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Review article

A BRIEF REVIEW OF APPLICATION OF FUZZY TECHNIQUES TOWARDS COVID-19 PANDEMIC ANALYSIS

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Abstract: COVID-19 continued to spread fast throughout the world since its outbreak from December, 2019. Most of the affected countries faced a huge challenge in managing the infection rate and providing the required treatments to the infected ones, which led the researchers to investigate the necessary causes and solutions regarding the infections. Researchers were also involved in estimating and forecasting the future trends and effects of COVID-19 as prediction is crucial to handling the unwanted pandemic situation. The uncertain nature of COVID-19 inspired researchers to adopt fuzzy sets for managing the pandemic. Researchers introduced various fuzzy logic-based models to analyze the pandemic situation and predict future directions. The aim of this study is to present an organized literature review to study the applicability of fuzzy set theory and its extensions in order to manage the pandemic situation. The COVID-19 related articles are grouped into six domains related to predictions (S1), related factor analysis (S2), prevention, control and managing the situation (S3), analysis of treatment (S4), after effects (S5), and distribution of vaccine (S6). Insights of the published articles are depicted using tabular representations. We have analyzed the significance of various categories to explore their societal impacts. This comprehensive review reveals a greater emphasis on experimenting

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with strategies to control the impact of COVID-19, while there is less focus on studying the effects of COVID-19, particularly in terms of vaccine distribution. The domain-wise data analysis from current research presents various approaches and directions. Additionally, this study predicts future research directions for each of the mentioned categories. Researchers initially focused on prevention, prediction, and control of COVID-19. The analysis reports illustrate the effects of COVID-19 factors and their social impacts on communities.

Keywords: COVID-19, fuzzy set theory, pandemic management, literature review.

MSC: 86A17, 85A99, 91E45, 93C42.

1. INTRODUCTION

Since December 2019, coronavirus has created a huge panic among the human beings due to its highly uncertain mutation capability and pandemic nature which has thrown a challenge to the entire medical system. Scientists and medical experts are struggling to suppress the fast spreading of the virus and to save the mankind from this kind of unprecedented situation. Besides coronavirus, a few pandemics such as Spanish flu (Influenza A/H1N1), Hong Kong flu (Influenza A/H3N2), Asian flu (Influenza A/H2N2), MERS (Middle East Respiratory Syndrome), Swine flu (Influenza A/H1N1), and severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) were observed from the beginning of 19th century [1]. COVID-19 is considered as another form of SARS-CoV-2. Among all the pandemics, COVID-19 has been considered as the most devastating one for the entire world, which causes respiratory infections with symptoms ranging from the normal cold to more severe diseases. The intensity of infection and maliciousness of coronavirus are higher than the other flu. Coronaviruses can cause severe damage to both animals as well as humans. Basically, COVID-19 is a special category of viruses with high mutant capability, which is a member of large family of viruses [2]. COVID-19 was unfamiliar prior to the outburst in Wuhan, in December 2019, but is now causing a pandemic distressing most countries globally. On January 30, 2020, WHO declared that the COVID-19 outbreak constitutes a PHEIC (Public Health Emergency of International Concern) and consequently WHO initiated the highest level of urgency to protect the COVID-19. On March 11, 2020, WHO did the evaluation that COVID-19 could be considered as a pandemic [3]. The affected persons of COVID-19 are the primary sources to transmit the disease to other persons through respiratory droplets, coughing from sneezing, and talking [4]. The tentative period to replicate the virus is from the 2nd days to 14th days of the infection with a median of 5 days. The virus is spread by aerosols which contain the dirty fomites. Recently it was noticed that the COVID-19 can be transmitted from those having mild to severe symptoms and also from those who are pre-symptomatic or asymptomatic [5]. The onset and duration of viral shedding and the period of infectiousness for COVID-19 are not yet precisely known. The epidemiology of COVID-19 changed rapidly through the third wave. As recorded on November 6, 2020, there were more than 48 million cases and 1.2 million deaths globally [6]. Throughout the world, a large number of researchers are working together to control the spread of disease, tracing the spread of disease, investigating critical interventions, allocating vital medical supplies and guiding the development of vaccines and therapeutics.

