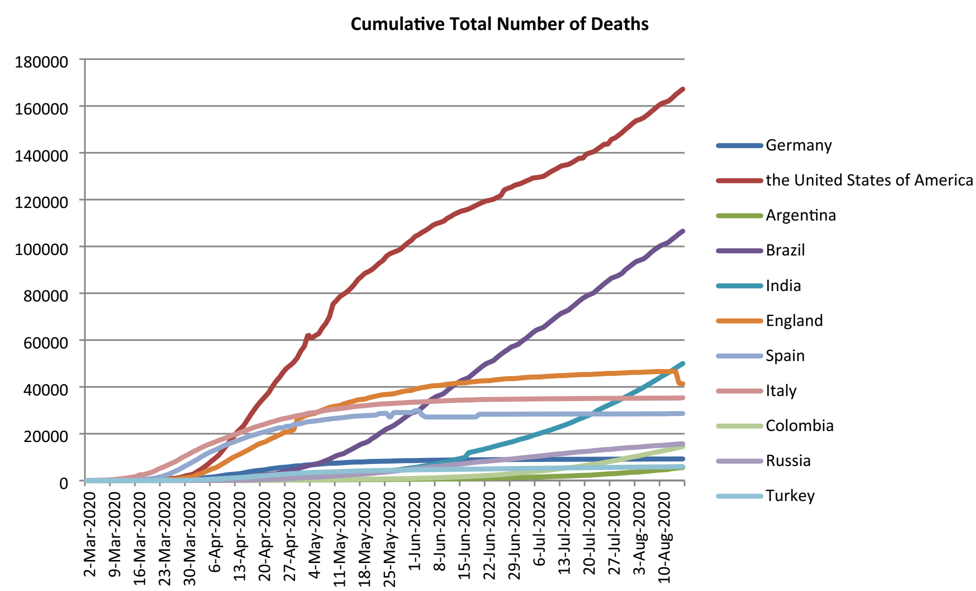

Fig. 5 Cumulative total number of deaths

why such a primitive indicator could be competitive with the multidimensional reflection of the problem. The issue is very complicated, and we used a successful approach called Value at Risk (VaR) to validate the advantage of such a simplistic approach for the decision-making process. On the other hand, it creates the illusion that the complex assessment of the phenomena could be simplified without discussing the consequences of such action. The calculated VaR values for the criteria are shown in Table 4.

In Table 4, the highest VaR result is 0.10816 for K1 in March. However, K1 is the "minimum value is better" type criteria and, the 0.10816 indicates the better VaR for March. So, the minimum VaR appears in March. Conversely, the maximum VaR appears in August for K1. Also, VaR is increasing from March to August for K1. IF–THEN fuzzy rules are determined according to the principles summarized in Sect. 3.5 and listed below:

$$\text{If } \underbrace{\textbf{VaR}}_{\mathbb{X}_1} \text{ is } \underbrace{\textbf{sharply increasing/decrease}}_{\mathbf{S_1}} \text{ from the time frame for the criteria, then } \underbrace{\textbf{importance}}_{\mathbb{X}_2} \text{ is } \underbrace{\text{“}\textbf{very important}\text{”}}_{\mathbf{S_2}}.$$

Fig. 6 Total reported new deaths

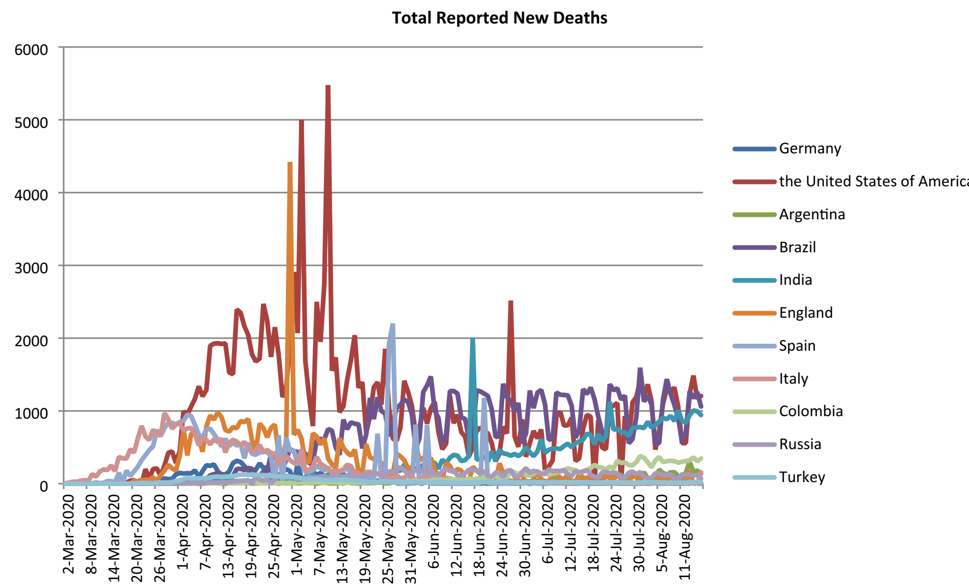

Table 1 Linguistic expressions and fuzzy numbers (Triantaphyllou and Lin 1996)

Linguistic expressions	Fuzzy number
Very low important (VLI)	(1; 1; 3)
Low important (LI)	(1; 3; 5)
Medium important (MI)	(3; 5; 7)
High important (HI)	(5; 7; 9)
Very High important (VHI)	(7; 9; 9)

Table 2 Evaluation criteria

Criteria code	Criteria
K1	Cumulative total cases
K2	Cases recorded in the last 24 h
K3	The total number of cumulative deaths
K4	The number of deaths recorded in the last 24 h

If VaR is extremly increasing/decrease from the time frame for the criteria, then importance is “very highly important.”

If VaR is highly increasing/decrease from the time frame for the criteria, then importance is “highly important.”

If VaR is a steady-state from the time frame for the criteria, then importance is “moderately important.”

If VaR is slightly increasing/decrease from the time frame for the criteria, then importance is “low important.”

If VaR is an ordinary increase/decrease from the time frame for the criteria, then importance is “very low important.”

We can easily assign linguistic values for the importance level of the criteria according to the graphics in Fig. 7. Once graphical illustrations are given for the VaR (see Fig. 7), the antecedents and consequents of the rules can be determined. A decision-maker needs to specify the linguistic terms used for each antecedent and consequent and also their corresponding fuzzy set models, as shown in

Table 3 Criteria weighting

Code	Lingiustic expressions			Corresponding fuzzy numbers			Geometric mean			Normalized Weights		
	From March to April	From April to June	From June to August									
K1	**HI**	**HI**	**LI**	(5, 7, 9)	(5, 7, 9)	(1, 3, 5)	2.924018	5.277632	7.398636	0.101483	0.250225	0.553004
K2	VHI	HI	LI	(7, 9, 9)	(5, 7, 9)	(1, 3, 5)	3.271066	5.738794	7.398636	0.113528	0.272089	0.553004
K3	VLI	MI	HI	(1, 1, 3)	(3, 5, 7)	(5, 7, 9)	2.466212	3.271066	5.738794	0.085594	0.155089	0.428941
K4	MI	VHI	HI	(3, 5, 7)	(7, 9, 9)	(5, 7, 9)	4.717694	6.804092	8.276773	0.163736	0.322597	0.61864

See Figs. 3 and 7 for detailed information

Table 3. The proposed weighting procedure is based on the data, which can be related to the trend of the pandemic. In the future, we may see different proportions of importance, possibly even a negative proportion. Therefore, IF–THEN rules are a necessary technique for modeling the criteria weights using linguistic evaluation in the proposed model.

