Applied Soft Computing 109 (2021) 107540

Contents lists available at ScienceDirect

Applied Soft Computing

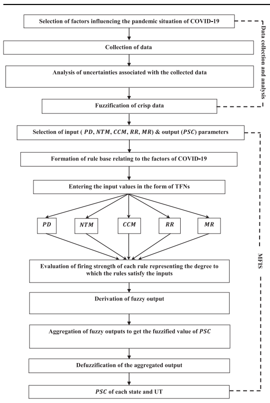
journal homepage: www.elsevier.com/locate/asoc

Status evaluation of provinces affected by COVID-19: A qualitative assessment using fuzzy system

Bappaditya Ghosh, Animesh Biswas *

Department of Mathematics, University of Kalyani, Kalyani 741235, India

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 20 January 2021
Received in revised form 15 May 2021
Accepted 23 May 2021
Available online 2 June 2021

Keywords:
COVID-19
Fuzzy inference system
Triangular fuzzy number
Qualitative assessment

ABSTRACT

The outbreak of COVID-19 had already shown its harmful impact on mankind, especially on health sectors, global economy, education systems, cultures, politics, and other important fields. Like most of the affected countries in the globe, India is now facing serious crisis due to COVID-19 in the recent times. The evaluation of the present status of the provinces affected by COVID-19 is very much essential to the government authorities to impose preventive strategies in controlling the spread of COVID-19 and to take necessary measures. In this article, a computational methodology is developed to estimate the present status of states and provinces which are affected due to COVID-19 using a fuzzy inference system. The factors such as population density, number of COVID-19 tests, confirmed cases of COVID-19, recovery rate, and mortality rate are considered as the input parameters of the proposed methodology. Considering positive and negative factors of the input parameters, the rule base is developed using triangular fuzzy numbers to capture uncertainties associated with the model. The application potentiality is validated by evaluating Pearson's correlation coefficient. A sensitivity analysis is also performed to observe the changes of final output by varying the tolerance ranges of the inputs. The results of the proposed method show that some of the provinces have very poor performance in controlling the spread of COVID-19 in India. So, the government needs to take serious attention to deal with the pandemic situation of COVID-19 in those provinces.

1. Introduction

The word 'Corona' is one of the most widely used words in the recent time. The spread of novel coronavirus disease which is termed as COVID-19 was started from the city of Wuhan, China since late December of 2019 [1–5]. Fever, fatigue, cough,

* Corresponding author.
E-mail address: abiswaskln@rediffmail.com (A. Biswas).

https://doi.org/10.1016/j.asoc.2021.107540

problem of breath, loss of taste and smell, etc., are the common symptoms of COVID-19 [6,7]. The primary symptoms of COVID-19 and common flu are almost the same, which makes this virus more dangerous. When a person comes to know that he is COVID-19 positive, some other people had already been infected by him/her, unknowingly. As on the end of 2020, it was reported that among the active COVID-19 cases, majorities are found in mild symptoms, in India [8–12]. The time of exposure of symptoms takes around four to five days and may remain up to fourteen days [13,14]. Corona virus mainly infects the lungs which may causes cardiovascular, gastrointestinal, nervous system, liver, kidney and ocular damages [15–17].

Most of the countries declared COVID-19 crisis as a national disaster. The outbreak of COVID-19 has already shown its harmful impact on mankind, especially on global economy, health sectors, cultures, education systems, politics, etc. The local and global marketing systems, manufacturing sectors are being hampered, significantly, which resulted a large unemployment of man powers all over the world. The major impact of this pandemic is being observed in health sectors. The inclusion of new COVID-19 hospitals has reduced the scopes of admission of the common people to the hospitals due to other major health issues. So, people are being deprived of their regular treatments from the hospitals due to the lack of doctors, nurses and other health workers. The increasing number of COVID-19 cases reduces the number of beds for common people in several hospitals. Many senior citizens were facing several mental health problems due to their loneliness during the lockdown periods. The art and cultural sectors including film and entertainment industries were temporarily closed due to the pandemic of COVID-19. All the major sport events have been either partially postponed or cancelled indefinitely. The pandemic also established its harmful impact on education system, globally. All the government, and private schools and educational institutes are either partially opened or indefinitely closed or running on virtual mode due to this pandemic which are adversely affecting the learning processes of the learners, worldwide. Lastly, the world political systems were also affected due to rescheduling of elections, death of politicians, lack of campaigning due to social distancing, etc.

Up to 30th November, 2020, around 6,36,09,507 people were found as COVID-19 positive, globally. Among them, around 4,39,83,871 people were recovered from this disease; whereas, around 14,74,186 people died due to this pandemic. USA was facing the worse effect of this pandemic at that time as it covered about 22% of total COVID-19 positive cases in the world. Around 1,66,904 new COVID-19 cases were found in USA; whereas, about 1,39,26,349 people were found as infected, of which around 82,24,314 people were recovered from this disease, and about 2,74,369 people died. According to the statistics of worldwide COVID-19 report on 30th November, 2020, India stood second in terms of number of COVID-19 positive cases. According to the data provided by the Department of Ministry of Health and Family Welfare (MoHFW), Government of India on 30th November, 2020, around 94,31,691 people were infected, of which about 88,47,600 people were recovered, and around 1,37,139 people lost their lives due this pandemic in India. These facts reflected very serious concern to the Government of India in controlling the spread of COVID-19. On 26th March, 2020, Nirmala Sitharaman, the finance minister of India, announced an incentive package of ₹170,000 crore in the purpose of helping the people affected by the lockdown. Most of the states and union territories (UTs) of India are facing the worse effect of COVID-19. But, as per the available report of MoHFW as on 30th November, 2020, one UT, viz., Lakshadweep remained free from COVID-19; and consequently, the administration of Lakshadweep requested to the central government to provide the permission of reopening the schools; but, other states and UTs were still hesitating to reopen in that circumstances.

It is the fact that most of the news channels, survey institutes or some other organizations are estimating the fight of a country or state against COVID-19 on the basis of confirmed corona positive cases. But, as per the recent report of World Health Organization (WHO), majority of the active COVID-19 cases are found either asymptomatic or in mild symptoms. Therefore, a country or state having large number of population or performing huge number of COVID-19 tests would obviously situate in the group of large number of positive COVID-19 cases. Thus, some other factors such as population, population density, number of COVID-19 tests, recovery rate, mortality rate, etc., are needed to be considered in assessing the fight of a country or state against COVID-19.

In this article, an effort is made for estimating the strategies which were taken by the states and UTs in India to combat against COVID-19. In this purpose, a methodology is developed to evaluate the performance score to control the spread of COVID-19 corresponding to each state and UT in India. The data were collected from the official website of MoHFW, Government of India. But, such a highly populated country like India, it is very difficult to find exact figures of relevant inputs, such as population of a state or UT, number of tests, confirmed cases, recovery rate, mortality rate, etc. Therefore, some sorts of uncertainties or inexactness are unavoidably occurred in collecting data. Thus, the inclusion of fuzziness in the process of data collection becomes very much essential. The concept of fuzziness was successfully implemented by Togacar et al. [18] for detection of COVID-19. Later, Govindan et al. [19] used fuzzy inference system to develop a decision support system for demand management in healthcare supply chains concerning COVID-19 outbreaks. Mardani et al. [20] proposed an extended approach based on hesitant fuzzy sets to rank the key challenges of digital health interventions in controlling COVID-19 outbreak. Mahmoudi et al. [21] developed a fuzzy clustering method for comparing the infection rate of COVID-19 in countries with high risks. Behnood et al. [22] used adaptive neuro-fuzzy inference system in determining the infection rate of the COVID-19 in U.S. Later, Ly [23] developed a methodology using adaptive neuro-fuzzy inference system for forecasting COVID-19 cases in United Kingdom. A decision making approach was proposed by Singh and Avikal [24] for prioritizing the preventive activities against COVID-19. Further, Ocampo and Yamagishi [25] performed an intuitionistic fuzzy DEMATEL analysis to develop a model of lockdown relaxation protocols concerning the COVID-19 pandemic under the Government of Philippine. The concept of hesitant fuzzy sets was used by Ren et al. [26] in selecting the medicines for the patients having mild symptoms of COVID-19. Li et al. [27] developed a consensus model for managing non-cooperative behaviours of individuals in group decision making problems during the pandemic of COVID-19. Shaban et al. [28] introduced a strategy for detecting COVID-19 patients using fuzzy inference engine and deep neural network. Further, Aggarwal et al. [29] proposed an approach to compare the criterion in decision support system for COVID-19. Ghorui et al. [30] used hesitant fuzzy multi-criteria decision making method to identify the risk factors involved with the spread of COVID-19. To select drugs for the patients with mild symptoms of COVID-19, a decision-making framework using hesitant fuzzy sets was introduced by Mishra et al. [31]. Later, Ecer and Pamucar [32] proposed a technique under intuitionistic fuzzy environment for ranking the performance of insurance companies during COVID-19 pandemic. In the recent past, Sharma et al. [33] developed a meditative fuzzy logic model to provide the relation between the growths of COVID-19 cases with respect to time. But no method has been developed yet to

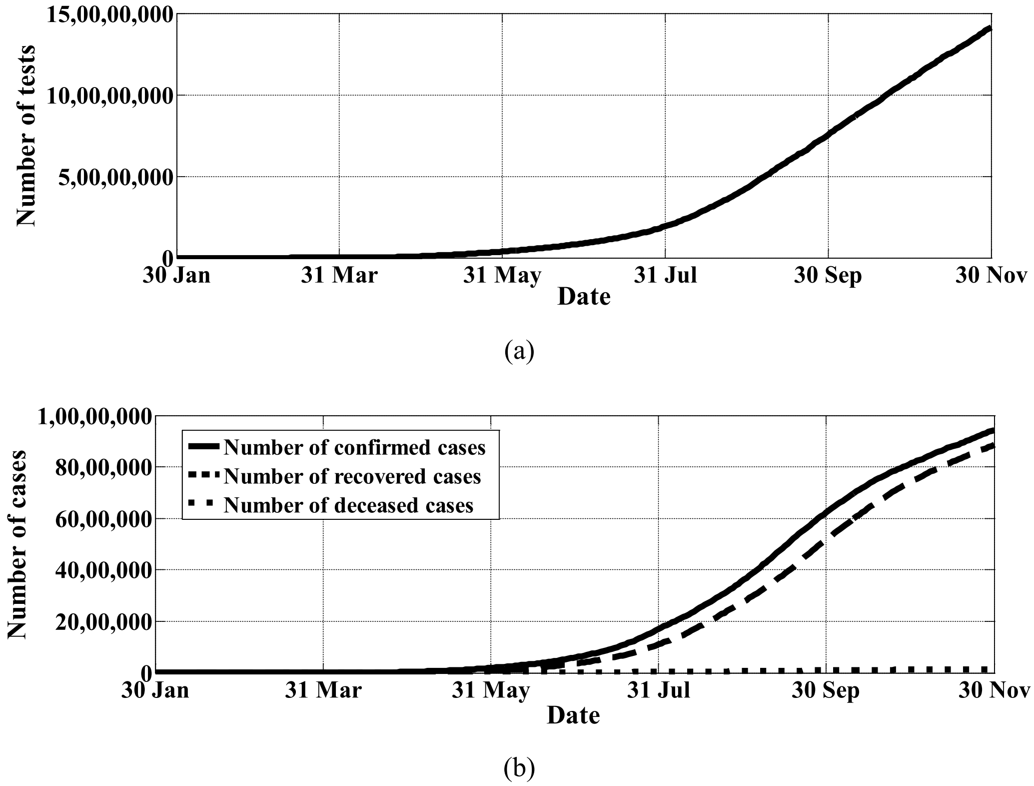


Fig. 1. Cumulative graph of number of (a) tests (b) confirmed cases, recovered cases, and deceased cases of covid-19.

evaluate the status of provinces affected by COVID-19 on the basis of the factors influencing the pandemic situation of COVID-19 using fuzzy systems. Getting informed about the recent status through this method, the concerned governing bodies might think about starting intra-state, and inter-state public transport services, reopening educational institutes, theatres, cinema halls, and museums, supplying medical equipment, declaring economic packages, awarding role model against COVID-19, building up strategies for equitable distribution of COVID-19 vaccines, and others.

