Decision Supportive Index to Rank the Countries According to the Transmission Risk of COVID-19: A Fuzzy Mathematical Approach

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***Abstract*—COVID-19 has emerged as a global pandemic reporting more than 33.5 million of cases around the world. Many researchers are still investigating for the facts which has caused to the outbreak of this disease. Currently, researchers have identified some risk factors which cause to the spread of COVID-19 more severely. Some of them are, population density, gross domestic product per capita, available hospital beds, handwashing facilities in a country, life expectancy and human development index etc. The objective of this research is to rank selected countries according to the risk of the spread of COVID-19 considering the combined effect of these factors. Due to the uncertainty and the impreciseness of the the factors a fuzzy mathematics technique is applied. With the assistance of the extent analysis method the weights of the risk factors are evaluated. The ranks of the countries are obtained using TOPSIS. Among the selected countries United States, Sri Lanka, India, Philippines and Thailand were the top five countries which has highest risk of spreading COVID-19 cases.**

Keywords—COVID-19, Fuzzy, Transmission risk, Rank

I. INTRODUCTION

COVID-19 is an infectious disease and the first confirmed case has been diagnosed in December 2019 in Wuhan city, China [1]. This disease is caused by a novel virus named coronavirus. Due to the severity, it is identified as a deadly disease. According to the available records, 213 countries around the world have reported more than 33.5 million of COVID-19 cases and nearly 1.01 million of deaths [2]. The typical symptoms of this disease are fever, dry cough and tiredness [3]. When someone gets affected from this disease it takes 5 to 6 days to show the symptoms. Coronavirus could be spread to a healthy person by having a close contact with an infected person [4]. The most common direct coronavirus droplets transmission modes are coughs sneezes and speaks. Apart from the direct method, people can indirectly become infected by touching their nose, mouth, and eyes after contacting with the objects or surfaces that this virus lands. Still vaccine has not discovered, and antibiotics do not work against this virus. Therefore, currently there is no specific recognize treatment for this novel disease. When someone gets infected from the disease, he or she must have to stay in isolation until they recover from the disease. People have to follow cross-protection techniques which is called as pre-immunization methods in order to protect against this disease.

It can be seen that some of the countries in the world have controlled spreading the disease in the society by implementing control strategies such as impose a nationwide lockdowns, restrict travel from endemic countries, introduce self quarantine methods, conduct the session regarding hygiene methods and introduce work from home programs [16]. Meantime the factors such as low population density, high GDP per capita, health conditions of the citizens, available hospital facilities and the number of doctors allocated also helpful to control the transmission and deaths of the disease. However, the global numbers of patients with COVID-19 are still increasing, and no country seems to be spared from this dangerous situation. This pandemic situation will weaken the socioeconomic growth of the developing countries and its consequences are still being unknown. Therefore, it is significant to distinguish the countries observing the behavior of the transmission of COVID-19. It will also help health authorities and travelers to recognize which country is severely affecting and which country is going to be affected with this disease in future. Therefore, our aim is to develop a decision supportive index to rank the countries according to the transmission of COVID-19.

Since 2019 December, many researchers have started to investigate about the spread on this novel disease. Showmitra had identified the susceptibilities in risky areas of Bangladesh using multi-criteria evaluation techniques [24]. Iwendi et al. proposed a fine-tuned random forest model to predict the severity of COVID-19 patients [10]. For that purpose, they had used the patients geographical, travel, health, and demographic data. Ganya et al. had captured the future trend of coronavirus [11]. They used a 4+1 penta-grouped model for predictions and using a BAT model they had forecasted the most suitable return date for university students. Moreover, Arsalan et al. had developed a multi-factor weighted spatial analysis to identify how the countries have impacted by the coronavirus. Also, the mortality risk of the global was considered and they have resulted that 44/153 countries are experiencing 20% increase in mortality due to CIVID-19 [8]. Many more researchers have carried out numerous studies on COVID-19. Most of these models were developed to predict the number of patients and to identify the factors associated with this disease. Currently, the numbers of reported cases are used to rank the world countries according to the COVID-19 spread. So, it is worthwhile to carry out a study to measure the risk of spreading COVID-19 considering the combined effect of multi factors such as population density, GDP per capita, health conditions of the citizens, available hospital facilities and the number of doctors. This type of study also helps to investigate factors contribution towards the spread of COVID-19.