Initially there were no specific treatments for the COVID-19 infected patients. The health experts provided the supplementary treatment to the COVID-19 infected patients based on their current symptoms and clinical status. This type of supplementary care may or may not be effective. Initially, there were no appropriate prediction techniques to estimate the number of occurrence of patients in future and to measure the spreading intensity of the disease [2]. Most of the health experts utilized their past experiences related to influenza and few investigations on HIV (human immunodeficiency virus) infection and SARS in order to provide the necessary treatment to the affected patients [3,7]. Consequently, the entire medical system faced some unexpected challenges and several threats to control the pandemic nature of COVID-19. Moreover, the authorized regulatory bodies struggled to collect the actual data and real information due to some obvious reasons. The researchers started investigations in various ways to manage this kind of unwanted situation, where fuzzy set or extended fuzzy sets played a crucial role because of their inherent capability to deal with the uncertainty.

Fuzzy Sets (FS) introduced by the Zadesh [8] in 1965 to manage the uncertainty with in data set or to develop the data sets. The basic idea behind the fuzzy system is the belongingness of the elements within the predefined region. The belongingness is measured by the parameter called membership degree or membership value. The fuzziness nature of an object is represented through the use of membership degree. The fuzzy set-based systems have been proved to be very supportive to deal the uncertainties which is existing within the system. The Fuzzy logic-based system has the capability to generate the most effective solution to the relatively complex issues. The concept of the type-2 fuzzy set (T2FS) was introduced by Zadeh [9] as the higher version of the ordinary FSs or type-1 fuzzy set. In the T2FS, the membership grade itself is considered as the type-1 fuzzy sets. T2FS can manage the situation more comfortably, where type-1 FS is unable to measure the accurate membership function. Intuitionistic fuzzy set (IFS) was introduced by Atanassov [10] as a generalization and extension of Zadeh's fuzzy set theory [8]. The IFS manage such kind of situations where a human being can represent the degree of belonging of an element to a set as well as degree of non-belonging of an element to a set. Atanassov et al. [11] further modified IFS and introduced the new sophisticated concept denoted as interval valued intuitionistic fuzzy sets (IVIFS), where the membership and non-membership values belong to some interval instead of having exact values. To resolve the ambiguous nature of artificial neural network (ANN), Jang [12] in 1993 explored Neuro-Fuzzy Systems (NFS). The fundamental concepts of the NFS is to represent the human-like reasoning style of fuzzy systems with the help of neural networks. NFS delivers powerful universal approximations to discover interpretable IF-THEN rules. The use of NFS is found in many sectors in our social and technological life. In order to extract the advantages of fuzzy sets and soft sets, Maji et al. [13] presented the flexible concept of the Fuzzy Soft Sets (FSS) by embedding the ideas of fuzzy sets within the domain of soft sets. This representation is more realistic as it involves uncertainty in the selection of a fuzzy set corresponding to each value of the parameter. Maji et al. [13] modified FSS and introduced the novel concept of intuitionistic fuzzy soft sets (IFSS) by merging the notion of soft set theory with the IFS theory [11]. Torra [14] extended the fuzzy sets into Hesitant Fuzzy Sets (HFS). This concept was introduced from the motivation of the common difficulties that frequently arise when the membership degree of an element must be recognized but rather because there are some possible values that make to hesitate about which one would be the right one. Yager [13] developed multi-fuzzy set (MFS). An element of a MFS can appear many times with possibly the same or different membership values. The MFS theory[15] is an extension of theories of fuzzy sets, L-fuzzy sets [16], and intuitionistic fuzzy sets [10]. Another alternative concept of MFS defined as fuzzy multi set (FMS) was studied in [17,15], which is the generalization of conventional multi sets with the help of fuzzy sets theory [8]. A significant revolution was initiated in domain of fuzzy sets by the Bui et al. [18], where the authors [18] extended the concepts of FS and IFS into another special form of fuzzy set known as picture fuzzy set (PFS), in which the neutral membership grade was considered along with two others decided positive and negative membership grade. PFSs based models are found to be more feasible in situations when we face human opinions involving more answers of types: yes, abstain, no, refusal [19]. O. Montiel et al. [20] introduced the concepts of mediative fuzzy logic (MFL) as an extension of intuitionistic fuzzy logic [10]. The information which was provided by experts can have big variations and sometimes can be contradictory. For managing this challenging situation, the contradiction fuzzy set was used. The MFL was the generalized form of the traditional fuzzy logic which can handle contradiction and doubtful information. Senapati and Yager [21] incorporated the novel concept of fermatean fuzzy sets (FFS) as a tool for managing the uncertain information more easily[22]. The newly introduced fuzzy set was most effective in the decision making process. The fundamental concepts of the FFS was derived from the IFS and pythagorean fuzzy sets and it provided more flexibility. The FFS was defined by the three components like the degree of membership (α), the degree of non-membership (β), and the degree of indeterminacy (π). Another modified version of fuzzy set known as square root fuzzy sets (denoted as SR- fuzzy sets) was introduced by Al-shami [23]. SR fuzzy sets effectively handle the situations where the degree of membership is highly skewed towards the extremes. Moreover, Al-shami [24] developed a special type of orthopair fuzzy sets denoted as (2,1)-Fuzzy sets that expands the space of membership and non-membership degrees more than intuitionistic fuzzy sets. (2,1)-fuzzy sets provides a more nuanced representation of uncertainty than traditional binary sets. S. Ashraf et al. [25] introduced an advanced tool of the FSs, IFSs and PFSs, called as the spherical fuzzy sets (SFSs). This modified version of fuzzy set can manage the uncertainty and complicated data in decision making process. The SFSs is the successful framework of the fuzzy system that can overcome the limitation of existing fuzzy set theories when total membership degrees be more than one. The SFS maintain the constraint that the summation of the squares of a positive grade, of an abstinence grade and of a negative grade should be restricted [26]. In addition of fuzzy set and its various extensions, rough set theory was also gained much popularity to solve the uncertain real life problems in the context of COVID-19 [27,28].