In the proposed study, a Mamdani fuzzy inference system (MFIS) [34] is generated to evaluate the state wise performance score to combat against COVID-19 in India. The score value of all the input factors, such as population density, number of COVID-19 tests per million, number of confirmed case per million, recovery rate, mortality rate corresponding to all the states and UTs in India are fuzzified to capture the uncertainties associated with the collected data. Here, linear type fuzzy numbers are used to represent the membership functions (MFs) for input and output parameters of the proposed MFIS. To establish the application potentiality and validity of the proposed methodology, Pearson's correlation coefficient [35] is evaluated between the final results and recovery rate of COVID-19. Later, a sensitivity analysis is also performed to observe the changes of final output by varying the tolerance ranges of the input values.

2. Data collection and analysis

In the proposed methodology, all the factors such as projected population in 2019, population density, number of COVID-19 tests, confirmed cases of COVID-19, recovery rate, mortality rate, etc., are considered as inputs for assessing the performance of all the states and UTs in India to combat against COVID-19. The projected population in 2019 and population density in 2011 of all the states and UTs were collected based on the census report of India which was conducted by National Commission on Population in 2011 [36]. The data regarding other inputs, such as number of tests, confirmed cases, recovered cases and deceased cases of COVID 19, as shown in Fig. 1, were collected from the official website of MoHFW, Government of India [37] and from another website [38]. But, it is very difficult to assign exact number against each of the above mentioned inputs for such a highly populated country like India due to continuous spread of COVID-19. Also, due to several issues like complexity in accounting exact figures of comorbidity, migratory cases, lack of communication between central and state governments, etc., a deviation up to 2% in the input values available on the website of MoHFW is inevitable. Therefore, the occurrence of uncertainties or inexactness associated with the data collection is unavoidable. Thus, all the crisp inputs for the proposed methodology are fuzzified into suitable fuzzy numbers to capture imprecision associated with the collected data. Since, the uncertainties or inexactness in collected data are found as a deviation of about 2% from the exact value, the triangular fuzzy numbers (TFNs) [39] are used for fuzzification of crisp input values.

Thus, if a be a crisp input of the proposed method, then it is fuzzified into a TFN as

$$N = \langle (1-l)\,a, a, (1+l)a \rangle\, ; l > 0$$

with the following membership function

$$N(x) = \begin{cases} \dfrac{x-(1-l)\,a}{a-(1-l)\,a}, & (1-l)\,a \le x \le a \\ \dfrac{(1+l)a - x}{(1+l)a - a}, & a \le x \le (1+l)a \\ 0, & otherwise \end{cases} \tag{1}$$

3. Proposed methodology

MFIS [34] is a systematic formulation of pre-defined if-then rules which interprets human perceptions. In the proposed method, a MFIS is generated to evaluate the performance of all the states and UTs in India to prevent the pandemic situation of COVID-19. The proposed methodology is described as follows:

Step 1: Selection of input and output parameters

The proposed MFIS consists of five input parameters, viz., *Population Density* (*PD*), *Number of Tests per Million* (*NTM*), *Confirmed Cases per Million* (*CCM*), *Recovery Rate* (*RR*), and *Mortality Rate* (*MR*) in the respective universe of discourses, X_1, X_2, X_3, X_4, and X_5 and one output parameter, viz., *Performance Score against COVID* − 19 (*PSC*) in the universe of discourse Z. To capture the uncertainties associated with the collected data, the MFs of both input and output variables are represented by TFNs.

Step 2: Development of rule base

The rule base of MFIS characterizes the relationship between the input and output parameters. The $i^{th}(i = 1, 2, \ldots, m)$ rule of a MFIS [39,40] is of the following form:

$$R_i : \text{If } x_1 \text{ is } F_i^{PD} \text{ and } x_2 \text{ is } F_i^{NTM} \text{ and } x_3 \text{ is } F_i^{CCM} \text{ and } x_4 \text{ is } F_i^{RR} \text{ and } x_5 \text{ is } F_i^{MR} \text{ then } z \text{ is } F_i^{PSC}, \quad (2)$$

where $F_i^{PD}, F_i^{NTM}, F_i^{CCM}, F_i^{RR}, F_i^{MR}$, *and* F_i^{PSC} are TFNs representing the qualitative descriptors of *PD*, *NTM*, *CCM*, *RR*, *MR*, *and PSC*, respectively, for the i^{th} rule; $x_i \in X_i$ $(i = 1, 2, \ldots, m)$, and $z \in Z$.

Here, three linguistic terms are considered corresponding to each input and output parameter. Thus, the rule base contains a total number of $3^5 = 243$ if-then fuzzy rules by combining all the possible outcomes corresponding to input–output parameters. It is to be noted here that in forming the rules, three input parameters, viz., *PD*, *NTM*, *RR* are considered as the positive factors and *CCM*, *MR* are considered as the negative factors for the evaluation of *PSC*.

Step 3: Evaluation of firing strength of each rule

The fuzzy intersection method is performed to evaluate the firing strength, δ_i, of the $i^{th}(i = 1, 2, \ldots, m)$ rule as follows:

$$\begin{aligned}
\delta_i &= \min\{\max\{N^{PD}(x_1) \wedge F_i^{PD}(x_1)\}, \max\{N^{NTM}(x_2) \wedge F_i^{NTM}(x_2)\}, \max\{N^{CCM}(x_3) \wedge F_i^{CCM}(x_3)\}, \\
&\quad \max\{N^{RR}(x_4) \wedge F_i^{RR}(x_4)\}, \max\{N^{MR}(x_5) \wedge F_i^{MR}(x_5)\}\} \\
&= \min\{\max\{\alpha \in [0,1]: \alpha = \min(N^{PD}(x_1), F_i^{PD}(x_1)), x_1 \in X_1\}, \\
&\quad \max\{\alpha \in [0,1]: \alpha = \min(N^{NTM}(x_2), F_i^{NTM}(x_2)), x_2 \in X_2\}, \\
&\quad \max\{\alpha \in [0,1]: \alpha = \min(N^{CCM}(x_3), F_i^{CCM}(x_3)), x_3 \in X_3\}, \\
&\quad \max\{\alpha \in [0,1]: \alpha = \min(N^{RR}(x_4), F_i^{RR}(x_4)), x_4 \in X_4\}, \\
&\quad \max\{\alpha \in [0,1]: \alpha = \min(N^{MR}(x_5), F_i^{MR}(x_5)), x_5 \in X_5\}\}, \quad (3)
\end{aligned}$$

where $N^{PD}(x_1), N^{NTM}(x_2), N^{CCM}(x_3), N^{RR}(x_4)$, and $N^{MR}(x_5)$ are the membership grades of the respective fuzzy inputs, N^{PD}, N^{NTM}, N^{CCM}, N^{RR}, *and* N^{MR} in the form of TFNs. $F_i^{PD}(x_1), F_i^{NTM}(x_2), F_i^{CCM}(x_3), F_i^{RR}(x_4)$, and $F_i^{MR}(x_5)$ are the membership grades of the corresponding qualitative descriptors, $F_i^{PD}, F_i^{NTM}, F_i^{CCM}, F_i^{RR}$, *and* F_i^{MR} of *PD*, *NTM*, *CCM*, *RR*, *and MR*, respectively, for the $i^{th}(i = 1, 2, \ldots, m)$ rule.

Step 4: Derivation of fuzzy output of each rule

The fuzzy output, PSC_i, for the $i^{th}(i = 1, 2, \ldots, m)$ rule is derived as follows:

$$PSC_i(z) = \delta_i \wedge F_i^{PSC}(z) = \min\{\delta_i, F_i^{PSC}(z)\}, \quad (4)$$

where $F_i^{PSC}(z)$ is the membership grade of the qualitative descriptor, F_i^{PSC} of the output variable, *PSC* and $z \in Z$.

Step 5: Aggregation of fuzzy outputs

The fuzzy output, AG^{PSC}, derived from all the rules are aggregated by operating fuzzy union as

$$AG^{PSC}(z) = \vee_{i=1}^{m} PSC_i(z) = \max\{PSC_1(z), PSC_2(z), \ldots, PSC_m(z)\}, z \in Z. \quad (5)$$

Step 6: Defuzzification of the aggregated output

The aggregated output is defuzzified by operating the centroid of area method which gives the final output, *PSC*, as follows:

$$PSC = \frac{\sum_{k=1}^{n} AG^{PSC}(z_k) \, . z_k}{\sum_{k=1}^{n} AG^{PSC}(z_k)}, \quad (6)$$

where $z_k \in Z$, $k = 1, 2, \ldots, n$ are n quantization of Z.

It is to be mentioned here that the higher value of *PSC* corresponding to a state or UT signifies the better performance of that state or UT to combat against the pandemic of COVID-19.

The proposed methodology is presented through a flowchart as presented in Fig. 2.

4. Performance score of the states and UTs in India to combat against the pandemic situation of COVID-19

In this section, the performance score of 28 states and 7 UTs in India are assessed by means of their efficiency to tackle the pandemic situation of COVID-19 based on the data available up to 30th November, 2020. As per the census report of India, conducted by National Commission on Population in 2011, and information provided by the Department of MoHFW, Government of India, available on the websites as on 30th November, 2020 [36,37], the crisp value of *PD*, *NTM*, *CCM*, *RR*, and *MR* are, respectively, found as 368, 1,06,046, 7,076, 93.81, and 1.45 in India. In the proposed methodology, the MFs of all the linguistic hedges representing the input parameters are defined by keeping those values near the centre point of the middle linguistic term of the respective input parameters. The crisp values of those input variables corresponding to all the states and UTs in India are presented in Fig. 3(a–e).

4.1. Selection of membership functions for input variables

***PD*:** According to the census report of India conducted in 2011 [36], the *PD* of the states and UTs, under consideration, is presented through Fig. 3(a). Following the report, it is observed that the UT of Delhi is recommended as the most densely populated region in India with population density of 11,320 persons per square Kilometre. Thus, the universe of discourse of *PD* is considered as the closed interval [0, 12000] on which three linguistic hedges, viz., Low, Average, and High are defined. Since, the average population density in India is 368 persons per square Kilometre [36], the respective TFNs are formulated as ⟨0, 0, 400⟩, ⟨0, 400, 800⟩, and ⟨400, 12000, 12000⟩ to represent those linguistic hedges, and are shown in Fig. 4(a).