However, these sorts of factors are highly uncertain. We can’t define the boundaries of these factors precisely. Therefore, aggregating these types of uncertain factors and ranking countries according to the results is a quite complicated task. However, Zadesh developed a mathematical tool in 1965 to handle these kind of uncertain environments and we called it as fuzzy mathematics [18]. Therefore, fuzzy mathematics concepts are used in this study to prioritize the multi factors and to rank the countries. Extent analysis method which was invented by Chang is used to derive the weights of the selected risk factors. The technique for order performance by similarity to ideal solution (TOPSIS) which was invented by Hwang and Yoon is used to obtain the ranks of the countries [[19] – [23]] according to the disease transmission risk.

This manuscript is collated as follows: In Section 2, mathematical theories behind the model building process is presented. Selected variables, countries and ranking model is presented in Section 3. Section 4 is used to present the results and discussion. Finally, in Section 5 conclusions and future directions of this study are pointed out.

II. Preliminaries

Mathematical theories namely fuzzy membership functions, operations on membership functions, extent analysis method and TOPSIS which are used in this research are presented in this section. These theories are obtained from the literature [18,24].

A. *Definitions in Fuzzy Mathematics*

Definition 1. Fuzzy Number

Let A be a fuzzy set in universe of discourse R then, m is a fuzzy number if and only if there exists a closed interval (which may be singleton) $[m,n] \neq \phi$

$$\mu_A(x) = \begin{cases} 1 & if\ x \in [m,n] \\ l(x) & if\ x \in (-\infty, m) \\ r(x) & if\ x \in (n, \infty) \end{cases} \tag{1}$$

Here l and r can be defined as follows:

(i) $l : (-\infty, m) \rightarrow [0,1]$ is monotonic increasing, continuous from the right such that,

$$l(x) = 0 \text{ for } x \text{ in } (-\infty, k_1),\ k_1 < m. \tag{2}$$

(ii) $r : (n, \infty) \rightarrow [0,1]$ is monotonic decreasing, continuous from the left such that

$$r(x) = 0 \text{ for } x \text{ in } (k_2, \infty),\ k_2 > n. \tag{3}$$

Definition 2. Triangular Fuzzy Number

A fuzzy number M on R is called a triangular fuzzy number if its membership function is in the below form.

$$\mu_M(x) = \begin{cases} \dfrac{x-l}{m-l}, & \text{if } x \in [l,m]; \\ \dfrac{u-x}{u-m}, & \text{if } x \in [m,u]; \\ 0, & \text{otherwise,} \end{cases} \tag{4}$$

Where,

l - smallest possible value of an event.

m - the most promising value of an event.

u - the largest possible value of an event.

Definition 3. Operations on Triangular Fuzzy Numbers

Let $P = (l_1, m_1, u_1)$ and $Q = (l_2, m_2, u_2)$ be two triangular fuzzy numbers. Then addition operation, multiplication operation and reciprocal value of a fuzzy number can be stipulated as follows:

$$P \oplus Q = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \tag{5}$$

$$P \otimes Q = (l_1 l_2, m_1 m_2, u_1 u_2) \tag{6}$$

$$P^{-1} \approx \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1} \right) . \tag{7}$$

Definition 4. Pair-Wise Comparison Matrix

Let $\tilde{P}$ is a $n \times n$ decision matrix in a fuzzy environment and there are n number of factors to be evaluated. This matrix contains all pair-wise comparisons between factor i and j for all $i, j \in 1,2,3,...,n$. The importance of i^{th} factor with respect to j^{th} factors can be denoted as $\tilde{p}_{ij}$. Therefore, $\tilde{P}$ can be defined as follows:

$$\tilde{P} = \begin{pmatrix} (1,1,1) & \tilde{p}_{12} & \cdots & \tilde{p}_{1n} \\ \tilde{p}_{21} & (1,1,1) & \cdots & \tilde{p}_{2n} \\ : & : & : & : \\ \tilde{p}_{n1} & \tilde{p}_{n2} & \cdots & (1,1,1) \end{pmatrix} , \tag{8}$$

where $\tilde{p}_{ij}$ is a triangular fuzzy number and $\tilde{p}_{ij} = (1,1,1) : \ \forall i = j, \ \ \tilde{p}_{ji} = \tilde{p}_{ij}^{-1}$

B. *Extent Analysis Method*

Let $O = \{o_1, o_2, ..., o_n\}$ be the object set and $G = \{g_1, g_2, ..., g_n\}$ be the goal set. Suppose each object is selected and extent analysis is performed for each goal. Therefore, now we have m extent analysis values for each object. Suppose these generated values are denoted as $E_{g_i}^1, E_{g_i}^2, ..., E_{g_i}^m,\ i = 1,2,...,n$. Here $E_{g_i}^j\ (j = 1,2,...,m)$ extent values are taken as triangular fuzzy numbers. The following four steps have to be considered in extent analysis method in order to find the weights of the factors.