Since the outbreak of COVID-19, numerous researchers have explored various strategies to control the infection and improve recovery rates. A significant focus has been on fuzzy set-based strategies, which include extensions of fuzzy sets, fuzzy logic, fuzzy rule-based systems, and other hybrid techniques involving fuzzy sets. To fully understand the research efforts utilizing fuzzy set theory in addressing the COVID-19 pandemic, an extensive review is essential for future researchers to generate more robust ideas. To the best of our knowledge, there is currently no comprehensive resource detailing COVID-19-related research employing fuzzy set theory, which could facilitate alternative research methods. Recognizing that understanding the benefits, limitations, and applications of existing research is crucial for further advancements, this article presents a literature survey assessing the use of fuzzy set theories in managing the pandemic related to COVID-19. The primary objective of this work is to provide an overview of the applications of fuzzy logic and theories in the diagnosis, treatment, management, and control of COVID-19. This information will assist researchers actively engaged in this field. Additionally, this study serves as a valuable resource for both novice and expert researchers due to its comprehensive exploration of current issues. New researchers can rely on this study to examine existing work in a more insightful way, potentially leading to improved accuracy in their findings. Most articles referenced in this paper were sourced from Elsevier, with additional contributions from reputable journals such as Hindawi, MDPI, and IOS Press. These articles are categorized into six domains based on COVID-19-related activities and functionalities: prediction (S1), factor analysis (S2), prevention, control, and management (S3), analysis of treatment (S4), aftereffects (S5), and vaccine distribution (S6). The discussions surrounding COVID-19 and related activities are conceptually illustrated through five logical diagrams. Additionally, statistical data is presented using eight tables and four figures. The important contribution of this proposed article is as follows:

- To encapsulate recently published article on COVID-19 in the domain of fuzzy system.
- To show the roadmap of the research activities for the pandemic of COVID-19 from the outbreak to still date.
- To highlight the significant publications of COVID-19 in the domain of fuzzy system.
- To provide analysis and synthesis of the published research activities. Also, we include a summary of proposed models and approaches using fuzzy system related to COVID-19 under each category.
- To point out some related uncertain problems, future trend of COVID-19 and probable research trajectory using fuzzy system.