The data from the selected dates (10th, 20th, and 30th of the month) were used to construct the decision matrix (World Health Organization 2020a-m). The data on the

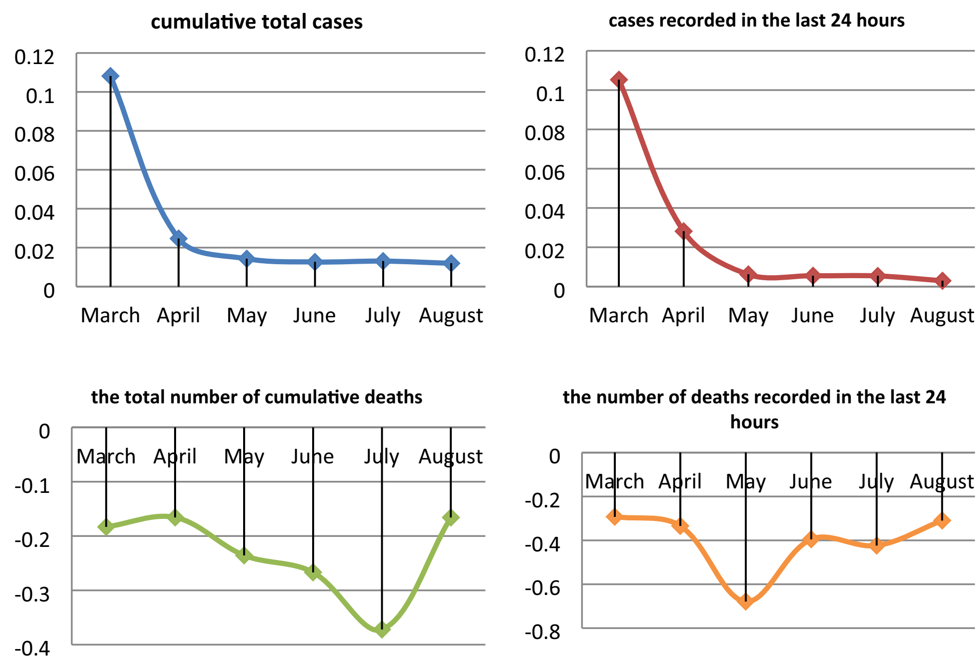

Fig. 7 Graphical illustrations for VaR

Table 4 Calculated VaR for selected time frame

Criteria Code	Criteria	Value at risk					
		March[a]	April	May	June	July	August
K1	Cumulative total cases	0.10816	0.02465	0.01429	0.01262	0.01307	0.01193
K2	Cases recorded in the last 24 h	0.105282	0.028139	0.006162	0.005503	0.005393	0.002946
K3	The total number of cumulative deaths	– 0.18318	– 0.16576	– 0.23559	– 0.26677	– 0.37207	– 0.16582
K4	The number of deaths recorded in the last 24 h	– 0.29207	– 0.33402	– 0.6786	– 0.39485	– 0.42346	– 0.30939

Table 5 Decision matrix

March 02, 2020	K1			K2			K3			K4		
	M	m	m	*m*	m	m	*m*	m	m	*m*	m	m
Germany	129	129	129	72	72	72	0	0	0	0	0	0
United States of America	62	62	62	2	2	2	0	0	0	0	0	0
Argentina	0	0	0	0	0	0	0	0	0	0	0	0
Brazil	2	2	2	0	0	0	0	0	0	0	0	0
India	3	3	3	0	0	0	0	0	0	0	0	0
England	36	36	36	13	13	13	0	0	0	0	0	0
Spain	45	45	45	0	0	0	0	0	0	0	0	0
Italy	1689	1689	1689	561	561	561	35	35	35	6	6	6
Colombia	0	0	0	0	0	0	0	0	0	0	0	0
Russia	2	2	2	0	0	0	0	0	0	0	0	0
Turkey	0	0	0	0	0	0	0	0	0	0	0	0

decision matrix was transformed into a fuzzy decision matrix. The $\widetilde{D}$ matrix created for March 02, 2020, was prepared as in Table 5. As an example of the K1 criteria, daily data values are shown in Appendix 1. Some of the data have zero value on some days in Appendix 1, as there are no COVID-19 case records for some countries on those days. However, all countries have COVID-19 cases based on the spread of the pandemic if we consider the data from the starting day to the final day in Appendix 1. We used data from March 02, 2020, to August 10, 2021, so the pandemic spread has volatility. In this perspective, the number of new cases is crucial when the pandemic spread is increasing, but in the case of decreasing, the cumulative cases are more important for the management of the pandemic by health authorities. Therefore, it is necessary to develop a unique model, such as TOPSIS, to monitor the pandemic trend in a country. All criteria are useful in the TOPSIS model, but sometimes one criterion is more important than the others. In this case, we use the weighting process in the TOPSIS model. This specification provides flexibility to monitor the impacts of the pandemic from different perspectives.

The distance of the alternatives to the ideal solution was calculated using Eqs. 15 and 16. Finally, the ranking values were calculated using Eq. 17 and shown in Table 6 and Fig. 8, respectively. The elements of the weighted normalized decision matrix are deffuzified using Eq. (12). Furthermore, positive ideal (A*) and negative ideal (A -) solutions are obtained by using the Eqs. (13) and (14), and the results are shown in Table 6. The steps applied for the data dated March 02, 2020, were repeated in order, taking the 10th, 20th, and 30th of each month (10th of the month for August only) for the dates included in the data set. Table 7 was created by arranging all the calculated TOPSIS scores in a common table. The graphic of the created table is shown in Fig. 9. According to Fig. 9, the USA, Brazil, and India are the most affected countries by the COVID-19 pandemic because their scores dramatically changed from March 2020 to August 2020. However, Turkey, Italy, England, Colombia, and Russia are the less affected countries by the COVID-19 pandemic from March 2020 to August 2020 time frame. The proposed fuzzy TOPSIS model has successfully ranked the countries according to the selected criteria. The proposed model can use by the authorities to monitor the COVID-19 pandemic, especially during the monthly periods.