(1) Calculate fuzzy synthetic extent values: The synthetic extent value with respect to the i^{th} factor can be derived as follows:

$$S_i = \sum_{j=1}^{m} E_{g_i}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} E_{g_i}^j \right]^{-1} . \tag{9}$$

To compute $\sum_{j=1}^{m} E_{g_i}^j$, we can use m extent analysis values of the decision matrix and we can aggregate them using (5). In order to compute $\left[\sum_{i=1}^{n}\sum_{j=1}^{m} E_{g_i}^{j}\right]^{-1}$, we can use $E_{g_i}^{j}$ $(j=1,2,...,m)$ values and we can aggregate these values using (5).

(2) Compute and compare degree of possibilities values: Let $P_1=(l_1,m_1,u_1)$ and $P_2=(l_2,m_2,u_2)$ be two triangular fuzzy numbers such that $P_2 \geq P_1$**.** The value of degree of possibility of the two fuzzy numbers P_1 and P_2 can be defined as follows:

$$D(P_2 \geq P_1)=\begin{cases} 1, & \text{if } m_2 \geq m_1; \\ 0, & \text{if } l_1 \geq u_2; \\ \dfrac{l_1-u_2}{(m_2-u_2)-(m_1-l_1)}, & \text{otherwise.} \end{cases} \quad (10)$$

According to the values of $D(P_1 \geq P_2)$ and $D(P_2 \geq P_1)$ we can compare the given two fuzzy numbers.

(3) Derive the weight vector: The degree of possibility values for a convex triangular fuzzy number to be greater than k convex triangular fuzzy number P_i ,$(i=1,2,......,k)$ can be defined as follows:

$$\begin{aligned} D(P \geq P_1, P_2,...., P_k) &= D[(M \geq M_1) \text{ and } (M \geq M_2) \text{ and} ....(M \geq M_k)] \\ &= \min D(M \geq M_i),\ i=1,2,...,k \end{aligned} \quad (11)$$

Assuming $D'(A_i)=\min D(S_i \geq S_k)$ for $k=1,2,...,n:\ k \neq i$, we can derive the weight vector of the factors and it is given by,

$$W'=(D'(A_1),D'(A_2),...,D'(A_n))^T \quad (12)$$

where, $A_i=(i=1,2,...,n)$ are n elements.

(4) Calculate the normalize weight: Normalizing the components values in (12) using $d(A_i)=\dfrac{D'(A_i)}{\sum_{i=1}^{n} D'(A_i)}$, we can obtain the normalize weight vector as follows:

$$W=(d(A_1),d(A_2),.....,d(A_n))^T. \quad (13)$$

Now the components of this normalize weight vector W are non-fuzzy numbers.

C. TOPSIS

This method is used to rank the countries according to the transmission risk of COVID-19. The following are the steps involved in TOPSIS method.

(1) Calculate normalize values of the given data: Given data values can be normalize as follows:

$$n_{ij}=\frac{x_{ij}}{\sqrt{\sum_{j=1}^{m} x_{ij}^2}},\quad j = 1,2, \ldots , m \quad i = 1,2, \ldots , n \quad (14)$$

where x_{ij} is the value of the i^{th} factor for the j^{th} country.

(2) Find the weighted normalized values: Weighted normalized decision matrix is given by

$$W_N = [d(A_i) \times n_{ij}]_{n \times m}, \quad (15)$$

for $i=1,2,...,n$ and $j=1,2,...,m$.