***NTM*:** *NTM* signifies the number of tests performed per million numbers of people of a state or UT. It is the most vital process to detect the positive COVID-19 patients. According to the data provided by the Department of MoHFW, Government of India [37] on 30th November, 2020 and the census report of India in 2011 [36], *NTM* of the states and UTs is presented in Fig. 3(b). According to that report, it is found that Andaman and Nicobar Islands had performed maximum number of COVID-19

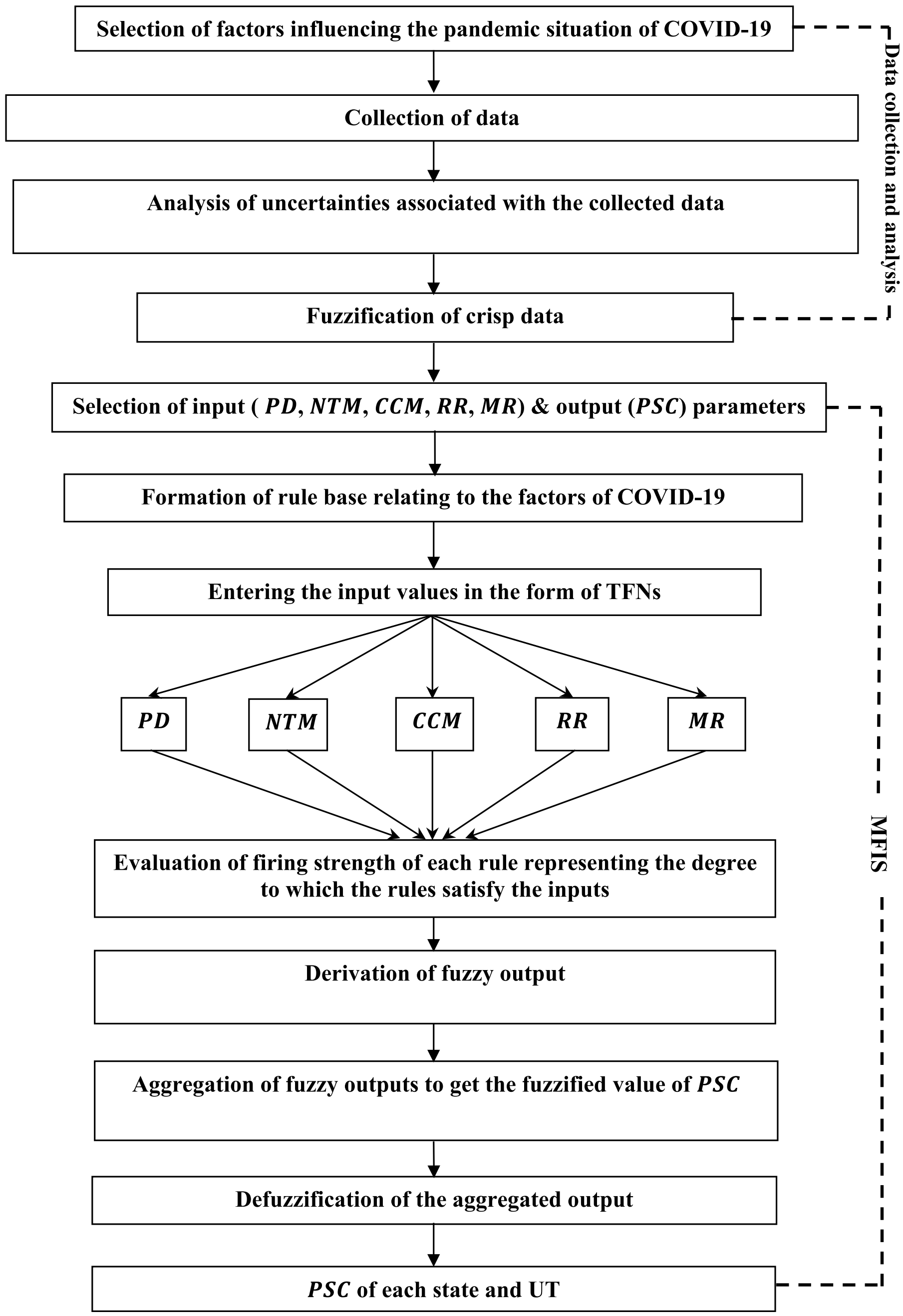


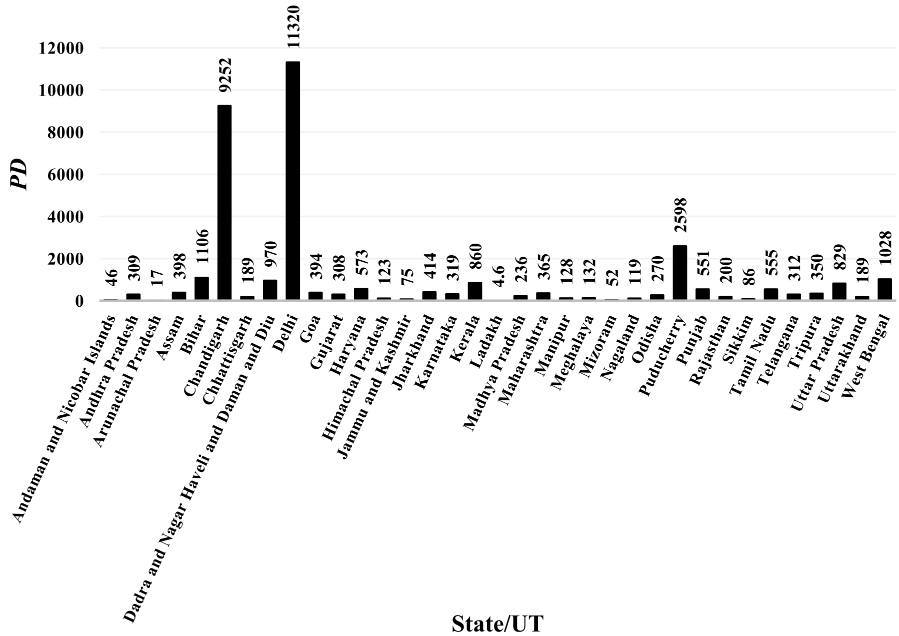
Fig. 2. Flowchart of the proposed methodology.

tests per million with score value of 3,25,917. Thus, the universe of discourse of *NTM* is considered as [0, 335000] on which three linguistic hedges, viz., Low, Average, and High are defined. Since, the average value of *NTM* in India were found as 1,06,046, the respective TFNs, viz., ⟨0, 0, 100000⟩, ⟨0, 100000, 200000⟩, and ⟨100000, 335000, 335000⟩ are considered to represent those linguistic hedges which are shown in Fig. 4(b).

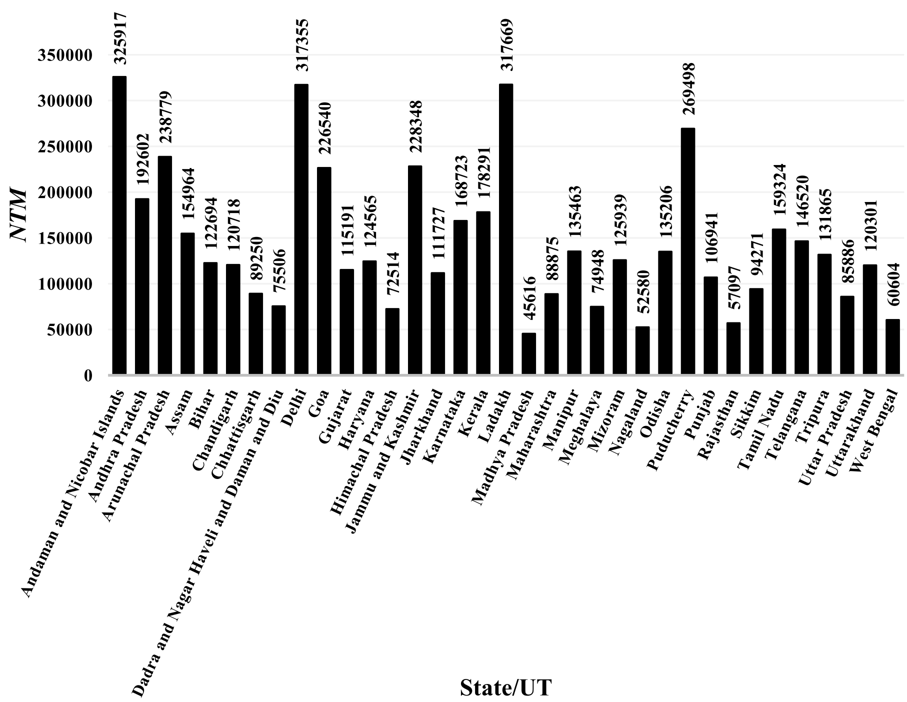
***CCM*:** *CCM* of the provinces represents the number of positive COVID-19 cases found in those provinces. The data provided by the Department of MoHFW [37], which are presented in Fig. 3(c), shows that Goa stood top in the table of confirmed COVID-19 positive cases per million numbers of people with score value of 31,042; whereas, the average score value of the confirmed COVID-19 positive cases per million numbers of people in India is found as 7,076. Thus, the universe of discourse of *CCM* is taken as [0, 35000] on which three linguistic hedges, viz., Low, Average, and High, as shown in Fig. 4(c), are defined with the respective representation of TFNs as ⟨0, 0, 7000⟩, ⟨0, 7000, 14000⟩, and ⟨7000, 35000, 35000⟩.

***RR*:** *RR* signifies the percentage of positive COVID-19 patients who had been recovered from this disease. The average value of *RR* in India is 93.81%. According to Fig. 3(d), in Dadra and Nagar Haveli and Daman and Diu maximum recovery rate with score value 99.28% is observed. Thus the TFNs, viz., ⟨0, 0, 90⟩, ⟨80, 90, 100⟩, and ⟨90, 100, 100⟩ are considered to represent the linguistic hedges, viz., Low, Medium, and High, respectively, defined on the universe of discourse, [0, 100], as shown in Fig. 4(d).

***MR*:** *MR* reflects the percentage of positive COVID-19 patients who died due to this disease. The data related to the *MR* of each state and UT under consideration which are available on



(a)



(b)

Fig. 3. Crisp value of (a) *PD* (b) *NTM* (c) *CCM* (d) *RR* (e) *MR* corresponding to each state and UT in India.

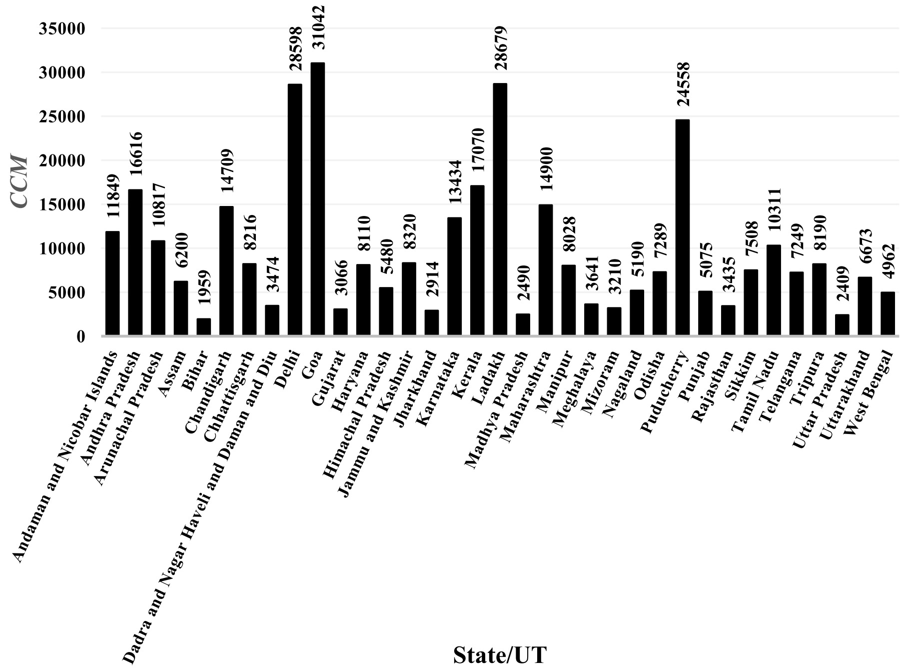
the official website of MoHFW, Government of India [37] as on 30th November, 2020, is summarized in Fig. 3(e). Following the report, the highest value of *MR* is found in Punjab with score value 3.15%. Thus, the universe of discourse of *MR* is considered as the closed interval [0, 4] on which three linguistic hedges, viz., Low, Medium, and High are defined. Since, the average value of *MR* in India is found as 1.45%, the respective TFNs, viz., $\langle 0, 0, 1.45\rangle$, $\langle 1, 1.45, 1.9\rangle$, and $\langle 1.45, 4, 4\rangle$ are introduced to represent these linguistic hedges and are shown in Fig. 4(e).