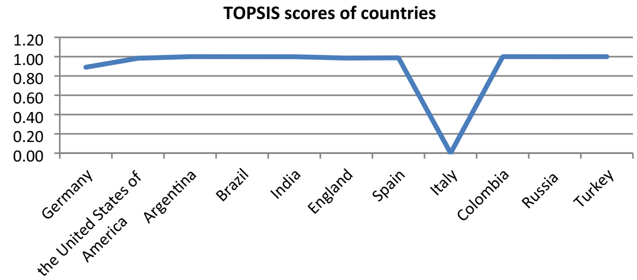

Fig. 8 TOPSIS scores of countries

The method applied in the study was re-applied for the data in the WHO report dated April 25, 2021, which is an up-to-date data set, and in Table 8. The obtained results were combined with the results of March 2, 2020's results (Fig. 10). The USA, Brazil, and India were the most affected countries by the epidemic. Germany, Italy, Russia, and Turkey were affected by the pandemic. Also, the least affected countries were Argentina, England, Spain, and Colombia, respectively. When the data set used in the study is updated, we can determine the level of exposure of the countries to the COVID-19 pandemic. Figure 8

Table 6 Defuzzification and positive and negative ideal solutions

March 02, 2020	K1	K2	K3	K4	d_i^+	d_i^-	C_i^*
Germany	0.17	0.10	0.00	0.00	0.197	1.595	0.89
United States of America	0.03	0.00	0.00	0.00	0.029	1.698	0.98
Argentina	0.00	0.00	0.00	0.00	0.000	1.712	1.00
Brazil	0.00	0.00	0.00	0.00	0.001	1.712	1.00
India	0.00	0.00	0.00	0.00	0.001	1.712	1.00
England	0.02	0.02	0.00	0.00	0.025	1.696	0.99
Spain	0.02	0.00	0.00	0.00	0.021	1.703	0.99
Italy	0.78	0.81	0.67	1.10	1.712	0.000	0.00
Colombia	0.00	0.00	0.00	0.00	0.000	1.712	1.00
Russia	0.00	0.00	0.00	0.00	0.001	1.712	1.00
Turkey	0.00	0.00	0.00	0.00	0.000	1.712	1.00
A^*	0.000	0.000	0.000	0.000			
A^-	0.776	0.813	0.670	1.105			

Table 7 Fuzzy TOPSIS results for selected dates

	Germany	USA	Argentina	Brazil	India	England	Spain	Italy	Colombia	Russia	Turkey
10-Mar-2020	0.939667	0.911614	0.998882	0.998685	0.997672	0.978189	0.832275	0.000000	0.999457	0.999632	1.000000
20-Mar-2020	0.816294	0.776992	0.999704	0.989986	0.996732	0.915365	0.613483	0.000000	0.999105	0.996742	0.998951
30-Mar-2020	0.777865	0.365468	0.997756	0.976527	0.995793	0.830234	0.403449	0.375862	0.997850	0.996841	0.934615
10-Apr-2020	0.815868	0.048193	0.999383	0.940182	0.984470	0.712154	0.660647	0.670289	0.996161	0.964376	0.904630
20-Apr-2020	0.890862	0.000000	0.998472	0.903876	0.964328	0.730652	0.750721	0.749334	0.994167	0.973628	0.891387
30-Apr-2020	0.909926	0.331151	1.000000	0.859580	0.961868	0.444888	0.824551	0.824323	0.995988	0.846837	0.916075
10-May-2020	0.939065	0.241747	0.998582	0.728844	0.911425	0.833598	0.881898	0.873391	0.986079	0.745344	0.939970
20-May-2020	0.901499	0.000000	1.000000	0.509885	0.815955	0.624885	0.835084	0.796463	0.985076	0.715755	0.928967
30-May-2020	0.938090	0.115263	0.994540	0.414355	0.820975	0.794325	0.880860	0.864379	0.984292	0.795034	0.948693
10-Jun-2020	0.940959	0.096411	0.973735	0.400476	0.684454	0.728811	0.885315	0.851235	0.950498	0.706156	0.946714
20-Jun-2020	0.949586	0.197936	0.961661	0.347364	0.680882	0.826916	0.590203	0.875520	0.930478	0.781868	0.951392
30-Jun-2020	0.965009	0.000000	0.969038	0.396379	0.631123	0.876288	0.918263	0.903981	0.883893	0.823287	0.965049
10-Jul-2020	0.973776	0.106261	0.963144	0.296613	0.662402	0.883378	0.928258	0.914321	0.915462	0.856679	0.975893
20-Jul-2020	0.979354	0.024416	0.963342	0.396031	0.496199	0.893625	0.933775	0.919509	0.855549	0.880205	0.979768
30-Jul-2020	0.984779	0.000000	0.925774	0.340977	0.452292	0.889992	0.935402	0.923618	0.836793	0.881915	0.985994
10-Aug-2020	0.988430	0.064357	0.926376	0.284381	0.351920	0.904085	0.943623	0.929781	0.832486	0.902006	0.986886

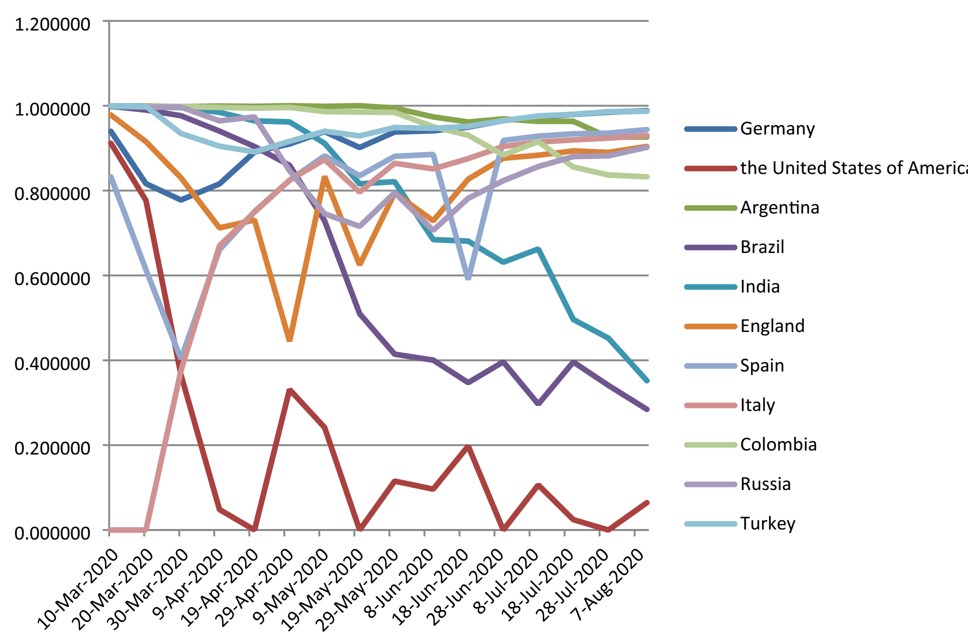

Fig. 9 Change of TOPSIS scores of countries by dates

illustrates March 2020 data. This date is the beginning of the pandemic. So, it is the expected result that most countries are rated at 1. As we can see in Fig. 10, the rating scores are diversified based on the spread of the COVID-19 pandemic based on the spread of pandemic all over the world.

By using the normalized fuzzy numbers and fuzzy weights, a weighted normalized matrix was created as shown in Table 9.