(3) Compute the values of *PIS* and *NIS:* We can define the positive ideal solution (PIS) and negative ideal Solution (NIS) as follows:

$$\text{PIS } A^{+}=\{w_1^{+}, w_2^{+},..., w_n^{+}\},\ w_j^{+}=\max\{d(A_i)\times n_{ij}; \forall i \in \{1,2,...,n\}\}. \quad (16)$$

$$\text{NIS } A^{-}=\{w_1^{-}, w_2^{-},..., w_n^{-}\},\ w_j^{-}=\min\{d(A_i)\times n_{ij}; \forall i \in \{1,2,...,n\}\}. \quad (17)$$

(4) Calculate the distances: The distances from each alternative to *PIS* can be measured as follows:

$$d_i^{+}=\sqrt{\sum_{j=1}^{m}(w_{ij}^{*}-w_j^{+})^2},\quad i=1,2,...,n. \quad (18)$$

The distances from each alternative to *NIS* can be measured as follows:

$$d_i^{-}=\sqrt{\sum_{j=1}^{m}(w_{ij}^{*}-w_j^{-})^2},\quad i=1,2,...,n \quad (19)$$

(5) Obtain the Ranks: The closeness coefficient given by,

$$CC_i=\frac{d_i^{-}}{d_i^{+}+d_i^{-}}. \quad (20)$$

can be used to rank the countries.

III. METHODOLOGY

The selected factors for this study are population density (PD), age 65 or older (AGE), gross domestic product per capita (GDP), cardiovascular death rate (CDR), diabetes mellitus prevalence (DIA), hand washing facilities (HWF), hospital beds availability (HB) and life expectancy (LE). An internet-based survey is carried out up to date 23rd of September 2020. Through these e-sources the very high, high, moderate, low, very low risky COVID-19 spreading countries are identified [25]. Fifteen different countries are selected to compare the transmission of COVID-19. These countries are USA, Afghanistan, Colombia, Pakistan, Philippines, South Africa, India, Sri Lanka, China, Laos, Thailand, Timor, Mongolia, Vietnam and Yemen.

The pair-wise comparison matrix of risk factors is determined after reviewing the available literature [[6]- [11]]. To compare the factors, linguistic scales are used. The selected linguistic scales and their triangular fuzzy representation are in Table 1. Using this matrix, weights of the factors are estimated using fuzzy extent analysis method [24]. Then obtained weights are compared, and the degrees of possibilities are calculated. Using these degrees of possibilities weight vector of the risk factors is derived. Finally, the ranks of the countries are obtained using TOPSIS method.

Table 1 Selected Linguistic scales to construct the pair-wise comparison matrix.

Linguistic scale	Triangular fuzzy numbers
Absolutely more important	(5/2, 3, 7/2)
Very strongly more important	(2, 5/2, 3)
Strongly more important	(3/2, 2, 5/2)
Weakly more important	(1, 3/2, 2)
Equally important Just equal	(1/2, 1, 3/2) (1, 1, 1)

IV. Results and Discussion

Step 1: Compare the factors and construct pair-wise comparison matrix

After reviewing the available facts [[6] – [11]] pair-wise comparison matrix which is shown in Table A1 (Refer Appendix) is constructed.

Step 2: Calculate the synthetic extent values

Deploying extent analysis method in (9), the calculated fuzzy synthetic extent values are given below.

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After comparing above values using (10) the following degrees of possibilities are found.

$$D(S_{PD} \geq S_{AGE}) = 0.93$$
$$D(S_{PD} \geq S_{GDP}) = 1$$
$$D(S_{PD} \geq S_{CDR}) = 1$$
$$D(S_{PD} \geq S_{DIA}) = 1$$
$$D(S_{PD} \geq S_{HWF}) = 1$$
$$D(S_{PD} \geq S_{HB}) = 1$$
$$D(S_{PD} \geq S_{LE}) = 1$$

$$D(S_{GDP} \geq S_{PD}) = 0.77$$
$$D(S_{GDP} \geq S_{AGE}) = 0.69$$
$$D(S_{GDP} \geq S_{CDR}) = 1$$
$$D(S_{GDP} \geq S_{DIA}) = 1$$
$$D(S_{GDP} \geq S_{HWF}) = 1$$
$$D(S_{GDP} \geq S_{HB}) = 1$$
$$D(S_{GDP} \geq S_{LE}) = 1$$

$$D(S_{DIA} \geq S_{PD}) = 0.3$$
$$D(S_{DIA} \geq S_{AGE}) = 0.2$$
$$D(S_{DIA} \geq S_{GDP}) = 0.5$$
$$D(S_{DIA} \geq S_{CDR}) = 0.63$$
$$D(S_{DIA} \geq S_{HWF}) = 1$$
$$D(S_{DIA} \geq S_{HB}) = 1$$
$$D(S_{DIA} \geq S_{LE}) = 1$$