It is to be mentioned here that only those states and UTs are considered in this study where at least one COVID-19 positive case was found up to 30th November, 2020. Hence, the UT of Lakshadweep is out of the consideration, as no positive COVID-19 case was found there up to that time.

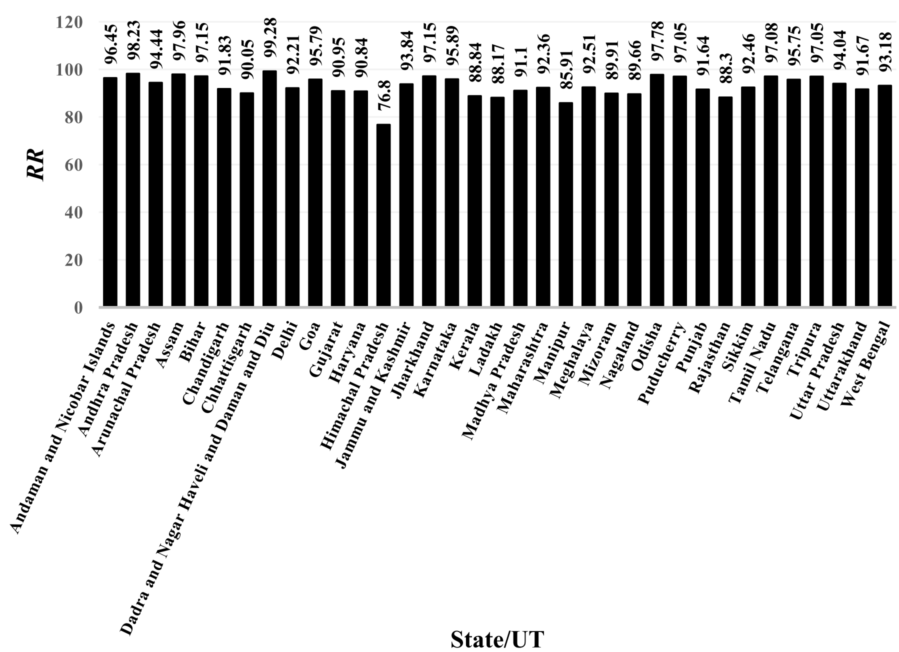
For simplicity, a deviation of about 2% of the collected data is considered for deriving the TFNs as inputs. The TFNs corresponding to the inputs are presented in Table 1.

4.2. Selection of membership functions for output variables

The universe of discourse of *PSC* is considered as the closed interval [0, 100] on which three linguistic hedges, viz., Poor,



(c)



(d)

Fig. 3. (*continued*).

Ordinary, and Excellent are defined. The MFs corresponding to these linguistic hedges are represented by the respective TFNs, $\langle 0, 0, 50\rangle$, $\langle 30, 50, 70\rangle$, and $\langle 50, 100, 100\rangle$ as shown in Fig. 4(f).

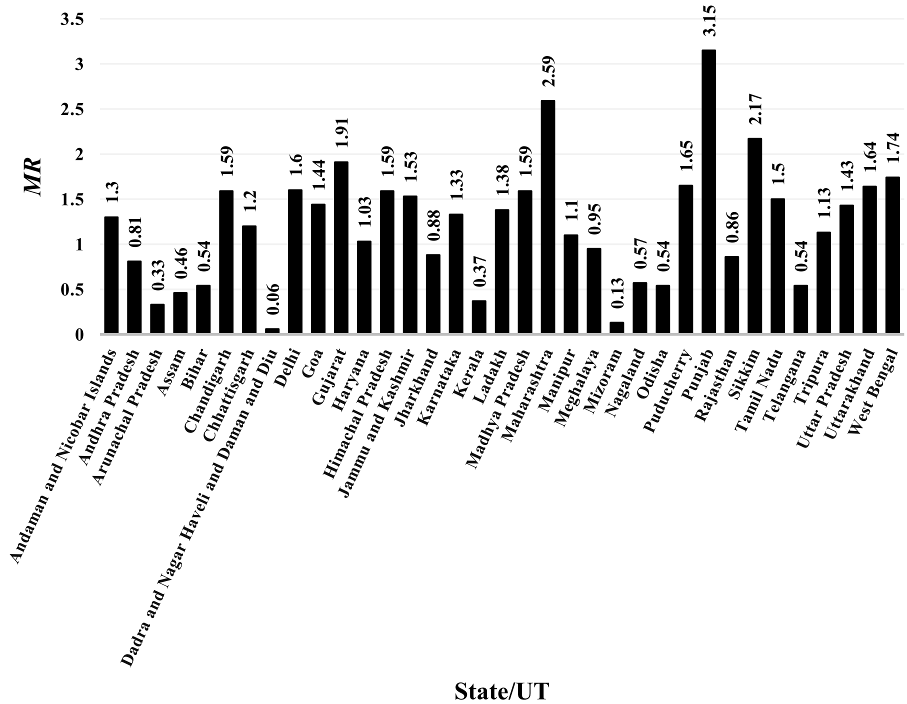
4.3. Formation of fuzzy rule base

Here, each input and output parameter consists of three linguistic terms. Thus, combining all the possible outcomes corresponding to input–output parameters, the rule base of the proposed MFIS contains a total number of $3^5 = 243$ if-then fuzzy rules which are presented in Table 2.

4.4. Evaluation of PSC

After, forming the fuzzy rule base, the values of *PSC* of the states and UTs in India under consideration are evaluated through the processes as described in Step 3 to Step 6 of Section 3 and executed through the *software* MATLAB (Ver. R2014a); and the achieved results are presented in Table 3. As for visual representation, a snapshot of the MATLAB programming for the evaluation of *PSC* of Andaman and Nicobar Islands is presented in Fig. 5.

It is important to note here that the *PSC* of each state and UT is evaluated according to the data provided by the Department



(e)

Fig. 3. (*continued*).

Table 1
Fuzzified input values.

State/UT	*PD*	*NTM*	*CCM*	*RR*	*MR*
Andaman and Nicobar Islands	⟨45, 46, 47⟩	⟨319399, 325917, 332435⟩	⟨11612, 11849, 12086⟩	⟨94.52, 96.45, 98.38⟩	⟨1.27, 1.3, 1.33⟩
Andhra Pradesh	⟨303, 309, 315⟩	⟨188750, 192602, 196454⟩	⟨16284, 16616, 16948⟩	⟨96.27, 98.23, 100⟩	⟨0.79, 0.81, 0.83⟩
Arunachal Pradesh	⟨17, 17, 17⟩	⟨234003, 238779, 243555⟩	⟨10601, 10817, 11033⟩	⟨92.55, 94.44, 96.33⟩	⟨0.32, 0.33, 0.34⟩
Assam	⟨390, 398, 406⟩	⟨151865, 154964, 158063⟩	⟨6076, 6200, 6324⟩	⟨96, 97.96, 99.92⟩	⟨0.45, 0.46, 0.47⟩
Bihar	⟨1084, 1106, 1128⟩	⟨120240, 122694, 125148⟩	⟨1920, 1959, 1998⟩	⟨95.21, 97.15, 99.09⟩	⟨0.53, 0.54, 0.55⟩
Chandigarh	⟨9067, 9252, 9437⟩	⟨118304, 120718, 123132⟩	⟨14415, 14709, 15003⟩	⟨89.99, 91.83, 93.67⟩	⟨1.56, 1.59, 1.62⟩
Chhattisgarh	⟨185, 189, 193⟩	⟨87465, 89250, 91035⟩	⟨8052, 8216, 8380⟩	⟨88.25, 90.05, 91.85⟩	⟨1.18, 1.2, 1.22⟩
Dadra and Nagar Haveli and Daman and Diu	⟨951, 970, 989⟩	⟨73996, 75506, 77016⟩	⟨3405, 3474, 3543⟩	⟨97.29, 99.28, 100⟩	⟨0.06, 0.06, 0.06⟩
Delhi	⟨11094, 11320, 11546⟩	⟨311008, 317355, 323702⟩	⟨28026, 28598, 29170⟩	⟨90.37, 92.21, 94.05⟩	⟨1.57, 1.6, 1.63⟩
Goa	⟨386, 394, 402⟩	⟨222009, 226540, 231071⟩	⟨30421, 31042, 31663⟩	⟨93.87, 95.79, 97.71⟩	⟨1.41, 1.44, 1.47⟩
Gujarat	⟨302, 308, 314⟩	⟨112887, 115191, 117495⟩	⟨3005, 3066, 3127⟩	⟨89.13, 90.95, 92.77⟩	⟨1.87, 1.91, 1.95⟩
Haryana	⟨562, 573, 584⟩	⟨122074, 124565, 127056⟩	⟨7948, 8110, 8272⟩	⟨89.02, 90.84, 92.66⟩	⟨1.01, 1.03, 1.05⟩
Himachal Pradesh	⟨121, 123, 125⟩	⟨71064, 72514, 73964⟩	⟨5370, 5480, 5590⟩	⟨75.26, 76.8, 78.34⟩	⟨1.56, 1.59, 1.62⟩
Jammu and Kashmir	⟨74, 75, 77⟩	⟨223781, 228348, 232915⟩	⟨8154, 8320, 8486⟩	⟨91.96, 93.84, 95.72⟩	⟨1.5, 1.53, 1.56⟩
Jharkhand	⟨406, 414, 422⟩	⟨109492, 111727, 113962⟩	⟨2856, 2914, 2972⟩	⟨95.21, 97.15, 99.09⟩	⟨0.86, 0.88, 0.9⟩
Karnataka	⟨313, 319, 325⟩	⟨165349, 168723, 172097⟩	⟨13165, 13434, 13703⟩	⟨93.97, 95.89, 97.81⟩	⟨1.3, 1.33, 1.36⟩
Kerala	⟨843, 860, 877⟩	⟨174725, 178291, 181857⟩	⟨16729, 17070, 17411⟩	⟨87.06, 88.84, 90.62⟩	⟨0.36, 0.37, 0.38⟩
Ladakh	⟨5, 5, 5⟩	⟨311316, 317669, 324022⟩	⟨28105, 28679, 29253⟩	⟨86.41, 88.17, 89.93⟩	⟨1.35, 1.38, 1.41⟩
Madhya Pradesh	⟨231, 236, 241⟩	⟨44704, 45616, 46528⟩	⟨2440, 2490, 2540⟩	⟨89.28, 91.1, 92.92⟩	⟨1.56, 1.59, 1.62⟩
Maharashtra	⟨358, 365, 372⟩	⟨87098, 88875, 90653⟩	⟨14602, 14900, 15198⟩	⟨90.51, 92.36, 94.21⟩	⟨2.54, 2.59, 2.64⟩
Manipur	⟨125, 128, 131⟩	⟨132754, 135463, 138172⟩	⟨7867, 8028, 8189⟩	⟨84.19, 85.91, 87.63⟩	⟨1.08, 1.1, 1.12⟩
Meghalaya	⟨129, 132, 135⟩	⟨73449, 74948, 76447⟩	⟨3568, 3641, 3714⟩	⟨90.66, 92.51, 94.36⟩	⟨0.93, 0.95, 0.97⟩
Mizoram	⟨51, 52, 53⟩	⟨123420, 125939, 128458⟩	⟨3146, 3210, 3274⟩	⟨88.11, 89.91, 91.71⟩	⟨0.13, 0.13, 0.13⟩
Nagaland	⟨117, 119, 121⟩	⟨51528, 52580, 53632⟩	⟨5086, 5190, 5294⟩	⟨87.87, 89.66, 91.45⟩	⟨0.56, 0.57, 0.58⟩
Odisha	⟨265, 270, 275⟩	⟨132502, 135206, 137910⟩	⟨7143, 7289, 7435⟩	⟨95.82, 97.78, 99.74⟩	⟨0.53, 0.54, 0.55⟩
Puducherry	⟨2546, 2598, 2650⟩	⟨264108, 269498, 274888⟩	⟨24067, 24558, 25049⟩	⟨95.11, 97.05, 98.99⟩	⟨1.62, 1.65, 1.68⟩
Punjab	⟨540, 551, 562⟩	⟨104802, 106941, 109080⟩	⟨4974, 5075, 5177⟩	⟨89.81, 91.64, 93.47⟩	⟨3.09, 3.15, 3.21⟩
Rajasthan	⟨196, 200, 204⟩	⟨55955, 57097, 58239⟩	⟨3366, 3435, 3504⟩	⟨86.53, 88.3, 90.07⟩	⟨0.84, 0.86, 0.88⟩
Sikkim	⟨84, 86, 88⟩	⟨92386, 94271, 96156⟩	⟨7358, 7508, 7658⟩	⟨90.61, 92.46, 94.31⟩	⟨2.13, 2.17, 2.21⟩
Tamil Nadu	⟨544, 555, 566⟩	⟨156138, 159324, 162510⟩	⟨10105, 10311, 10517⟩	⟨95.14, 97.08, 99.02⟩	⟨1.47, 1.5, 1.53⟩
Telangana	⟨306, 312, 318⟩	⟨143590, 146520, 149450⟩	⟨7104, 7249, 7394⟩	⟨93.84, 95.75, 97.67⟩	⟨0.53, 0.54, 0.55⟩
Tripura	⟨343, 350, 357⟩	⟨129228, 131865, 134502⟩	⟨8026, 8190, 8354⟩	⟨95.11, 97.05, 98.99⟩	⟨1.11, 1.13, 1.15⟩
Uttar Pradesh	⟨812, 829, 846⟩	⟨84168, 85886, 87604⟩	⟨2361, 2409, 2457⟩	⟨92.16, 94.04, 95.92⟩	⟨1.4, 1.43, 1.46⟩
Uttarakhand	⟨185, 189, 193⟩	⟨117895, 120301, 122707⟩	⟨6540, 6673, 6806⟩	⟨89.84, 91.67, 93.5⟩	⟨1.61, 1.64, 1.67⟩
West Bengal	⟨1008, 1028, 1049⟩	⟨59392, 60604, 61816⟩	⟨4863, 4962, 5061⟩	⟨91.32, 93.18, 95.04⟩	⟨1.71, 1.74, 1.77⟩