Rest of the article is organized as follows. There are six Sections, indexing from 2 to 7 for presenting the category wise discussions on fuzzy sets and extended fuzzy sets towards COVID-19 pandemic analysis. In Section 2, we briefly discuss different types of proposed techniques to predict the COVID-19 infection (S1). Section 3 highlights the incorporated approaches for analyzing the relevant factors of COVID-19 (S2). Next, the fundamental concepts for the prevention, control and managing the infection of COVID-19 (S3) are presented in Section 4. Section 5 shows the fuzzy set based approaches used for the treatments of COVID-19 patients (S4). Section 6 contains the research works which includes the after effects of COVID-19 (S5). Section 7 explains the methods related with distributing of the COVID-19 vaccine (S6). Section 8 presents the necessary discussions related to the functionalities, applications and limitations of fuzzy set and extended fuzzy set based methodologies for managing the COVID-19 situation. Finally, Section 9 contains a brief conclusion and future outline.

2. PREDICTION OF COVID-19

In this Section, we explore and analyse the research studies associated with COVID-19 prediction. This section has been divided into eight sub-sections based on the used concepts.

2.1. Commonly used prediction tools

Since COVID-19 is fully unpredicted in nature, so the health experts find it difficult to determine the presence of the virus in human body by the diagnosis of clinical trials at the early stage of the symptoms [3,29]. Initially the RT-PCR (Reverse Transcription

Polymerase Chain Reaction) a nucleic acid-based test was the only option to determine COVID-19 infected patients. When RT-PCR fails to detect one COVID-19 infected patient, then the patient does not get any medical treatment to recover from the virus infection. Such uninformed patients are extremely dangerous and act as active elements to spread COVID-19 within the surrounding community. Besides RT-PCR, the CT scan image and some pathology based clinical tests are also used to predict COVID-19 infection which are considered as more reliable, robust and generate the final result quickly [30,31]. The overall COVID-19 diagnosis technique based on active symptoms are given in Fig 1. Rapid and precise detection of COVID-19 is very much important factor to reduce the active cause of infection as well as for taking related precaution, and to provide the proper treatment in time to recover from the disease. The researchers used various technique such as machine learning, image analysis, expert systems, inference system, soft computing techniques along with fuzzy set theories to detect the COVID-19 infection patients [32]. In this context, Al-shami et al. [27] suggested an algorithm that used a variety of neighbourhoods, including Cj-neighborhoods, to safeguard medical personnel against exposure of COVID-19. Once some patients are detected positive, immediately those patients are isolated to break the chain of transmission. This section has discussed some of the relevant fuzzy sets theory-based articles which are used for prediction of COVID-19. A summary of the various approaches used for the purpose of prediction of COVID-19 is depicted in Table 1.

2.2. Predictions using ANN based methods

To enhance the accuracy and reduce processing time of the test-based identification of the virus infected patient, Shaban et al. [32] proposed a novel diagnose strategy through the combination of deep neural network and fuzzy inference engine which worked as fast and precise based on patient's laboratory test reports. To predict COVID-19 infected patients, Nivethitha et al. [33] introduced artificial neural network (ANN) based diagnosis process which was executed based on artificial intelligence algorithm and fuzzy relations using biological signal. The authors [33] considered various heart dysfunctions to generate the signal of heart pulse and extracted various features like largest Lyapunov exponent, spectral entropy, detrended fluctuation analysis and Poincare plot in order to classify the patients. The authors claimed the ANN based model to be the most convenient due to having less input variables for analyzing.

2.3. Prediction using fuzzy rule-based systems

Once some persons are flu infected, then those patients may be either COVID-19 positive or negative, which is normally decided by the past experience. In this regard, the authors [34] developed an intuitionistic fuzzy set based model to find the patients are COVID-19 affected or not. In the Kozae et al. [34], the patient's conditions were represented by five COVID-19 related parameters (Headache, Temperature, Cough, Lost smell sense and Almond pain) which was obtained from the clinical test. Similar approach was considered in [35], where the authors introduced intelligent fuzzy inference system to identify the COVID-19 infected patients through the basic diagnosis. The suggested system measured the probable level of COVID-19 infection by present symptoms of the patients. They developed a COVID-19 related fuzzy inference system through the detection of the input as well as output variables in addition to the FSs and membership functions of each variable. Then, a collection of fuzzy rules were used to connect input variables with output variables of the set. In [36], the authors proposed similar type of approach more accurately, where the authors [36] proposed a rule based model under fuzzy rule based system. This model considered eleven symptoms of the patients with two factors, anosmia and loss of hearing ability. Initially, the model compared patient's status with the symptoms of COVID-19 as per declaration of WHO. Then the model used fifteen rules according to COVID-19 guideline of WHO during comparison. The main goal of this model is to identify the patients who are affected by COVID-19 or not. According to the performances report, the authors claimed that their model can be used to reduce both of the cost and time that is very important to save life and stop the new infections.