5 Discussion

5.1 Practical perspective

In this paper, we propose a methodology based on a published data set for predicting the impacts of the COVID-19 pandemic on different countries. The management of pandemics is a complex, unpredictable, and challenging task that can be worrying. Therefore, usable decision-support

Table 8 Data set for April 25, 2021

	K1	K2	K3	K4
Germany	3,287,418	145,156	81,564	1650
USA	31,656,636	406,001	565,809	4951
Argentina	2,824,652	166,024	61,176	2092
Brazil	14,237,078	404,623	386,416	17,667
India	16,960,172	2,172,063	192,311	15,161
England	4,403,174	17,232	127,417	157
Spain	3,456,886	32,476	77,496	214
Italy	3,949,517	92,074	119,021	2345
Colombia	2,740,544	121,122	70,446	2882
Russia	4,762,569	60,468	108,232	2650
Turkey	4,591,416	378,771	38,011	2403

tools are crucial for simplifying the management of pandemics. In chaotic processes like the COVID-19 pandemic, producing, collecting, and publishing data is crucial for developing suitable decision support tools. WHO is one of the organizations responsible for publishing data on the spread of the COVID-19 pandemic. Firstly we collected all daily published data from the WHO's website. Then we analyzed their suitabilities to construct a decision support tool to measure the COVID-19 impacts on the countries. As an example of the K1, some daily data values have zero numbers for some days (Appendix 1).

Some days, there are no COVID-19 case records for the related criterion in some countries. However, entire countries have COVID-19 cases based on the spread of the pandemic if we consider the data from the starting day to the final day. Therefore, the spread of the pandemic is volatile. In light of this, it is important to develop a decision support

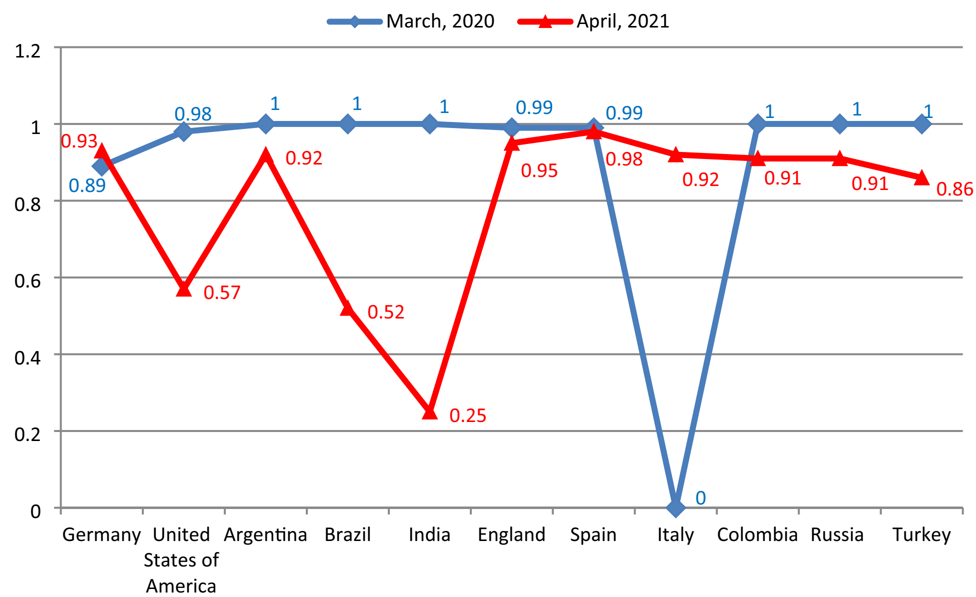

Fig. 10 Ranking comparison for March 02 and April 25

Table 9 Weighted normalized matrix

March 02, 2020	K1			K2			K3			K4		
	a	b	C	*a*	B	c	*a*	B	c	*a*	B	c
Germany	0.007	0.050	0.110	0.013	0.030	0.061	0.000	0.000	0.000	0.000	0.000	0.000
United States of America	0.003	0.008	0.017	0.000	0.001	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Argentina	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Brazil	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
India	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
England	0.002	0.005	0.010	0.002	0.005	0.011	0.000	0.000	0.000	0.000	0.000	0.000
Spain	0.002	0.006	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Italy	0.087	0.215	0.475	0.098	0.236	0.479	0.086	0.155	0.429	0.164	0.323	0.619
Colombia	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Russia	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Turkey	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

tool that can effectively process this data and monitor the spread of the COVID-19 pandemic and its effects on different countries. If we only use daily and volatile data, it becomes difficult to predict the extent of the pandemic's impact on a country, as the cases can vary greatly from one day to another. So, we developed an easy-to-use, modifiable, flexible, reusable, and robust model for monitoring the COVID-19 spread. For example, the number of new cases is crucial when the pandemic's spread is increasing. So, it is necessary to develop a robust model, like TOPSIS, to effectively monitor the pandemic trend in a country from one date to another. In this manner, we proposed a fuzzy TOPSIS model to effectively manage the COVID-19 pandemic's effect on the countries that are useful for the responsible institutions and their authorities.

5.2 Comparative analysis

We compared the fuzzy TOPSIS results with the Multi-Objective Optimization by Ratio Analysis (MOORA) results in this section. The MOORA method was developed by Brauers (2008). It is a multi-objective optimization method. The application steps of the MOORA method are simple and easier to understand. After the Eq. (12) in the fuzzy TOPSIS method, we can develop the MOORA index by using the Eq. (22):

$$Y_i = \sum_{j=1}^{g} v_{ij} - \sum_{j=g+1}^{n} v_{ij} \tag{22}$$

where g is the number of criteria to be maximized, (n-g) is the number of criteria to be minimized, and (Y_i) is the ranking score of ith country. A larger (Y_i) value for the countries is better performance. As we used a cost-type criteria in our model, we should use a modified equation for Eq. (22) is as follows:

$$Y_i = -\sum_{j=1}^{n} v_{ij} \tag{23}$$

For comparative analysis of the ranking results, the statistical significance of the differences between the rankings obtained by the fuzzy TOPSIS model and the MOORA method using Spearman's rank correlation test (Table 10). This test is applied when "the related values of compared ranking data are substituted which the values occupy in the respective samples" (Parkan and Wu 1999). In the application to test the null hypothesis (H_0: There is no similarity between the corresponding ranks), a test statistic, Z, is calculated using Eqs. (24) and (25) and compared with a pre-obtained significance level value (a). For the a = 0.05, if the test statistic is computed by Eq. (25) exceeds 1.645, the null hypothesis is rejected, and it is to be concluded that 'H1: The two ranking results are similar' is accepted.

$$r_s = 1 - \left[\frac{6 \times \sum_{i=1}^{n} \left(d_i\right)^2}{n \times \left(n^2 - 1\right)}\right] \tag{24}$$

$$Z = r_s \sqrt{n-1} \tag{25}$$

where d_i is the ranking differences for each alternative, n is the number of alternatives to be compared, and rs presents Spearman's rank-correlation coefficient.