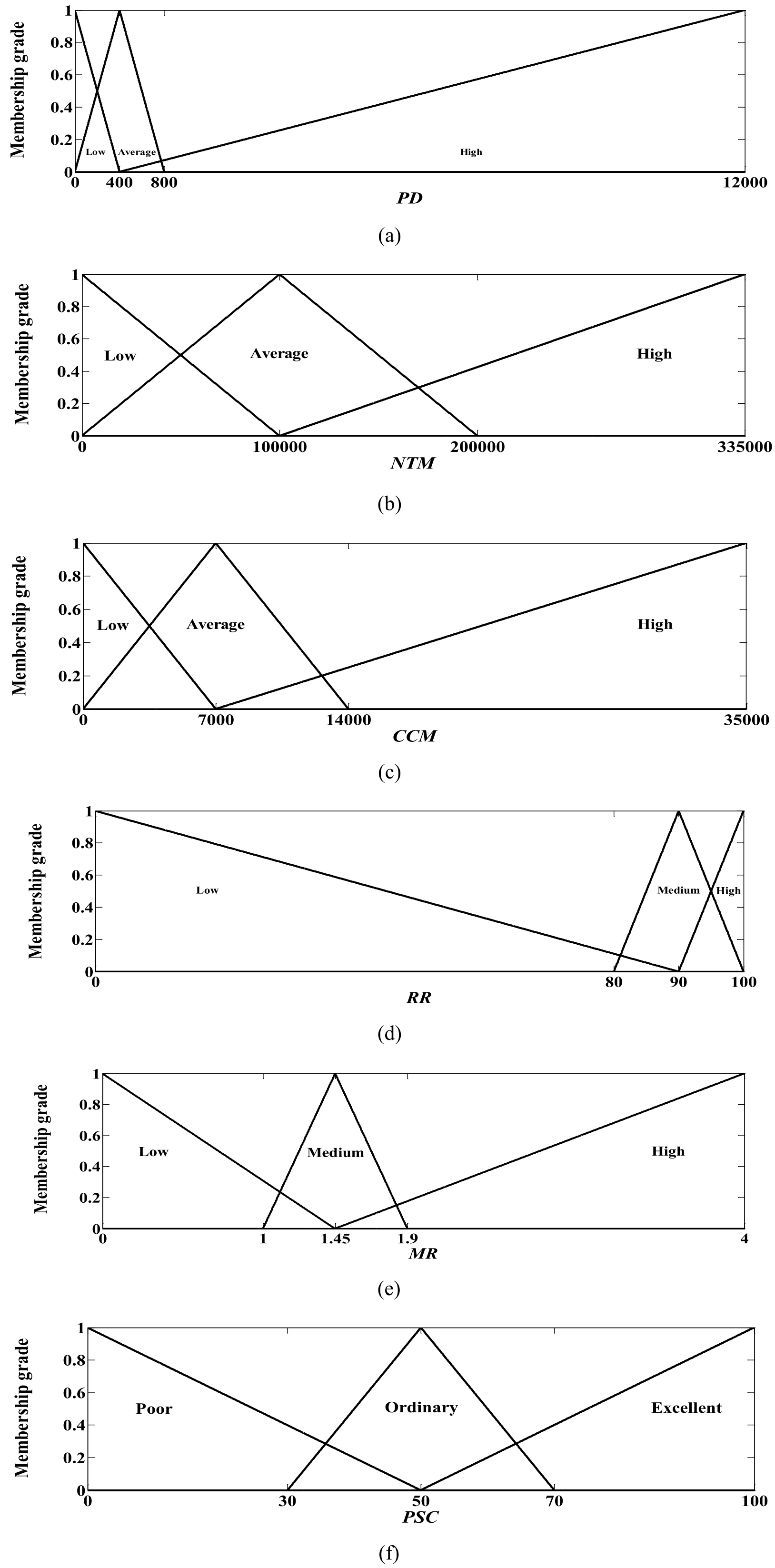


Fig. 4. MFs representing the linguistic hedges of (a) *PD* (b) *NTM* (c) *CCM* (d) *RR* (e) *MR* (f) *PSC*.

of MoHFW, Government of India available up to 30th November, 2020, which may differ, in future.

5. Results and discussions

It is found from the derived results, as presented in Table 3, that Bihar positioned at the top of the table in case of taking

Table 2
Fuzzy rule base.

PSC		*PD* is Low								
		RR								
		Low			Medium			High		
NTM	*CCM*	*MR*			*MR*			*MR*		
		Low	Medium	High	Low	Medium	High	Low	Medium	High
Low	Low	Poor	Poor	Poor	Poor	Poor	Poor	Ordinary	Poor	Poor
	Average	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor
	High	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor
Average	Low	Ordinary	Poor	Poor	Ordinary	Poor	Poor	Ordinary	Ordinary	Poor
	Average	Poor	Poor	Poor	Ordinary	Poor	Poor	Ordinary	Poor	Poor
	High	Poor	Poor	Poor	Poor	Poor	Poor	Ordinary	Poor	Poor
High	Low	Excellent	Ordinary	Poor	Excellent	Ordinary	Poor	Excellent	Excellent	Ordinary
	Average	Ordinary	Poor	Poor	Ordinary	Poor	Poor	Ordinary	Poor	Poor
	High	Ordinary	Poor	Poor	Ordinary	Poor	Poor	Excellent	Ordinary	Poor
PSC		*PD* is Average								
		RR								
		Low			Medium			High		
NTM	*CCM*	*MR*			*MR*			*MR*		
		Low	Medium	High	Low	Medium	High	Low	Medium	High
Low	Low	Ordinary	Poor	Poor	Ordinary	Poor	Poor	Excellent	Ordinary	Poor
	Average	Ordinary	Poor	Poor	Ordinary	Poor	Poor	Ordinary	Poor	Poor
	High	Poor	Poor	Poor	Poor	Poor	Poor	Ordinary	Poor	Poor
Average	Low	Excellent	Ordinary	Poor	Excellent	Ordinary	Poor	Ordinary	Ordinary	Ordinary
	Average	Ordinary	Ordinary	Poor	Excellent	Ordinary	Poor	Excellent	Ordinary	Poor
	High	Ordinary	Poor	Poor	Ordinary	Poor	Poor	Ordinary	Poor	Poor
High	Low	Excellent	Excellent	Poor	Excellent	Excellent	Poor	Excellent	Excellent	Ordinary
	Average	Excellent	Ordinary	Poor	Excellent	Excellent	Poor	Excellent	Excellent	Poor
	High	Ordinary	Ordinary	Poor	Ordinary	Poor	Poor	Excellent	Poor	Poor
PSC		*PD* is High								
		RR								
		Low			Medium			High		
NTM	*CCM*	*MR*			*MR*			*MR*		
		Low	Medium	High	Low	Medium	High	Low	Medium	High
Low	Low	Excellent	Ordinary	Poor	Excellent	Ordinary	Poor	Excellent	Excellent	Ordinary
	Average	Ordinary	Ordinary	Poor	Excellent	Ordinary	Poor	Excellent	Poor	Poor
	High	Poor	Poor	Poor	Ordinary	Ordinary	Poor	Ordinary	Poor	Poor
Average	Low	Excellent	Excellent	Ordinary	Excellent	Excellent	Ordinary	Excellent	Excellent	Excellent
	Average	Excellent	Excellent	Ordinary	Excellent	Excellent	Ordinary	Excellent	Excellent	Ordinary
	High	Excellent	Ordinary	Ordinary	Excellent	Ordinary	Ordinary	Excellent	Ordinary	Ordinary
High	Low	Excellent	Excellent	Ordinary	Excellent	Excellent	Ordinary	Excellent	Excellent	Excellent
	Average	Excellent	Excellent	Ordinary	Excellent	Excellent	Ordinary	Excellent	Excellent	Ordinary
	High	Excellent	Excellent	Ordinary	Excellent	Ordinary	Ordinary	Excellent	Ordinary	Excellent