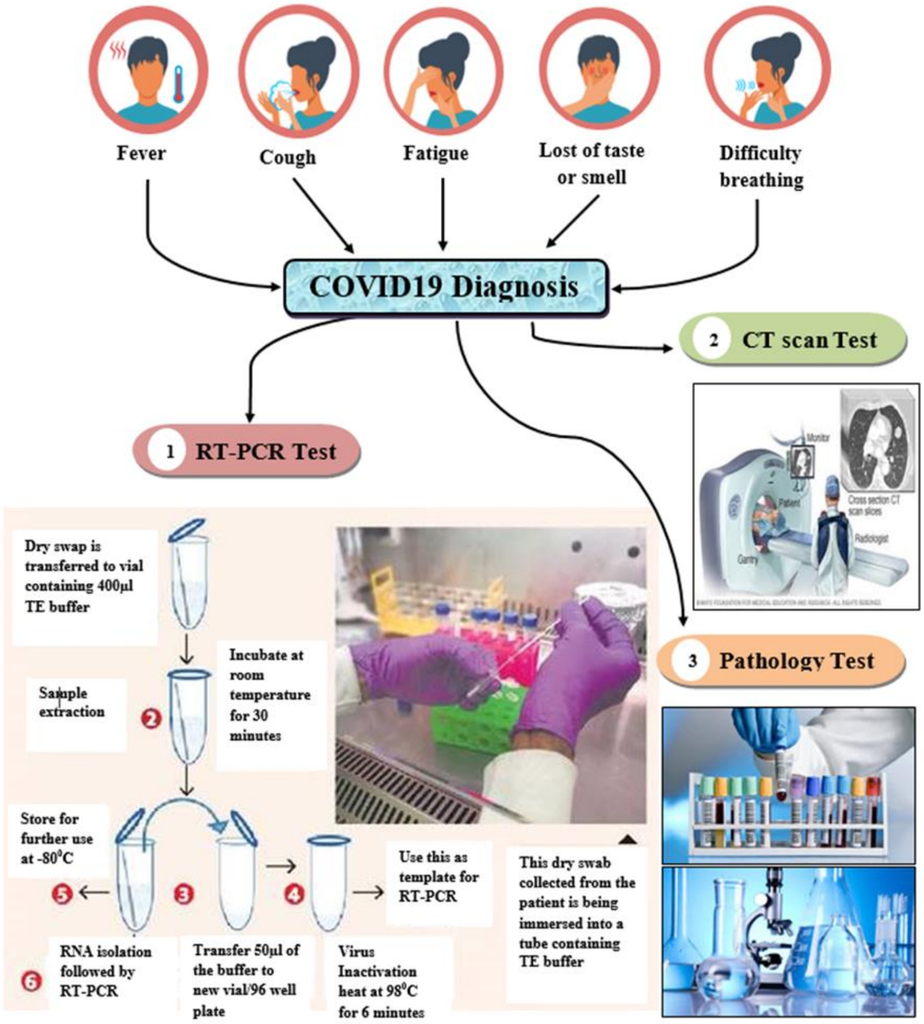

Figure 1: COVID-19 diagnosis techniques

2.4. Predictions using fuzzy expert systems

The fuzzy expert system based diagnostic model developed by the authors in [37], where the authors proposed novel fuzzy expert system based diagnostic model for determining the infection risk in advance stage with the help of major clinical investigations and symptoms. A smart fuzzy inference system was introduced in [38] to predict the COVID-19 infected patients at initial phase. The proposed system was used to control the rapid spread of COVID-19 infection within the communities and break the chain of COVID-19. This system identified the COVID-19 infection based on the patient symptoms along with travel and contact history which is very important to control the severe health issues and death cases. They considered the symptoms of patient such as cold, cough, flu, fever, throat pain, breathing difficulties and headache. The author [39] developed the fuzzy rule base system for detecting the COVID-19 patients, this system considered six important parameters and those are represented hexagonal intuitionistic fuzzy numbers (HIFN). HIFN are used because they provide a detailed representation of uncertainty, incorporating both membership and non-membership degrees through six parameters. To improve the better accuracy, another type-2 fuzzy based three phase rule base system introduced by Sahin et al. [40]. Initially this model analysis the common factors of the COVID-19, then consider the clinical reports, finally justify the risk level based on outcomes of previous stages.