$$D(S_{AGE} \geq S_{PD}) = 1$$
$$D(S_{AGE} \geq S_{GDP}) = 1$$
$$D(S_{AGE} \geq S_{CDR}) = 1$$
$$D(S_{AGE} \geq S_{DIA}) = 1$$
$$D(S_{AGE} \geq S_{HWF}) = 1$$
$$D(S_{AGE} \geq S_{HB}) = 1$$
$$D(S_{AGE} \geq S_{LE}) = 1$$

$$D(S_{CDR} \geq S_{PD}) = 0.64$$
$$D(S_{CDR} \geq S_{AGE}) = 0.55$$
$$D(S_{CDR} \geq S_{GDP}) = 0.89$$
$$D(S_{CDR} \geq S_{DIA}) = 1$$
$$D(S_{CDR} \geq S_{HWF}) = 1$$
$$D(S_{CDR} \geq S_{HB}) = 1$$
$$D(S_{CDR} \geq S_{LE}) = 1$$

$$D(S_{HWF} \geq S_{PD}) = 0$$
$$D(S_{HWF} \geq S_{AGE}) = 0$$
$$D(S_{HWF} \geq S_{GDP}) = 0$$
$$D(S_{HWF} \geq S_{CDR}) = 0.125$$
$$D(S_{HWF} \geq S_{DIA}) = 0.43$$
$$D(S_{HWF} \geq S_{HB}) = 1$$
$$D(S_{HWF} \geq S_{LE}) = 1$$

$$D(S_{HB} \geq S_{PD}) = 0$$
$$D(S_{HB} \geq S_{AGE}) = 0$$
$$D(S_{HB} \geq S_{GDP}) = 0$$
$$D(S_{HB} \geq S_{CDR}) = 0$$
$$D(S_{HB} \geq S_{DIA}) = 0$$
$$D(S_{HB} \geq S_{HWF}) = 0.6$$
$$D(S_{HB} \geq S_{LE}) = 1$$

$$D(S_{LE} \geq S_{PD}) = 0$$
$$D(S_{LE} \geq S_{AGE}) = 0$$
$$D(S_{LE} \geq S_{GDP}) = 0$$
$$D(S_{LE} \geq S_{CDR}) = 0$$
$$D(S_{LE} \geq S_{DIA}) = 0$$
$$D(S_{LE} \geq S_{HWF}) = 0$$
$$D(S_{LE} \geq S_{HB}) = 0$$

By using (11), following values are derived.

$$D^{/}(A_{PD}) = D(S_{PD} \geq S_{AGE}, S_{GDP}, S_{CDR}, S_{DIA}, S_{HWF}, S_{HB}, S_{LE}) = 0.93$$
$$D^{/}(A_{AGE}) = D(S_{AGE} \geq S_{PD}, S_{GDP}, S_{CDR}, S_{DIA}, S_{HWF}, S_{HB}, S_{LE}) = 1$$
$$D^{/}(A_{GDP}) = D(S_{GDP} \geq S_{PD}, S_{AGE}, S_{CDR}, S_{DIA}, S_{HWF}, S_{HB}, S_{LE}) = 0.69$$
$$D^{/}(A_{CDR}) = D(S_{CDR} \geq S_{PD}, S_{AGE}, S_{GDP}, S_{DIA}, S_{HWF}, S_{HB}, S_{LE}) = 0.55$$
$$D^{/}(A_{DIA}) = D(S_{DIA} \geq S_{PD}, S_{AGE}, S_{GDP}, S_{CDR}, S_{HWF}, S_{HB}, S_{LE}) = 0.2$$
$$D^{/}(A_{HWF}) = D(S_{HWF} \geq S_{PD}, S_{AGE}, S_{GDP}, S_{CDR}, S_{DIA}, S_{HB}, S_{LE}) = 0.125$$
$$D^{/}(A_{HB}) = D(S_{HB} \geq S_{PD}, S_{AGE}, S_{GDP}, S_{CDR}, S_{DIA}, S_{HWF}, S_{LE}) = 0$$
$$D^{/}(A_{LE}) = D(S_{LE} \geq S_{PD}, S_{AGE}, S_{GDP}, S_{CDR}, S_{DIA}, S_{HWF}, S_{HB}) = 0$$

Then the derived weight vector for the selected factors is given by,

$$W^{/} = (0.93, 1, 0.69, 0.55, 0.2, 0.125, 0, 0)^{T}$$

Using (13) following normalized weight vector is derived,

$$W = (0.34, 0.37, 0.26, 0.204, 0.074, 0.046, 0, 0)^{T}$$

Factor wise distribution of these weights are graphically shown in Figure 1.