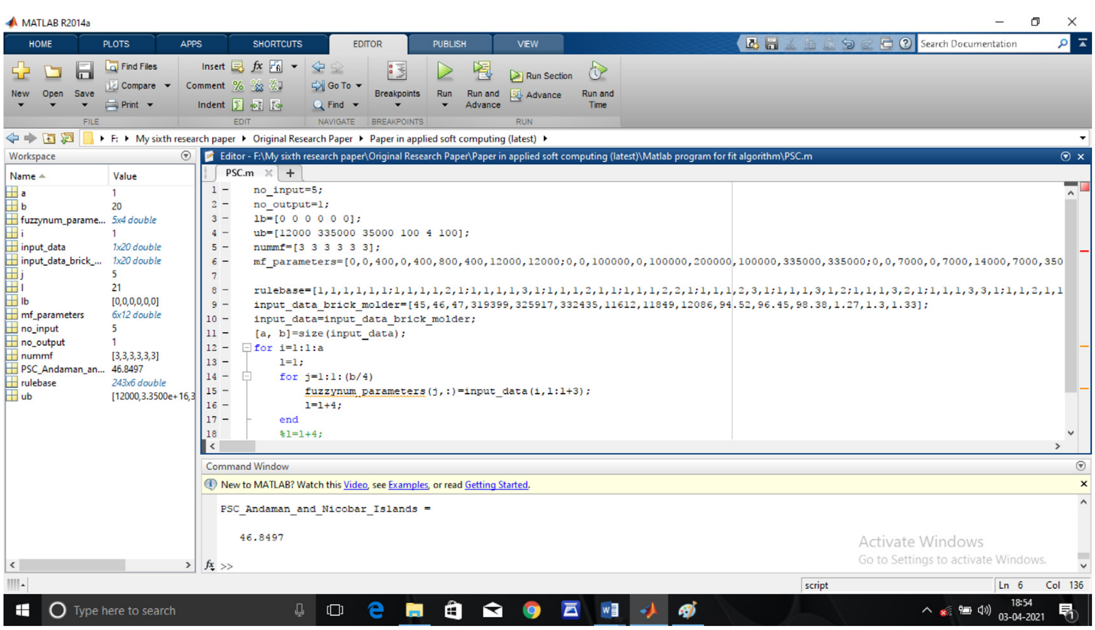


Fig. 5. A snapshot of MATLAB programming for the Evaluation of *PSC* of Andaman and Nicobar Islands.

preventive measures against COVID-19 with *PSC* of 75.7746. In spite of being densely populated state, Bihar, recorded low number of confirmed COVID-19 cases (1959 per million) along with very high recovery rate of 97.15% and low mortality rate of 0.54%. Also, it is the fact that the Assembly election was held in Bihar in October, 2020. So, it might be assumed that the state government of Bihar tightened up the grip over the pandemic of COVID-19; and as a result, a downfall in the active cases and mortality rate of COVID-19 was recorded in Bihar. It is also the fact that the recovery rate from COVID-19 was also found high in Bihar due to the increase of corona-dedicated beds and ICUs in the hospitals.

Table 3
Achieved results through the proposed methodology.

State/UT	*PSC*	Rank
Andaman and Nicobar Islands	46.8497	23
Andhra Pradesh	60.6695	10
Arunachal Pradesh	74.6466	5
Assam	75.0416	4
Bihar	**75.7746**	**1**
Chandigarh	55.9679	13
Chhattisgarh	41.1934	25
Dadra and Nagar Haveli and Daman and Diu	75.6282	2
Delhi	53.6759	17
Goa	22.5984	32
Gujarat	40.3565	27
Haryana	68.0894	8
Himachal Pradesh	34.2012	29
Jammu and Kashmir	56.3987	12
Jharkhand	66.9933	9
Karnataka	41.0502	26
Kerala	75.5097	3
Ladakh	**19.6694**	**35**
Madhya Pradesh	31.3055	30
Maharashtra	21.5832	33
Manipur	49.8450	22
Meghalaya	52.6629	18
Mizoram	55.8357	15
Nagaland	45.3849	24
Odisha	70.9396	7
Puducherry	59.7758	11
Punjab	27.9819	31
Rajasthan	50	19
Sikkim	21.5425	34
Tamil Nadu	55.9669	14
Telangana	72.1552	6
Tripura	54.5099	16
Uttar Pradesh	50	20
Uttarakhand	36.3188	28
West Bengal	50	21

In Result Table 3, the UT in the western India, Dadra and Nagar Haveli and Daman and Diu, ranks just below the rank of Bihar with *PSC* of 75.6282. Though, Dadra and Nagar Haveli and Daman and Diu is a densely populated region in India, but the facts behind this ranking might be very low number of confirmed COVID-19 cases (3474 per million) along with highest recovery rate of 99.28% in India and very low mortality rate of 0.06%. The administrative bodies in Dadra and Nagar Haveli and Daman and Diu recognized the people as 'Corona Warriors' who have completely maintained the lockdown rules. Also, the administration built up a large number of quarantine centres and got successes in isolating the COVID-19 positive people by performing free and rapid COVID-19 tests.

The first COVID-19 positive case was found in Kerala. The state government of Kerala was performing very significant jobs both in administrative and ground level for fighting against COVID-19 during the complete lockdown periods. As a result, Kerala became one of the most progressing states in India for adapting preventive strategies against COVID-19. But, in the last week of August, Kerala celebrates the festival, called "Onam"; and after that a significant jump in the active COVID-19 cases was found. It is suspected that there might be an effect of celebrating that festival, in which gathering of a large number of people took place. As a result, Kerala faced worse effect of COVID-19 during that time. According to the Result Table 3, Kerala remains at the upper side of the table as rank 3rd position with *PSC* of 75.5097.

In spite of performing a high number of COVID-19 tests, an average number of confirmed COVID-19 cases (6200 per million) along with very high recovery rate of 96.99% and very low mortality rate of 0.46% were found in a state of eastern India, viz., Assam. Considering those facts, Assam belongs to the upper side of Table 3 as 4th, with *PSC* of 75.0416. More than 1000 medical teams had been appointed in Assam for screening and monitoring the people having seasonal fevers. Further, the accredited social health activists and multi-purpose workers regularly monitored the home quarantined patients. The Government of Assam launched the mobile app 'COVASS' and 'COVID Suraksha' to spread the information related with COVID-19 and to monitor the patients who had suggested staying under home quarantine, respectively.

Further, Arunachal Pradesh, another state in the eastern India, also shows good fight against COVID-19 with *PSC* of 74.6466. Having conducting a high number of COVID-19 tests (2,38,779 per million) by the Government of Arunachal Pradesh, very low mortality rate of 0.33% were found there.

The state, Telangana, had performed a high number of COVID-19 tests. From the collected data, it is seen that this state recorded an average number of COVID-19 cases (7249 per million) along with very high recovery rate of 95.75% and very low mortality rate of 0.54%. Thus, Telangana remains at the top side of Table 3 with *PSC* of 72.1552. Proper face mask utilization, early detection and isolation of COVID-19 patients might also be the reasons for the improvement of COVID-19 situations in Telangana.

Odisha, situated in the eastern coast of India, is habituated for tackling natural disasters, which are frequently faced by this state. This state had shown its proficiency in managing the pandemic situation of COVID-19 as like other disasters. The *PSC* for this state is evaluated as 70.9396. From the data it is clear that the state Government of Odisha had performed a high number of COVID-19 tests (1,35,206 per million) to isolate the COVID-19 positive people. As a result, a high recovery rate of 97.78% and low mortality rate of 0.54% were found in Odisha.

Further, the state of Haryana, Jharkhand and Andhra Pradesh had also shown significant performances in controlling the spread of COVID-19 having *PSC* of 68.0894, 66.9933 and 60.6695, respectively. The input data corresponding to those states reflects higher ranking in the Result Table 3. So, those states and UTs can be considered as role model to others in fighting against the pandemic of COVID-19.

On the contrary, the UT of Ladakh which is situated at the north most region of India has the least *PSC* of 19.6694 in controlling the spread of COVID-19. Though, this state is least densely populated area of India, but it had a high number of confirmed COVID-19 cases (28,679 per million) with recovery rate of 88.17%. The deficiency of COVID-19 hospitals and medical facilities might be one of the primary reasons for this low scoring.

Sikkim, one of the north-eastern states of India, had also faced the worse effect of COVID-19 pandemic in the recent times having *PSC* of 21.5425. A large number of health workers were found as COVID-19 positive in Sikkim; and hence, the healthcare sectors of Sikkim faced major shortages of workforce during that times. As a result, high mortality rate of 2.17% were recorded in Sikkim.

The state of Maharashtra, situated in the western part of India, has also scored poor *PSC* of 21.5832 in controlling the spread of COVID-19. According to the COVID-19 statistics on 30th November, 2020, in Maharashtra around 20% of total COVID-19 positive cases and about 34% of total deceased cases of India were found. The city of Mumbai which is the capital of Maharashtra is also the financial capital of India. People from all the states and UTs in India come to Mumbai for their livelihood; and hence most number of migrated COVID-19 cases are found in Maharashtra. For that reason, it became difficult for Maharashtra to control the spread of COVID-19.

The pandemic situation of COVID-19 is worsening rapidly with an increase of confirmed COVID-19 positive cases (31,042 per million) in Goa, a state on the south-western coast in India. The government and private hospitals faced problems in increasing

Table 4
Pearson's correlation coefficient between the Achieved results and recovery rate of COVID-19.

State/UT	Achieved result	Recovery rate of COVID-19	Pearson's correlation coefficient
Andaman and Nicobar Islands	46.8497	96.45	
Andhra Pradesh	60.6695	98.23	
Arunachal Pradesh	74.6466	94.44	
Assam	75.0416	97.96	
Bihar	**75.7746**	97.15	
Chandigarh	55.9679	91.83	
Chhattisgarh	41.1934	90.05	
Dadra and Nagar Haveli and Daman and Diu	75.6282	99.28	
Delhi	53.6759	92.21	
Goa	22.5984	95.79	
Gujarat	40.3565	90.95	
Haryana	68.0894	90.84	
Himachal Pradesh	34.2012	76.8	
Jammu and Kashmir	56.3987	93.84	
Jharkhand	66.9933	97.15	
Karnataka	41.0502	95.89	0.4284
Kerala	75.5097	88.84	
Ladakh	**19.6694**	88.17	
Madhya Pradesh	31.3055	91.1	
Maharashtra	21.5832	92.36	
Manipur	49.8450	85.91	
Meghalaya	52.6629	92.51	
Mizoram	55.8357	89.91	
Nagaland	45.3849	89.66	
Odisha	70.9396	97.78	
Puducherry	59.7758	97.05	
Punjab	27.9819	91.64	
Rajasthan	50	88.3	
Sikkim	21.5425	92.46	
Tamil Nadu	55.9669	97.08	
Telangana	72.1552	95.75	
Tripura	54.5099	97.05	
Uttar Pradesh	50	94.04	
Uttarakhand	36.3188	91.67	
West Bengal	50	93.18	

the beds for COVID-19 patients. As a result, Goa was showing poor performance in controlling the spread of COVID-19 with *PSC* of 22.5984.

Further, the *PSC* corresponding to Punjab, Madhya Pradesh, Himachal Pradesh, and Uttarakhand are evaluated low, i.e., those states performed poorly in fighting against COVID-19. So, those states and UTs have lots of works to do for controlling the spread of COVID-19.