2.5. Prediction using image analysis

Two digital image analysis technique for COVID-19 detection based on unsupervised machine learning technique was proposed by Chakraborty and Mali [31,41]. Initially they [31] proposed a novel approach known as Superpixel based Fuzzy Modified Flower Pollination Algorithm (SuFMoFPA) to detect the COVID-19 infected patients quickly. Basically, this method analyzed the radiological image for the said purpose because the radiological image of the infected patients contains some indicators which helped to the health worker to identify the infection. The type 2 fuzzy clustering system was attached with the newly introduced method for better segmented outcome. The authors claimed that this method can be considered as an alternative approach of time consuming RT-PCR test. Later Chakraborty and Mali [41] modified this approach and proposed another novel framework to segment the radiological images for identifying the COVID-19 affected patients more accurately when ground truth are not available. In this framework, they developed an innovative unsupervised machine learning-based method denoted as SUperpixel based Fuzzy Memetic Advanced Cuckoo Search (SUFMACS) for proficiently interpreting and segmenting the COVID-19 radiological images. This proposed approach incorporated the super pixel technique for reducing large amount of spatial information. Another image analysis based COVID-19 detection method was proposed by Anter et al. [42]. This article provided the robust model for finding the elevated factors of COVID-19 from chest X-ray images that can be used to diagnosis the patients with in stipulated time. During the analysis of the model the authors proposed an optimization model for COVID-19 diagnosis based on AFCM (adaptive Fuzzy C-means) and improved SMA (Slime Mould Algorithm) based on Levy distribution denoted as AFCM-LSMA. Khatua et al. [43], introduced a fuzzy based optimal control model for COVID-19 using granular differentiability. The developed model denoted as SEIAHRD model which is analyzed by granular differentiability, and generated the disease dynamics for time-independent disease control parameters. Then, upgraded the fuzzy dynamical system and granular differentiability model with the time-dependent disease control parameters.

2.6. Prediction using machine learning based tools

The machine learning based intelligent models are used to predict COVID-19 infected patient for obtaining the better accuracy and a group of experts proposed different analytical approaches for this purpose. Initially COVID-19 related database was developed based on the collected information from the reliable sources in order to train the developed machine learning model and testing the performance of the model. The clinical reports of the patients are considered as the input of the model to generate the infection tendency and status of infection. In [51], the authors developed a machine learning method for predicting and analyzing the expansion rate and increasing tendency of COVID-19. They used the Elman neural network, support vector machine (SVM) and long short-term memory (LSTM) and applied on the Wuhan based dataset for estimating the relative confirmed cases, casualties and recovery rate. A fuzzy granulation based SVM was used to predict the increasing rate of confirmed newly affected cases, new casualty and new recovery cases. LSTM were used for accurately predict the relative confirmed cases. Tuncer et al. [50] introduced COVID-19 detection technique using fuzzy tree classification. Basically this is a machine learning approach denoted as exemplar and for the training purpose they constructed three class dataset as on pneumonia, COVID-19 and normal chest x-ray images. Initially the fuzzy tree transformation was applied on the chest x-ray images and generated number of intermediate images. Then those images were classified by the exemplar divisor and produced the features by the multi-kernel local binary pattern (MKLBP). Similarly, Dey et al. [30] developed a machine learning based ensemble classifier technique where they used the Choquet fuzzy integral and the convolutional neural network (CNN) based models. The classifier model classified the chest X-ray images of patients into three clusters like healthy lungs, common Pneumonia and confirmed COVID-19. The standard CNN model was used for training due to less number of COVID-19 cases. The transfer learning scheme like InceptionV3, DenseNet121, and VGG1 were used to train for base classifiers. The pre-trained CNN models were used to extract features and classify the chest X-ray images using two dense layers and one soft max layer. Another convolutional neural network based model was developed in [47], where automated COVID-19 detection system used CT-scan images of the lungs for detecting the COVID-19 infection cases. Three transfer learning-based CNN models (VGG-11, Inception v3, and Wide ResNet-50-2) were used to generate the decision scores[52]. Sinha et al. [53], combined the fuzzy set theory with deep learning concepts to detecting the COVID-19 patients prominently. Basically use the CNN to optimize the algorithm by reducing useless components by the principal component analysis and the fuzzy inference system manages the confidence level.