According to Figure 1, the risk factor "Age" takes the highest weight and the second, third, fourth, fifth and sixth places are taken by the factors "population density", "GDP", "cardiovascular death rate", "diabetes prevalence" and handwashing facilities respectively. The factors "hospital beds" and "life expectancy" takes zero weights. Therefore, from now onwards they have not considered as the significant risk factors in the study.

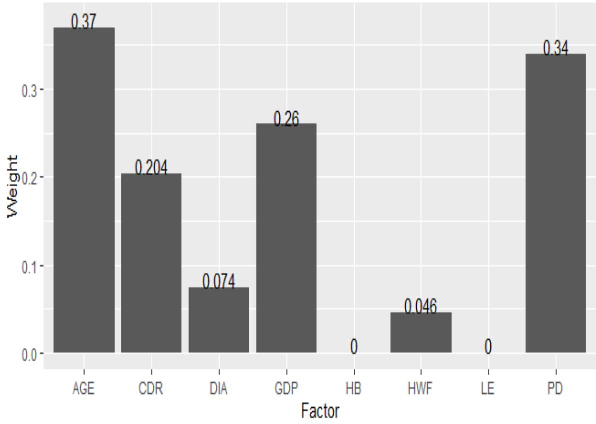

Fig 15 Plot of weights of selected factors

Table 2 . Normalized weighted decision matrix

Country	PD	Age 65 or Older	GDP	CDR	DIA	HWF
United States	0.0149	0.1946	0.2151	0.0235	0.0262	0.0070
Afghanistan	0.0227	0.0326	0.0072	0.0930	0.0233	0.0167
Colombia	0.0185	0.0965	0.0526	0.0194	0.0180	0.0097
Pakistan	0.1067	0.0567	0.0200	0.0659	0.0202	0.0106
Philippines	0.1469	0.0606	0.0301	0.0577	0.0171	0.0080
South Africa	0.0195	0.0675	0.0488	0.0312	0.0134	0.0144
India	0.1880	0.0756	0.0255	0.0440	0.0252	0.0106
Sri Lanka	0.1427	0.1271	0.0463	0.0307	0.0259	0.0069
China	0.0616	0.1343	0.0607	0.0408	0.0236	0.0120
Laos	0.0124	0.0509	0.0254	0.0573	0.0097	0.0127
Thailand	0.0564	0.1436	0.0646	0.0171	0.0171	0.0070
Timor	0.0364	0.0449	0.0261	0.0522	0.0166	0.0224
Mongolia	0.0008	0.0509	0.0470	0.0717	0.0117	0.0089
Vietnam	0.1286	0.0903	0.0245	0.0382	0.0145	0.0074
Yemen	0.0223	0.0369	0.0059	0.0771	0.0130	0.0127