The validation of the proposed method is performed in the next section.

6. Validation of the proposed method and sensitivity analysis

To test the validity of the proposed model, Pearson's correlation coefficient is evaluated between the final results and recovery rate of COVID-19 corresponding to each state and UT, and is presented in Table 4. The value of Pearson's correlation coefficient is found as 0.4284. The positive value of Pearson's correlation coefficient establishes the consistency and steadiness of the processes followed in the proposed methodology.

Further, a sensitivity analysis is performed to observe the changes of the values of *PSC* by varying the tolerance ranges, l of the input arguments in Eq. (1), and is presented in Table 5. It is seen from Table 5 that the proposed estimation is sensitive under the tolerance range, l and preserves the same rank of the provinces as like Table 3 up to $l = 0.025$, which is a deviation of 2.5% from the exact values of the inputs. The changes of the values of *PSC* corresponding to different values of l are presented in Fig. 6.

7. Conclusions

The results in Table 3 show that 14 states and UTs in India have scored less than 50. This is very alarming concern to the Government of India to fight against the pandemic situation of COVID-19. Considering the pandemic situation, the proposed study would become very much helpful to the authorities of both central and state governments to identify the district wise containment zones of COVID-19 within a particular state by evaluating the district wise *PSC* of that state. The proposed study would also be helpful to the government authorities in starting intra-state, and inter-state public transport services and reopening educational institutes, theatres, cinema halls, museums, etc., in those states and UTs having higher value of *PSC*. The states and UTs having higher *PSC* score could be considered as role models to others for taking preventive strategies to get rid of from the pandemic situation of COVID-19. Further, the proposed research work might also be helpful for the government authorities of India for performing fair and equitable distribution of the economic packages announced by the central Government of India, and also for supplying medical equipment to the states and UTs having lower *PSC*.

It is clear now from the experiences of last few months that vaccine is the only solution for controlling the spread of COVID-19. But it is also becoming doubtful about the preventive power of the vaccines due to the appearance of different new strains of Corona virus. In fact, the world is now facing the challenges of second wave of COVID-19. In the month of July, 2020 WHO

Table 5
Changes of the values of *PSC* for different values of *l*.

State/UT	*PSC*											
	$l = 0.005$	$l = 0.01$	$l = 0.015$	$l = 0.02$	$l = 0.025$	$l = 0.03$	$l = 0.04$	…	$l = 0.07$	…	$l = 0.1$	…
Andaman and Nicobar Islands	46.6741	46.6419	46.611	46.8497	46.8744	47.0302	47.3257	…	48.0787	…	48.6883	…
Andhra Pradesh	63.2689	62.4052	61.4657	60.6695	59.9843	59.4694	58.7555	…	56.9319	…	55.4817	…
Arunachal Pradesh	74.6310	74.6367	74.6415	74.6466	74.6495	74.6536	74.6577	…	74.6569	…	74.6377	…
Assam	75.2693	75.1928	75.1163	75.0416	74.9698	74.8996	74.7615	…	74.3845	…	72.6897	…
Bihar	75.7582	75.7637	75.7692	75.7746	75.7801	75.7855	75.7964	…	75.8289	…	75.8611	…
Chandigarh	55.42	55.626	55.8247	55.9679	56.2019	56.3849	56.7330	…	57.6690	…	58.4739	…
Chhattisgarh	41.137	41.1605	41.1841	41.1934	41.2366	41.2393	41.2578	…	41.3653	…	41.7488	…
Dadra and Nagar Haveli and Daman and Diu	75.6140	75.6188	75.6237	75.6282	75.6334	75.6383	75.6479	…	75.6769	…	74.1079	…
Delhi	53.3223	53.4518	53.58	53.6759	53.83	53.9526	54.1907	…	54.8644	…	55.4855	…
Goa	21.6873	21.9942	22.3328	22.5984	23.0595	23.6026	24.6343	…	27.3492	…	29.6108	…
Gujarat	38.3986	39.3541	40.2263	40.3565	40.7522	40.9823	41.3545	…	42.3585	…	43.3654	…
Haryana	69.3681	68.9042	68.4645	68.0894	67.671	67.3146	66.6523	…	65.0681	…	63.9271	…
Himachal Pradesh	34.254	34.2363	34.2188	34.2012	34.1841	34.167	34.1333	…	34.0355	…	34.7909	…
Jammu and Kashmir	56.5329	56.4734	56.4164	56.3987	56.3045	56.2494	56.1409	…	55.6404	…	54.9794	…
Jharkhand	66.9605	66.9700	66.9792	66.9933	66.9975	67.0067	67.0247	…	67.0775	…	65.6925	…
Karnataka	38.4259	39.377	40.2475	41.0502	41.2301	42.4568	43.6608	…	46.4036	…	48.2471	…
Kerala	75.4967	75.5011	75.5054	75.5097	75.5143	75.5186	75.5273	…	75.4721	…	65.2688	…
Ladakh	19.1955	19.3398	19.4811	19.6694	20.7323	20.8625	21.1143	…	21.8589	…	22.5242	…
Madhya Pradesh	31.3025	31.3034	31.3045	31.3055	31.3065	31.3087	31.3092	…	31.3132	…	32.4368	…
Maharashtra	21.6454	21.6246	21.6038	21.5832	21.5631	21.5427	21.5025	…	21.3847	…	21.2782	…
Manipur	49.9823	49.9325	49.8884	49.8450	49.5035	49.2734	48.8741	…	47.9780	…	47.3412	…
Meghalaya	52.8786	52.798	52.7223	52.6629	52.5612	52.4921	52.3439	…	51.9474	…	51.5916	…
Mizoram	55.3128	55.5757	55.7028	55.8357	55.9621	56.1004	56.2428	…	56.6802	…	57.1256	…
Nagaland	45.3655	45.3712	45.3788	45.3849	45.4083	45.4157	45.4363	…	45.4798	…	45.5259	…
Odisha	71.2480	71.1431	71.0368	70.9396	70.8313	70.7298	70.5300	…	69.9589	…	69.4208	…
Puducherry	59.2286	59.4473	59.6547	59.7758	59.9533	60.2472	60.6115	…	61.5901	…	62.4188	…
Punjab	25.9868	26.8284	27.5462	27.9819	28.0222	28.0644	28.1421	…	28.3641	…	28.5739	…
Rajasthan	50	50	50	50	50	50	50	…	50	…	50	…
Sikkim	21.6307	21.5975	21.5649	21.5425	21.5001	21.4684	21.4057	…	21.3559	…	22.7267	…
Tamil Nadu	55.33	55.61	55.8134	55.9669	56.1113	56.2925	56.5111	…	57.3352	…	58.1232	…
Telangana	72.4909	72.3745	72.2584	72.1552	72.0368	71.9249	71.7094	…	71.0999	…	70.2683	…
Tripura	54.9080	54.81	54.6766	54.5099	54.4406	54.3261	54.1163	…	53.6008	…	53.2103	…
Uttar Pradesh	50	50	50	50	50	50	50	…	50	…	49.0732	…
Uttarakhand	36.0325	36.1320	36.2247	36.3188	36.4126	36.5059	36.6865	…	37.2093	…	37.6984	…
West Bengal	50	50	50	50	50	50	50	…	50	…	50	…

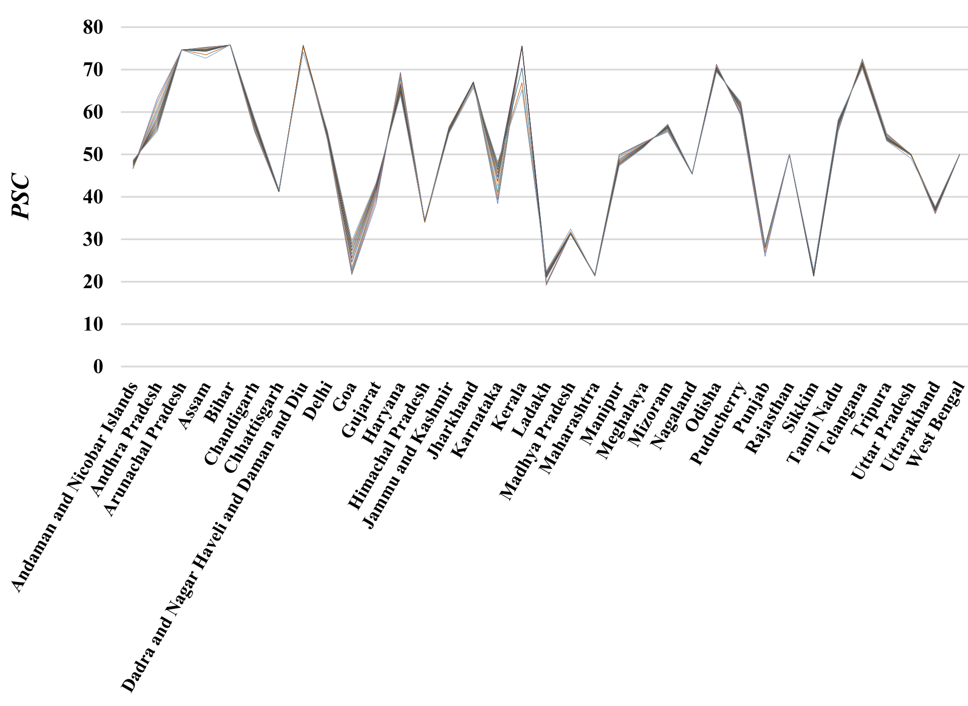


Fig. 6. The changes of the values of *PSC* by varying the tolerance ranges.

declared that 165 countries sharing up to 60% of the world population had signed an agreement of WHO COVAX plan in purpose of fair distribution of the licenced vaccines of COVID-19. But, for such a highly populated country like India, it might be difficult to organize fair and equitable distribution processes of the COVID-19 vaccines among the people. The proposed methodology would be helpful to build up the strategies for selecting the worse affected districts, states or UTs of India where the vaccines are needed to reach first than others, well in advance. Finally, the proposed research methodology may also be implemented in global interests by evaluating the *PSC* of each country which is affected by COVID-19 for taking preventive strategies, announcing economic packages, supplying medical equipment and distributing COVID-19 vaccines, etc. From that view point, the developed model is applicable for not only in India but also other countries for evaluation of their current COVID-19 status.

In spite of its usefulness in assessing recent situations and for building up strategies to prevent the spread of COVID-19, there are some potential limitations of the proposed study which are described as follows:

- Although the proposed method possesses the input values as fuzzy numbers, but it is unable to provide the fuzzy outcomes. Other kind of inference system may be used for this purpose.
- Here, the obtained results represent the current status of the provinces due to COVID-19. But, the proposed method is unable to provide any solution to overcome from that pandemic situation.
- The proposed model is designed in the context of pandemic situation of COVID-19 in India. So, direct application of the methodology may not provide accurate results for other countries. However, modifications of the input variables, MFs, rule base may increase the reliability of the proposed method for assessing current pandemic scenario of different parts of a country.

Some future research scopes of this article are summarized as follows:

– In this article, *PSC* of each state and UT in India is evaluated by generating the MFIS with five input parameters, viz., *PP*, *NTM*, *CCM*, *RR*, and *MR*. But depending on the context of research, some other factors such as daily new cases, serious or critical cases of COVID-19, rate of vaccinations, etc., can be considered as input parameters which may enrich the process of MFIS.
– The proposed methodology can also be applicable in estimating the performance of a country, state or UT against other serious virus affected diseases like mumps, rubella, hepatitis, measles, etc., which will be helpful in taking preventive measures, well in advance.
– The proposed method may also be extended in several branches of fuzzy environments, viz., *q*-rung orthopair fuzzy, intuitionistic fuzzy, Pythagorean fuzzy, and other domains.