Table 10 Comparative analysis result

Country	March 2, 2020				April 25, 2021				Ranking Differences	
	Fuzzy Topsis		MOORA		Fuzzy Topsis		MOORA		March 2, 2020	April 25, 2021
	C_i^*	Rank	Y_i	Rank	C_i^*	Rank	Y_i	Rank	Fuzzy Topsis-MOORA	Fuzzy Topsis-MOORA
Germany	0.89	10	– 0.04	10	0.93	3	– 0.0669	4	0	– 1
USA	0.98	9	0.03	1	0.57	9	– 0.0991	8	8	1
Argentina	1	1	0	6	0.92	4	– 0.0782	6	– 5	– 2
Brazil	1	4	0	4	0.52	10	– 0.4721	10	0	0
India	1	6	0	3	0.25	11	– 0.7365	11	3	0
England	0.99	8	0	9	0.95	2	– 0.0112	2	– 1	0
Spain	0.99	7	0.02	2	0.98	1	– 0.0069	1	5	0
Italy	0	11	– 1.81	11	0.92	4	– 0.0764	5	0	– 1
Colombia	1	1	0	6	0.91	6	– 0.0886	7	– 5	– 1
Russia	1	4	0	4	0.91	6	– 0.0636	3	0	3
Turkey	1	1	0	6	0.86	8	– 0.1091	9	– 5	– 1
								r_s	0.209	0.918
								Z	***0.661***	***2.904***

The Z-score for the Spearman's rank correlation test for the fuzzy TOPSIS and MOORA method's rankings on the March 2, 2020 case is 0.661, which is lower than the critical value of 1.645. This implies that the differences between the rankings generated by the two methods are statistically significant. On the other hand, the Z-score for April 25, 2021, case is 2.904, which is higher than the critical value of 1.645. This means that the differences between the rankings generated by the two methods are statistically insignificant. Based on the test results, we can conclude that the proposed model is robust when the data are sufficiently accessible fuzzy TOPSIS (i.e., April 25, 2021 case). Additionally, the results indicate that the rankings generated by the MOORA method are similar to the ones generated by the fuzzy TOPSIS method. The TOPSIS model is used to calculate the distances between the negative and positive ideal solutions for the alternatives. However, the MOORA method does not use distance-based or compromise solution steps. The TOPSIS method is the preferred method for this study as it uses a distance-based MCDM procedure. For future studies, if a benefit-type criterion is available for evaluation, the TOPSIS method has the advantage of modeling the problem.

5.3 Sensitivity analysis

In this section, we present a sensitivity analysis to analyze how robust are the presented results obtained from the fuzzy TOPSIS model. We analyzed some scenarios, such as if one of the criteria is deleted, how does the ranking? And deletion of a criterion or deletion of a country reverse the country rankings? We used six different cases as follows:

- Deleting the K3 criterion on the March 2 case (starting day for the analysis).
- Deleting the K1 criterion on the March 2 case (starting day for the analysis).
- Deleting the K3 criterion on the April 25 case (ending the day for the analysis).
- Deleting the K1 criterion on the April 25 case(ending day for the analysis).
- Deleting the USA alternative on the April 25 case (ending the day for the analysis/for the largest population country).
- Deleting the Brazil alternative on the April 25 case (ending day for the analysis/for the second largest population country).

There are no significant ranking differences among the cases for March 2, 2020, as shown in Table 11. Also, Table 11 presents the test results between the different cases for April 25, 2021. The last rows in Table 11 show Spearman's rank correlation coefficients and Z-scores for the ranking differences. All the Z-scores, 3.119, 3.119, 2.745, and 2.964, are higher than the critical value of 1.645, which implies that the differences in the rankings are statistically insignificant. Based on the test results, it can be concluded that the rankings obtained by the proposed model are statistically similar to the rankings obtained from sensitivity analysis cases. Therefore, it can be concluded that the proposed model is robust as the results of sensitivity analysis indicate that the rankings obtained by the model are consistent across different cases. The rankings change little across both cases of March 2 and April 25, which further supports the conclusion that the proposed model is robust.

6 Conclusions

We present the decision-making model, using the fuzzy TOPSIS for monitoring the country's COVID-19 pandemic trend monthly basis. The proposed model is easily adapted for the statistical data by using the effective processing capability of the TOPSIS model. On the other hand, in linguistic evaluations, the graphical representation of the criteria trends is analyzed by the decision-makers for a selected time frame. This cognitive evaluation is converted to the fuzzy number integrated with Value at Risk (VaR) combined IF Then rules, and all modeling steps of the TOPSIS method are handled in the Excel Program. This model can be converted into a computer program to evaluate the COVID-19 pandemic daily analysis.

The COVID-19 pandemic has become endemic in most countries. However, the proposed methodology could also be extended to other possible diseases in the near future. Although the COVID-19 pandemic is not currently the most pressing problem in the world, its impact is a hot topic.

Also, the COVID-19 pandemic illustrates that the new potential pandemics would be impacted the population. So, our paper is the exemplified case study that illustrates how the new pandemic disease can be modeled with an MCDM methodology to determine its possible impacts on the countries.

All pandemics have unique characteristics. So, our model cannot be generalized to all pandemics. But, it can be modified with the new pandemic's specifications. The proposed approach can be adapted to incorporate the unique characteristics of future pandemics.

Table 11 Sensitivity analysis results

Country	Fuzzy Topsis Results: March 2, 2020			Fuzzy Topsis Results: April 25, 2021										Ranking Differences for April 25, 2021 case			
	Original Case	Delation of K3	Delation of K1	Original Case		Delation of K3		Delation of K1		Delation of USA		Delation of India		Original-Delation of K3	Original-Delation of 1	Original-Delation of USA	Original-Delation of India
	C_i^*	C_i^*	C_i^*	C_i^*	Rank	C_i^*	Rank	C_i^*	Rank	C_i^*	Rank	C_i^*	Rank				
Germany	0.89	0.93	0.93	0.93	**3**	0.94	**3**	0.93	**3**	0.89	2	0.86	**3**	0	0	1	0
USA	0.98	0.98	1	0.57	**9**	0.61	**9**	0.68	**9**	N/A	N/A	0.43	**9**	0	0	N/A	0
Argentina	1	1	1	0.92	**4**	0.92	5	0.92	**4**	0.89	3	0.85	5	– 1	0	1	– 1
Brazil	1	1	1	0.52	**10**	0.53	**10**	0.51	**10**	0.47	9	0.26	**10**	0	0	1	0
India	1	1	1	0.25	**11**	0.2	**11**	0.2	**11**	0.14	10	N/A	N/A	0	0	1	N/A
England	0.99	0.98	0.99	0.95	**2**	0.98	**2**	0.95	**2**	0.89	4	0.9	**2**	0	0	– 2	0
Spain	0.99	0.99	1	0.98	**1**	0.99	**1**	0.98	**1**	0.92	**1**	0.93	**1**	0	0	0	0
Italy	0	0	0	0.92	**4**	0.93	**4**	0.91	5	0.87	6	0.85	**4**	0	– 1	– 2	0
Colombia	1	1	1	0.91	**6**	0.91	7	0.9	7	0.88	5	0.84	7	– 1	– 1	1	– 1
Russia	1	1	1	0.91	**6**	0.92	5	0.91	5	0.86	7	0.85	**6**	1	1	– 1	0
Turkey	1	1	1	0.86	**8**	0.86	8	0.85	8	0.83	8	0.74	**8**	0	0	0	0
													r_s	0.986	0.986	0.915	0.988
													Z	3.119	3.119	2.745	2.964