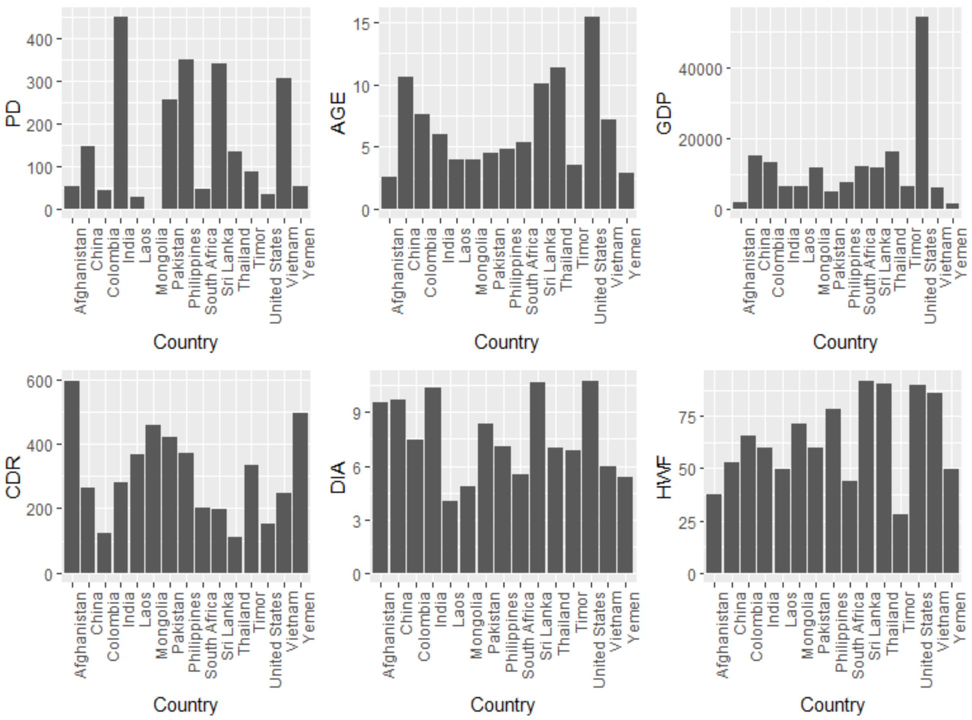

Figure 16 Factor distribution of selected countries

According to the Figure 2, it depicts how the factors distribute in each selected country. Among the selected countries India shows the highest population density and United States has the highest elder population as well as the highest GDP. Afghanistan has the highest cardiovascular deaths rate and United states has the highest diabetes prevalence techniques. Sri Lanka also shows a tie with United States in preventing diabetes. Finally, moving to the handwashing facilities, Sri Lanka, United States as well as Thailand and Yemen are notable.

Step 3: Find the ranks of the countries

Factor distributions of the countries are shown graphically in Figure 2. After multiplying each normalized value of factors with their weights, Table 2 is constructed.

Using (16) derived PIS A^+ vector is

[0.1880, 0.1946, 0.2151, 0.0930, 0.0262, 0.0224]. Using (17) derived NIS A^- vector is [0.0008, 0.0326, 0.0059, 0.0171, 0.0097, 0.0069]. The solution distance of each country from PIS A^+ and NIS A^- are measured with the aid of (18) and (19). Finally, the ranks are obtained using (20). Table 3 shows the selected countries with their corresponding ranks.

The Centers of Disease Control and Prevention (CDC) [25] prohibited some countries to travel according to the spread of COVID-19 categorized the risk as very high, high, moderate, low and very low. They have noticed that United States, Afghanistan, Colombia, Pakistan, Philippines, South Africa, India, China, Sri Lanka, Vietnam and Yemen as high risky COVID-19 spreading countries. Also, Mongolia as a moderately COVID-19 spreading country. Thailand as a low spreading country and Laos and Timor as very low COVID-19 spreading countries.

According to the final ranking the countries Timor and Laos ranked as 14 and 15 and it tallies with the CDC given information. Even though, Thailand was under low COVID-19 spreading category, it has taken the 5th place. Considering the country details, it can be decided that their adult population (age above 65+) are similar to the adult population in China and Sri Lanka. Therefore, it may cause to rank it in the 5th place. Mongolia is ranked in the 11th place and CDC also categorized it as a moderately COVID-19 spreading country. So, it matches with the CDC specification. United States, Afghanistan, Colombia, Pakistan, Philippines, South Africa, India, China, Sri Lanka, Vietnam and Yemen are ranked in the places of 1st, 10th, 9th, 8th, 4th, 12th, 3rd, 6th, 2nd, 7th and 13th. According to the current world situation United States has reported the highest number of coronavirus cases. Considering the data set it can be observed that the USA has the highest adult population among the selected countries. Also, it has the highest GDP and its CDR is also highly noticeable. So, concerning these facts we can say it is at the top. Even though Sri Lanka got the 2nd place, as a highly COVID-19 spreading country we are able to control this disease as the government took the relevant actions by making the public aware about the horrendousness of this pandemic. According to the world's statistics [26] it is confirmed that India is the country which has second most reported COVID-19 cases. Considering the dataset, it can be concluded that India has low handwashing facilities compared to US and Sri Lanka. So, it could be a reason to have many more COVID-19 cases inside the country.

Considering about Yemen and Afghanistan we can notice that their adult population is very low comparing to the other countries. It may have caused them to have 13th and 10th places even they are categorized under the high risk COVID-19 countries. Philippines and Pakistan have a higher population density and also currently it is identifying as a fast COVID-19 spreading country. Sometimes the uncontrollable factor population density may cause to the fast spread. South Africa also became noticeable since the reported COVID-19 cases are higher than the other countries. Analyzing the data set it can be concerned that in South

Africa all the factors we have considered takes a moderate value compared to the other countries.