Finally, it is expected that the proposed method would be helpful to identify the COVID-19 affected regions and to alarm that zone to take preventive measures, well in advance, so that the spread of COVID-19 can be minimized.

CRediT authorship contribution statement

Bappaditya Ghosh: Software, Formal analysis, Investigation, Data curation, Writing - original draft, Review. **Animesh Biswas:** Conceptualization, Methodology, Formal analysis, Investigation, Writing - review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors remain very much grateful and appreciable to the learned reviewers for their constructive comments and helpful suggestions to improve the quality of the manuscript.

References

[1] A. Behnood, E.M. Golafshani, S.M. Hosseini, Determinants of the infection rate of the COVID-19 in the U.S. using ANFIS and virus optimization algorithm (VOA), Chaos Solitons Fractals 139 (2020) 110051, http://dx.doi.org/10.1016/j.chaos.2020.110051.
[2] S. Lahmiri, S. Bekiros, The impact of COVID-19 pandemic upon stability and sequential irregularity of equity and cryptocurrency markets, Chaos Solitons Fractals 138 (2020) 109936, http://dx.doi.org/10.1016/j.chaos.2020.109936.
[3] T. Sun, Y. Wang, Modeling COVID-19 epidemic in heilongjiang province, China, Chaos Solitons Fractals 138 (2020) 109949, http://dx.doi.org/10.1016/j.chaos. 2020.109949.
[4] R.M.A. Velásquez, J.V.M. Lara, Forecast and evaluation of COVID-19 spreading in USA with reduced-space Gaussian process regression, Chaos Solitons Fractals 136 (2020) 109924, http://dx.doi.org/10.1016/j.chaos.2020.109924.
[5] M.H.D.M. Ribeiro, R.G. da Silva, V.C. Mariani, L.D.S. Coelho, Short-term forecasting COVID-19 cumulative confirmed cases: perspectives for Brazil, Chaos Solitons Fractals 135 (2020) 109853, http://dx.doi.org/10.1016/j.chaos.2020.109853.
[6] H.A. Rothan, S.N. Byrareddy, The epidemiology and pathogenesis of coronavirus disease (COVID-19) outbreak, J. Autoimmun. 109 (2020) 102433, http://dx.doi.org/10.1016/j.jaut.2020.102433.
[7] W. Wang, T. Tang, F. Wei, Updated understanding of the outbreak of 2019 novel coronavirus (2019-nCoV) in Wuhan, China, J. Med. Virol. 92 (4) (2020) 441–447.
[8] COVID-19: 99% active cases are with mild symptoms, Down To Earth, 2020, https://www.downtoearth.org.in/news/health/covid-19-99-active-cases-are-with-mild-symptoms-72757. (Accessed 11 August 2020).
[9] Coronavirus now less fatal 90% patients have mild symptoms: AIIMS Director, Hindustan Times, 2020, https://www.hindustantimes.com/india-news/coronavirus-now-less-fatal-90-patients-have-mild-symptoms-aiims-director/story-axggNvvJwUkjRz9hTpYQ8N.html. (Accessed 3 June 2020).
[10] Official website of World Health Organization, 2020, https://www.who.int/health-topics/coronavirus#tab=tab_1. (Accessed 30 November 2020).
[11] Z. Wu, J.M. McGoogan, Characteristics of and important lessons from the coronavirus disease 2019 (COVID-19) outbreak in China: summary of a report of 72314 cases from the Chinese center for disease control and prevention, J. Am. Med. Accoc. 323 (13) (2020) 1239–1242.
[12] L. Xia, J. Chen, T. Friedemann, Z. Yang, Y. Ling, X. Liu, S. Lu, T. Li, Z. Song, W. Huang, Y. Lu, S. Schröder, H. Lu, The course of mild and moderate COVID-19 infections—The unexpected long-lasting challenge, Open Forum Infect. Dis. 7 (9) (2020) http://dx.doi.org/10.1093/ofid/ofaa286.
[13] Q. Ye, B. Wang, J. Mao, The pathogenesis and treatment of the 'Cytokine Storm' in COVID-19, J. Infect. 80 (6) (2020) 607–613.
[14] S. Murthy, C.D. Gomersall, R.A. Fowler, Care for critically Ill patients with COVID-19, J. Am. Med. Accoc. 323 (15) (2020) 1499–1500.
[15] I. Hamming, W. Timens, M.L.C. Bulthuis, A.T. Lely, G.J. Navis, H. van Goor, Tissue distribution of ACE2 protein, the functional receptor for SARS coronavirus. A first step in understanding SARS pathogenesis, J. Pathol. 203 (2) (2004) 631–637.
[16] K. Renu, P.L. Prasanna, A.V. Gopalakrishnan, Coronaviruses pathogenesis, comorbidities and multi-organ damage - a review, Life Sci. 255 (2020) 117839, http://dx.doi.org/10.1016/j.lfs.2020.117839.
[17] M. Ciotti, M. Ciccozzi, A. Terrinoni, W.-C. Jiang, C.-B. Wang, S. Bernardini, The COVID- 19 pandemic, Crit. Rev. Clin. Lab. Sci. (2020) http://dx.doi.org/10.1080/10408363.2020.1783198.
[18] M. Togacar, B. Ergen, Z. Z. Comert, COVID-19 detection using deep learning models to exploit Social Mimic Optimization and structured chest X-ray images using fuzzy color and stacking approaches, Comput. Biol. Med. 121 (2020) 103805, http://dx.doi.org/10.1016/j.compbiomed.2020.103805.
[19] K. Govindan, H. Mina, B. Alavi, A decision support system for demand management in healthcare supply chains considering the epidemic outbreaks: A case study of coronavirus disease 2019 (COVID-19), Transp. Res. E 138 (2020) 101967, http://dx.doi.org/10.1016/j.tre.2020.101967.

[20] A. Mardani, M.K. Saraji, A.R. Mishra, P. Rani, A novel extended approach under hesitant fuzzy sets to design a framework for assessing the key challenges of digital health interventions adoption during the COVID-19 outbreak, Appl. Soft Comput. 96 (2020) 106613, http://dx.doi.org/10.1016/j.asoc.2020.106613.

[21] M.R. Mahmoudi, D. Baleanu, Z. Mansor, B.A. Tuan, K.-H. Pho, Fuzzy clustering method to compare the spread rate of Covid-19 in the high risks countries, Chaos Solitons Fractals 140 (2020) 110230, http://dx.doi.org/10.1016/j.chaos.2020.110230.

[22] A. Behnood, E.M. Golafshani, S.M. Hosseini, Determinants of the infection rate of the COVID-19 in the U.S. using ANFIS and virus optimization algorithm (VOA), Chaos Solitons Fractals 139 (2020) 110051, http://dx.doi.org/10.1016/j.chaos.2020.110051.

[23] K.T. Ly, A COVID-19 forecasting system using adaptive neuro-fuzzy inference, Finance Res. Lett. (2020) 101844, http://dx.doi.org/10.1016/j.frl.2020.101844.

[24] R. Singh, S. Avikal, COVID-19: A decision-making approach for prioritization of preventive activities, Int. J. Healthc. Manag. (2020) http://dx.doi.org/10.1080/20479700.2020.1782661.

[25] L. Ocampo, K. Yamagishi, Modeling the lockdown relaxation protocols of the philippine government in response to the COVID-19 pandemic: An intuitionistic fuzzy DEMATEL analysis, Socioecon. Plann. Sci. 72 (2020) 100911, http://dx.doi.org/10.1016/j.seps.2020.100911.

[26] Z. Ren, H. Liao, Y. Liu, Generalized Z-numbers with hesitant fuzzy linguistic information and its application to medicine selection for the patients with mild symptoms of the COVID-19, Comput. Ind. Eng. 145 (2020) 106517, http://dx.doi.org/10.1016/j.cie.2020.106517.

[27] X. Li, H. Liao, Z. Wen, A consensus model to manage the non-cooperative behaviors of individuals in uncertain group decision making problems during the COVID-19 outbreak, Appl. Soft Comput. 99 (2021) 106879, http://dx.doi.org/10.1016/j.asoc.2020.106879.

[28] W.M. Shaban, H. Asmaa, A.H. Rabie, A.I. Saleh, M.A. Abo-Elsoud, Detecting COVID-19 patients based on fuzzy inference engine and Deep Neural Network, Appl. Soft Comput. 99 (2021) 106906, http://dx.doi.org/10.1016/j.asoc.2020.106906.

[29] L. Aggarwal, P. Goswami, S. Sachdeva, Multi-criterion intelligent decision support system for COVID-19, Appl. Soft Comput. 101 (2021) 107056, http://dx.doi.org/10.1016/j.asoc.2020.107056.

[30] N. Ghorui, A. Ghosh, S.P. Mondal, M.Y. Bajuri, A. Ahmadian, S. Salahshour, M. Ferrara, Identifcation of dominant risk factor involved in spread of COVID-19 using hesitant fuzzy MCDM methodology, Results Phys. 21 (2021) 103811, http://dx.doi.org/10.1016/j.rinp.2020.103811.

[31] A.R. Mishra, P. Rani, R. Krishankumar, K.S. Ravichandran, S. Kar, An extended fuzzy decision-making framework using hesitant fuzzy sets for the drug selection to treat the mild symptoms of Coronavirus Disease 2019 (COVID-19), Appl. Soft Comput. 103 (2021) 107155, http://dx.doi.org/10.1016/j.asoc.2021.107155.

[32] F. Ecer, D. Pamucar, MARCOS technique under intuitionistic fuzzy environment for determining the COVID-19 pandemic performance of insurance companies in terms of healthcare services, Appl. Soft Comput. 104 (2021) 107199, http://dx.doi.org/10.1016/j.asoc.2021.107199.

[33] M.K. Sharma, N. Dhiman, Vandana, V.N. Mishra, Mediative fuzzy logic mathematical model: A contradictory management prediction in COVID-19 pandemic, Appl. Soft Comput. 105 (2021) 107285, http://dx.doi.org/10.1016/j.asoc.2021.107285.

[34] E.H. Mamdani, S. Assilian, An experiment in linguistic synthesis with a fuzzy logic controller, Int. J. Man-Mach. Stud. 7 (1) (1975) 1–13.

[35] K. Pearson, Notes on regression and inheritance in the case of two parents, Proc. R. Soc. Lond. 58 (1895) 240–242.

[36] Office of the Registrar General & Census Commissioner, India, Ministry of Home Affairs, Government of India, 2020, https://censusindia.gov.in. (Accessed 30 November 2020).

[37] Ministry of Health and Family Welfare, Government of India, 2020, https://www.mohfw.gov.in. (Accessed on 30 November 2020).

[38] Worldometer, info., COVID-19 coronavirus pandemic, Worldometers, 2020, https://www.worldometers.info/coronavirus. (Accessed on 30 November 2020).

[39] D. Majumder, J. Debnath, A. Biswas, Risk analysis in construction sites using fuzzy reasoning and fuzzy analytic hierarchy process, Procedia Technol. 10 (2013) 604–614.

[40] M. An, Y. Chen, C.J. Baker, A fuzzy reasoning and fuzzy analytical hierarchy process based approach to the process of railway risk information: A railway risk management system, Inform. Sci. 181 (2011) 3946–3966.