Same ranking with the original ranking results

Appendix

K1: Cumulative total cases

Date	Germany	USA	Argentina	Brazil	India	UK	Spain	Italy	Colombia	Russia	Turkey
02.03.2020	129	62	0	2	3	36	45	1689	0	2	0
03.03.2020	157	64	0	2	5	39	114	2036	0	3	0
04.03.2020	196	108	1	2	6	51	151	2502	0	3	0
05.03.2020	262	129	1	3	29	89	198	3089	0	3	0
06.03.2020	534	148	1	7	30	118	257	3858	0	4	0
07.03.2020	639	213	2	13	31	167	374	4636	1	7	0
08.03.2020	795	213	9	19	34	210	430	5883	1	7	0
09.03.2020	1112	213	12	25	43	277	589	7375	1	7	0
10.03.2020	1139	472	12	25	44	323	1024	9172	3	7	0
11.03.2020	1296	696	17	34	60	373	1639	10,149	3	7	0
12.03.2020	1567	987	19	52	73	460	2140	12,462	9	20	1
13.03.2020	2369	1264	31	77	74	594	2965	15,113	9	34	1
14.03.2020	3062	1678	34	98	82	802	4231	17,660	16	34	5
15.03.2020	3795	1678	45	121	107	1144	5753	21,157	24	34	5
16.03.2020	4838	1678	56	200	114	1395	7753	24,747	24	63	5
17.03.2020	6012	3503	65	234	137	1547	9191	27,980	45	93	47
18.03.2020	7156	3536	65	234	137	1954	11,178	31,506	45	93	47
19.03.2020	8198	7087	79	291	151	2630	13,716	35,713	93	147	191
20.03.2020	10,999	10,442	97	428	195	3277	17,147	41,035	108	199	191
21.03.2020	18,323	15,219	128	621	195	3983	19,980	47,021	145	253	670
22.03.2020	21,463	15,219	158	904	283	5018	24,926	53,578	196	306	947
23.03.2020	24,774	31,573	225	904	415	5687	28,572	59,138	196	438	1236
24.03.2020	29,212	42,164	266	1546	434	6654	33,089	63,927	277	438	1529
25.03.2020	31,554	51,914	301	2201	562	8081	39,673	69,176	306	658	1872
26.03.2020	36,508	63,570	387	2433	649	9533	47,610	74,386	470	840	2433
27.03.2020	42,288	68,334	502	2433	724	11,662	56,188	80,539	470	1036	3629
28.03.2020	48,582	85,228	589	2915	724	14,547	64,059	86,498	491	1264	5698
29.03.2020	52,547	103,321	690	3417	979	17,093	72,248	92,472	539	1534	7402
30.03.2020	57,298	122,653	745	3904	1071	19,526	78,797	97,689	608	1534	9271
31.03.2020	61,913	140,640	820	4256	1071	22,145	85,195	101,739	702	1837	10,827
01.04.2020	67,366	163,199	966	4579	1636	25,154	94,417	105,792	798	2337	13,531
02.04.2020	73,522	187,302	1054	5717	1636	29,478	102,136	110,574	906	2777	15,679
03.04.2020	79,696	213,600	1133	6836	1965	33,722	110,238	115,242	1065	3548	18,135
04.04.2020	85,778	241,703	1265	7910	2301	38,172	117,710	119,827	1161	4149	20,921
05.04.2020	91,714	273,808	1353	9056	3374	41,907	124,736	124,632	1267	4731	23,934
06.04.2020	95,391	307,318	1451	10,278	4067	47,810	130,759	128,948	1406	5389	27,069
07.04.2020	99,225	333,811	1554	11,130	4067	51,612	135,032	132,547	1485	6343	30,217
08.04.2020	103,228	363,321	1628	12,056	5194	55,246	140,510	135,586	1579	7497	34,109
09.04.2020	108,202	395,030	1715	13,717	5734	60,737	146,690	139,422	1780	10,131	38,226
10.04.2020	113,525	425,889	1795	15,927	6412	65,081	152,446	143,626	2054	11,917	42,282
11.04.2020	117,658	461,275	1929	17,857	7447	70,276	157,022	147,577	2223	13,584	47,029
12.04.2020	120,479	492,881	1975	19,638	8356	78,995	161,852	152,271	2473	15,770	52,167
13.04.2020	123,016	524,514	1975	20,727	9152	84,283	166,019	156,363	2709	18,328	56,956
14.04.2020	125,098	553,822	2252	22,169	10,363	88,625	169,496	159,516	2776	21,102	61,049
15.04.2020	127,584	578,268	2336	23,430	11,439	93,877	172,541	162,488	2852	24,490	65,111
16.04.2020	130,450	604,070	2477	25,262	12,380	98,480	177,633	165,155	2979	27,938	69,392
17.04.2020	133,830	632,781	2598	28,320	13,387	103,097	182,816	168,941	3105	32,008	74,193