Table 3 Ranks of the countries

Country	No of Cases	CC_i Value	Rank
United States	6896274	0.5866	1
Afghanistan	39145	0.2060	10
Colombia	777537	0.2352	9
Pakistan	307418	0.3214	8
Philippines	291784	0.3990	4
South Africa	663282	0.1800	12
India	5646010	0.4601	3
Sri Lanka	3313	0.4712	2
China	90399	0.3831	6
Laos	23	0.1435	15
Thailand	3514	0.3840	5
Timor	27	0.1673	14
Mongolia	313	0.1955	11
Vietnam	1068	0.3808	7
Yemen	2032	0.1713	13

China is in a prominent place when taking about COVID-19. Their adult population is similar to Sri Lanka and their hand washing facilities are not at the level of Sri Lanka. But they are succeeded in controlling the virus due to their awareness about the hazardous of this epidemic and in this study the place they took tallies with the data set. Considering Vietnam and Colombia, Vietnam has a high population density compared to Colombia, but their handwashing facilities are rather impressive compared to Colombia.

All in all, the ranking of this study can be concluded that these results are agreed with the prior knowledge.

V. Conclusion

In this study a fuzzy mathematical approach is used to rank the selected countries according to the risk of the spread of COVID-19. Since COVID-19 is a novel virus, the researchers are investigating for factors which cause to the outbreak of this disease. Some countries are selected considering the spread of COVID-19 as vey high, high, moderate, low and very low and for each country the data are obtained for each selected factor. The selected factors are population density, age 65 or older, GDP, cardiovascular death rate, diabetes mellitus prevalence, hand washing facilities, hospital beds availability and life expectancy and the selected countries are United States, Afghanistan, Colombia, Pakistan, Philippines, South Africa, India, Sri Lanka, China, Laos, Thailand, Timor, Mongolia, Vietnam and Yemen.

To obtaine the results a fuzzy extent approach and TOPSIS are together used concerning the uncertainty and the impreciseness of the factors. Some data such as handwashing facilities are not available for most of the countries. So, it is a limitation of this study. Here we have taken only a limited number of countries. It is important to modify this analysis by adding more risk factors such as male/female smoking, poverty, human development index etc for a more accurate ranking.

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APPENDIX

Table A1. Pairwise comparison matrix

	PD	AGE	GDP	CDR	DIA	HWF	HB	LE
PD	(1,1,1)	(1.75,2.25,2.75)	(1.75,2.25,2.75)	(2,2.5,3)	(2,2.5,3)	(2.25,2.75,3.25)	(2,2.5,3)	(2,2.5,3)
AGE	(0.39,1,0.7)	(1,1,1)	(2.25,2.75,3.25)	(2.5,3,3.5)	(2.5,3,3.5)	(2.5,3,3.5)	(2.5,3,3.5)	(2.5,3,3.5)
GDP	(0.37,0.45,0.58)	(0.31,0.37,0.45)	(1,1,1)	(2.25,2.75,3.25)	(2.25,2.75,3.25)	(2.25,2.75,3.25)	(2.5,3,3.5)	(2.25,2.75,3.25)
CDR	(0.34,0.42,0.53)	(0.29,0.33,0.4)	(0.31,0.37,0.45)	(1,1,1)	(2.5,3,3.5)	(2.5,3,3.5)	(2.5,3,3.5)	(2.5,3,3.5)
DIA	(0.34,0.42,0.53)	(0.29,0.33,0.4)	(0.31,0.37,0.45)	(0.29,0.33,0.4)	(1,1,1)	(2.5,3,3.5)	(2.5,3,3.5)	(2.5,3,3.5)
HWF	(0.31,0.37,0.45)	(0.29,0.33,0.4)	(0.31,0.37,0.45)	(0.29,0.33,0.4)	(0.29,0.33,0.4)	(1,1,1)	(2.25,2.75,3.25)	(2.25,2.75,3.25)
HB	(0.34,0.42,0.53)	(0.29,0.33,0.4)	(0.29,0.33,0.4)	(0.29,0.33,0.4)	(0.29,0.33,0.4)	(0.31,0.37,0.45)	(1,1,1)	(2.5,3,3.5)
LE	(0.34,0.42,0.53)	(0.29,0.33,0.4)	(0.31,0.37,0.45)	(0.29,0.33,0.4)	(0.29,0.33,0.4)	(0.31,0.37,0.45)	(0.29,0.33,0.4)	(1,1,1)