K1: Cumulative total cases

Date	Germany	USA	Argentina	Brazil	India	UK	Spain	Italy	Colombia	Russia	Turkey
18.04.2020	137,439	665,330	2694	30,425	14,378	108,696	188,068	172,434	3233	36,793	78,546
19.04.2020	139,897	695,353	2784	33,682	15,712	114,221	191,726	175,925	3439	42,853	82,329
20.04.2020	141,672	723,605	2839	36,599	17,265	120,071	195,944	178,972	3621	42,853	86,306
21.04.2020	143,457	751,273	2960	38,654	18,601	124,747	200,210	181,228	3792	52,763	90,980
22.04.2020	145,694	776,907	3073	40,581	19,984	129,048	204,178	183,957	3977	57,999	95,591
23.04.2020	148,046	800,926	3197	43,079	21,393	133,499	208,389	187,327	4149	62,773	98,674
24.04.2020	150,383	830,053	3340	45,757	23,077	138,082	213,024	189,973	4356	68,622	101,790
25.04.2020	152,438	860,772	3479	49,492	24,506	143,468	219,764	192,994	4561	68,622	104,912
26.04.2020	154,175	899,281	3701	52,995	26,496	148,381	219,764	195,351	4881	74,588	107,773
27.04.2020	155,193	931,698	3838	58,509	27,892	152,844	207,634	197,675	5142	87,147	110,130
28.04.2020	156,337	960,916	3892	61,888	29,435	157,153	209,465	199,414	5379	93,558	112,261
29.04.2020	157,641	983,457	4019	66,501	31,332	161,149	210,773	201,505	5597	99,399	114,653
30.04.2020	159,119	1,003,974	4201	71,886	33,050	165,225	212,917	203,591	5949	106,498	117,589
01.05.2020	159,119	1,035,353	4304	78,162	35,043	171,257	212,917	205,463	6211	114,431	120,204
02.05.2020	161,703	1,067,127	4476	85,380	37,336	177,458	215,216	207,428	6507	124,054	122,392
03.05.2020	162,496	1,093,880	4532	91,589	39,980	182,264	216,582	209,328	7006	134,687	124,375
04.05.2020	163,175	1,125,719	4681	96,559	42,533	186,603	217,466	210,717	7285	145,268	126,045
05.05.2020	163,860	1,154,985	4799	101,147	46,433	190,588	218,011	211,938	7668	155,370	127,659
06.05.2020	164,897	1,171,185	4922	107,780	49,391	194,994	219,329	213,013	7973	165,929	129,491
07.05.2020	166,091	1,193,452	5076	114,715	52,952	201,205	220,325	214,457	8613	177,160	131,744
08.05.2020	167,300	1,215,571	5305	125,218	56,342	206,719	221,447	215,858	8959	187,859	133,721
09.05.2020	168,551	1,245,874	5530	135,106	59,662	211,368	222,857	217,185	9456	198,676	135,569
10.05.2020	169,218	1,245,775	5680	145,328	62,939	215,264	223,578	218,268	10,051	209,688	137,115
11.05.2020	169,575	1,271,645	5924	155,939	67,152	219,187	224,390	219,070	10,495	221,344	138,657
12.05.2020	170,508	1,298,287	6034	162,699	70,756	223,064	227,436	219,814	11,063	232,243	139,771
13.05.2020	171,306	1,322,054	6278	168,331	74,281	226,467	228,030	221,216	11,613	242,271	141,475
14.05.2020	172,239	1,340,098	6563	177,589	78,003	229,709	228,691	222,104	12,272	252,245	143,114
15.05.2020	173,152	1,361,522	6973	188,974	81,970	233,155	229,540	223,096	12,930	262,843	144,749
16.05.2020	173,772	1,382,362	7134	202,918	85,940	236,715	230,183	223,885	13,610	272,043	146,457
17.05.2020	174,355	1,409,452	7479	218,223	90,927	240,165	230,698	224,760	14,216	281,752	148,067
18.05.2020	174,697	1,432,265	7805	233,142	96,169	243,699	231,350	225,435	14,939	290,678	149,435
19.05.2020	175,210	1,464,232	8068	241,080	101,139	246,410	231,606	225,886	15,574	299,941	150,593
20.05.2020	176,007	1,477,459	8371	254,220	106,750	248,822	232,037	226,699	16,295	308,705	151,615
21.05.2020	176,752	1,501,876	8809	271,628	112,359	248,297	232,555	227,364	16,935	317,554	152,587
22.05.2020	177,212	1,525,186	9283	291,579	118,447	250,912	233,037	228,006	17,687	326,448	153,548
23.05.2020	177,850	1,547,973	9931	310,087	125,101	254,199	234,824	228,658	18,330	335,882	154,500
24.05.2020	178,281	1,568,448	10,649	330,890	131,868	257,158	235,290	229,327	19,131	344,481	155,686
25.05.2020	178,570	1,592,599	11,353	347,398	138,845	259,563	235,772	229,858	20,177	353,427	156,827
26.05.2020	179,002	1,618,757	12,076	363,211	145,380	261,188	235,400	230,158	21,175	362,342	157,814
27.05.2020	179,364	1,634,010	12,628	374,898	151,767	265,231	236,631	230,555	21,981	370,680	158,762
28.05.2020	179,717	1,658,896	13,228	391,222	158,333	267,244	237,141	231,139	23,003	379,051	159,797
29.05.2020	180,458	1,675,258	13,933	411,821	165,799	269,131	238,278	231,732	24,104	387,623	160,979
30.05.2020	181,196	1,694,864	14,702	438,238	173,763	271,226	238,936	232,248	25,366	396,575	162,120
31.05.2020	181,482	1,716,078	14,702	465,166	182,143	272,830	239,600	232,664	26,688	405,843	163,103
01.06.2020	181,815	1,734,040	16,214	498,440	190,535	274,766	239,801	233,019	28,236	414,878	163,942
02.06.2020	182,028	1,783,638	16,851	514,849	198,706	276,336	240,010	233,197	29,383	423,741	164,769
03.06.2020	182,370	1,798,330	17,415	526,447	207,615	277,989	240,304	233,515	30,493	432,277	165,555
04.06.2020	182,764	1,823,220	18,319	555,383	216,919	279,860	240,326	233,836	31,833	441,108	166,422
05.06.2020	183,271	1,837,803	19,268	584,016	226,770	281,665	240,660	234,013	33,354	449,834	167,410
06.06.2020	183,678	1,857,872	20,197	614,941	236,657	283,315	240,978	234,531	35,120	458,689	168,340

K1: Cumulative total cases

Date	Germany	USA	Argentina	Brazil	India	UK	Spain	Italy	Colombia	Russia	Turkey
07.06.2020	183,979	1,886,794	21,037	645,771	246,628	284,872	241,310	234,801	36,635	467,673	169,218
08.06.2020	184,193	1,915,712	22,020	672,846	256,611	286,198	241,550	234,998	38,027	476,658	170,132
09.06.2020	184,543	1,933,560	22,794	691,758	266,598	287,403	241,717	235,278	39,236	485,253	171,121
10.06.2020	184,861	1,951,096	23,620	707,412	276,583	289,144	241,966	235,561	40,719	493,657	172,114
11.06.2020	185,416	1,968,331	24,761	739,503	286,579	290,147	242,280	235,763	42,078	502,436	173,036
12.06.2020	185,674	1,988,646	25,987	772,416	297,535	291,413	242,707	236,142	43,682	511,423	174,023
13.06.2020	186,022	2,010,391	27,373	802,828	308,993	292,954	243,209	236,305	45,212	520,129	175,218
14.06.2020	186,269	2,032,524	28,764	828,810	320,922	294,379	243,605	236,651	46,858	528,964	176,677
15.06.2020	186,461	2,057,838	30,295	850,514	332,424	295,893	243,928	236,989	48,746	537,210	178,239
16.06.2020	186,839	2,079,592	31,577	867,624	343,091	296,861	244,109	237,290	50,939	545,458	179,831
17.06.2020	187,184	2,098,106	32,785	888,271	354,065	298,140	244,328	237,500	53,063	553,301	181,298
18.06.2020	187,764	2,126,027	34,159	923,189	366,946	299,255	244,683	237,828	54,931	561,091	182,727
19.06.2020	187,764	2,149,166	35,552	955,377	380,532	300,473	245,268	238,159	57,046	569,063	184,031
20.06.2020	189,135	2,172,212	37,510	978,142	395,048	301,819	245,575	238,011	60,217	576,952	185,245
21.06.2020	189,822	2,208,829	39,570	1,032,913	410,461	303,114	245,938	238,275	63,276	584,680	186,493
22.06.2020	190,359	2,241,178	41,204	1,067,579	425,282	304,335	246,272	238,499	65,633	592,280	187,685
23.06.2020	190,862	2,268,753	42,785	1,085,038	440,215	305,293	246,504	238,720	68,652	599,705	188,897
24.06.2020	191,449	2,295,272	44,931	1,106,470	456,183	306,214	246,752	238,833	71,183	606,881	190,165
25.06.2020	192,079	2,329,463	47,216	1,145,906	473,105	306,866	247,086	239,410	73,572	613,994	191,657
26.06.2020	192,556	2,367,064	49,851	1,188,631	490,401	307,984	247,486	239,706	77,113	620,794	193,115
27.06.2020	193,243	2,407,590	52,457	1,228,114	508,953	309,364	247,905	239,961	80,599	627,646	194,511
28.06.2020	193,499	2,452,048	55,343	1,274,974	528,859	310,254	248,469	240,136	84,442	634,437	195,883
29.06.2020	193,761	2,496,628	57,744	1,313,667	548,318	311,155	248,770	240,310	88,591	641,156	197,239
30.06.2020	194,259	2,537,636	59,933	1,344,143	566,840	311,969	248,970	240,436	91,769	647,849	198,613
01.07.2020	194,725	2,573,393	62,268	1,368,195	585,493	312,658	249,271	240,578	95,043	654,405	199,906
02.07.2020	194,725	2,616,949	64,530	1,402,041	604,641	313,487	249,659	240,760	97,846	661,165	201,098
03.07.2020	195,674	2,671,220	67,197	1,448,753	625,544	283,761	250,103	240,961	102,009	667,883	202,284
04.07.2020	196,096	2,724,433	69,941	1,496,858	648,315	284,280	250,545	241,184	106,110	674,515	203,456
05.07.2020	196,335	2,776,366	72,786	1,539,081	673,165	284,904	250,545	241,419	109,505	681,251	204,610
06.07.2020	196,554	2,833,552	75,376	1,577,004	697,413	285,420	250,545	241,611	113,389	687,862	205,758
07.07.2020	196,944	2,877,238	77,815	1,603,055	719,665	285,772	251,789	241,819	117,110	694,230	206,844
08.07.2020	197,341	2,923,432	80,447	1,623,284	742,417	286,353	252,130	241,956	120,281	700,792	207,897
09.07.2020	197,783	2,973,695	83,426	1,668,589	767,296	286,983	252,513	242,149	124,494	707,301	208,938
10.07.2020	198,178	3,038,325	87,030	1,713,160	793,802	287,625	253,056	242,363	128,638	713,936	209,962
11.07.2020	198,556	3,097,300	90,693	1,755,779	820,916	288,137	253,908	242,639	133,973	720,547	210,965
12.07.2020	198,804	3,163,581	94,060	1,800,827	849,553	288,957	253,908	242,827	140,776	727,162	211,981
13.07.2020	198,963	3,225,950	97,509	1,839,850	878,254	289,607	253,908	243,061	145,362	733,699	212,993
14.07.2020	198,963	3,286,063	100,166	1,864,681	906,752	290,137	255,953	243,230	150,445	739,947	214,001
15.07.2020	199,726	3,344,783	103,265	1,884,967	936,181	291,377	256,619	243,344	154,277	746,369	214,993
16.07.2020	200,260	3,405,494	106,910	1,926,824	968,876	291,915	257,494	243,506	159,898	752,797	215,940
17.07.2020	200,843	3,472,659	111,160	1,966,748	1,003,832	292,556	258,855	243,736	165,169	759,203	216,873
18.07.2020	201,372	3,544,143	114,783	2,012,151	1,038,716	293,243	260,255	243,967	173,206	765,437	217,799
19.07.2020	201,574	3,544,143	119,301	2,046,328	1,077,618	294,070	260,255	244,216	182,140	771,546	218,717
20.07.2020	201,823	3,685,460	122,524	2,074,860	1,118,043	294,796	260,255	244,434	190,700	777,486	219,641
21.07.2020	202,345	3,748,248	126,755	2,098,389	1,155,191	295,376	264,836	244,624	197,278	783,328	220,572

K1: Cumulative total cases

Date	Germany	USA	Argentina	Brazil	India	UK	Spain	Italy	Colombia	Russia	Turkey
22.07.2020	202,799	3,805,524	130,774	2,118,646	1,192,915	295,821	266,194	244,752	204,005	789,190	221,500
23.07.2020	203,368	3,868,453	136,118	2,159,654	1,238,635	296,381	267,551	245,032	211,038	795,038	222,402
24.07.2020	204,183	3,938,094	141,900	2,227,514	1,287,945	297,150	270,166	245,338	218,428	800,849	223,315
25.07.2020	204,964	4,009,808	148,027	2,287,475	1,336,861	297,918	272,421	245,590	226,373	806,720	224,252
26.07.2020	205,269	4,009,808	153,520	2,343,366	1,385,522	298,685	272,421	245,864	233,541	812,485	225,173
27.07.2020	205,609	4,148,011	158,321	2,394,513	1,435,453	299,430	272,421	246,118	240,795	818,120	226,100
28.07.2020	206,242	4,209,509	162,526	2,419,091	1,483,156	300,115	278,782	246,286	248,976	823,515	227,019
29.07.2020	206,926	4,263,531	167,416	2,442,375	1,531,669	300,696	280,610	246,488	257,101	828,990	227,982
30.07.2020	206,926	4,323,160	173,355	2,483,191	1,583,792	301,459	282,641	246,776	267,385	834,499	228,924
31.07.2020	207,828	4,388,566	178,996	2,552,265	1,638,870	302,305	285,430	247,158	276,055	839,981	229,891
01.08.2020	209,653	4,456,389	185,373	2,610,102	1,695,988	303,185	288,522	247,537	286,020	845,443	230,873
02.08.2020	209,893	4,523,888	191,302	2,662,485	1,750,723	303,956	288,522	247,832	295,508	850,870	231,869
03.08.2020	210,402	4,582,276	196,543	2,707,877	1,803,695	304,699	288,522	248,070	306,181	856,264	232,856
04.08.2020	211,281	4,629,459	201,919	2,733,677	1,855,745	305,627	297,054	248,229	317,651	861,423	233,851
05.08.2020	212,022	4,678,610	206,743	2,750,318	1,908,254	306,297	302,814	248,419	327,850	866,627	234,934
06.08.2020	213,067	4,728,239	213,535	2,801,921	1,964,536	307,188	305,767	248,803	334,979	871,894	236,112
07.08.2020	214,214	4,781,612	220,682	2,859,073	2,027,074	308,138	309,855	249,204	345,714	877,135	237,265
08.08.2020	215,336	4,836,930	228,195	2,912,212	2,088,611	309,009	314,362	249,756	357,710	882,347	238,450
09.08.2020	215,891	4,897,958	235,677	2,962,442	2,153,010	309,767	314,362	250,103	367,196	887,536	239,622
10.08.2020	216,327	4,951,851	241,811	3,012,412	2,215,074	310,829	314,362	250,566	376,870	892,654	240,804
11.08.2020	217,293	4,999,815	246,499	3,035,422	2,268,675	311,645	314,362	250,825	387,481	897,599	241,997
12.08.2020	218,519	5,039,709	253,868	3,057,470	2,329,638	312,793	326,612	251,237	397,623	902,701	243,180
13.08.2020	219,964	5,094,500	260,911	3,109,630	2,396,637	313,802	329,784	251,713	410,453	907,758	244,392
14.08.2020	221,413	5,150,407	268,574	3,164,785	2,461,190	313,802	337,334	252,235	422,519	912,823	245,635
15.08.2020	222,828	5,203,206	276,072	3,224,876	2,526,192	316,371	342,813	252,809	433,805	917,884	246,861
16.08.2020	223,453	5,258,565	282,437	3,275,520	2,589,682	316,371	342,813	253,438	445,111	922,853	248,117

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Declarations

Conflict of interest The authors declare that they have no competing interests.

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Consent to Participate Not applicable.

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