2.7. Predictions using deep learning

Deep learning is the higher version of machine learning used to predict more accurately. In [54], the authors proposed a framework which was trained by deep learning concept using chest X-ray images for detecting the COVID-19 infected patients. The fuzzy logic was used to enhance the quality of the X-ray images by improvising the pixel intensity and suppressed background noise. Togaçar et al. [55] further improved the performance of the prediction technique and developed support vector machine based another deep learning model for detecting the COVID-19 affected patients using the three-class dataset. Fuzzy Color technique was used to restructured the original X-ray image and both the original and restricted images were stacked that was considered as the dataset. The deep learning models (MobileNetV2, SqueezeNet) was trained based on the stacked dataset and feature sets obtained by the models were administered using the Social Mimic optimization method.

2.8. Predictions using hybrid models

In order to know the future trends of COVID-19, a multiple ensemble neural network and fuzzy response aggregation-based model was introduced in [56] to predict the COVID-19 time series. The ensemble neural networks were used to compose a set of modules and produced numerous predictions under different conditions. Fuzzy logic was used for aggregating the responses of several predictor modules and improved the final prediction through the merging the outputs of the modules in an intelligent way. The developed model was tested for predicting the COVID-19 time series at state as well as country label in Mexico. Husain et al. [44] developed the forecasting model of COVID-19 cases that was used to estimate day wise infection of COVID-19 patients and adjusted the healthcare protocols related to COVID-19 for better performance. This COVID-19 forecasting model was accepted by government of Indonesia which was developed by the fuzzy time series method using frequency density-based partitioning. They used the dataset of the COVID-19 cases which are collected from the website of Nasional Kompas of the month of June 2020. Symptom based diagnosis process was incorporated by Majumder et al. [46]. They proposed a novel procedure to identify COVID-19 susceptible person by the three different ways according to linguistic based information system. The linguistic based information analysis was performed through the probabilistic rough fuzzy hybrid model. This model helped the health worker to presume the COVID-19 infected patient and take the decision like requirement of home quarantine, self-isolation and medical treatment in a crisis situation according to patients' conditions.

Table 1: Literature review for prediction of COVID-19 infected persons

Cite	Methodology	Advantage	Disadvantage
[32]	Deep Neural Network and Fuzzy inference engine	a. Contains three phases such as pre-processing, feature ranking, and classification. b. Shows better performance in terms of accuracy, error, F-score.	a. Unable to manage the uncertainty related to the input parameters.
[34]	Distance based estimation	a. Simple and easy distance based decision making method.	a. Standard datasets was not used
[35]	Fuzzy Inference Systems (FIS)	a. Parameter based smart fuzzy inference system	a. No learning techniques are applied for updating rule based systems.
[52]	Fuzzy time series and frequency density-based partitioning	a. Partitioning based on frequency density. b. Successfully forecasts the infection rate.	a. Only the infection rate is predicted by this method. b. Not recommends any decision.

Table 1: (continued)

Cite	Methodology	Advantage	Disadvantage
[36]	Rule based system	a. Simple and easy fuzzy rule based system.	a. No learning techniques are there for updating rule based systems.
[37]	Knowledge based System	a. Simple and easy Fuzzy Expert System.	a. Difficult to construct initial knowledge base. b. No knowledge base updation technique.
[44]	Elman neural network, long short-term memory, and support vector machine	a. Predict the growth range and development trend. b. Analyze using machine learning technique.	a. Difficult for the local maximum in the dataset with irregular growth.
[53]	Probabilistic rough fuzzy hybrid model	a. Manage the linguist form of inputs and considers the evidence of the input parameters.	a. No scientific way to estimate the threshold values.
[49]	Deep Learning based ANN	a. Reduces the feature distance between similar samples, increasing accuracy overall. b. Bias and weight have been decreased in this framework.	a. Require appropriate structure of ANN with accurate weight assignment. b. Require sufficient quantity of dataset for training
[51]	Multiple ensemble neural network and fuzzy aggregation	a. Number of modules made by ensemble-based neural networks. b. Related uncertainty handled through fuzzy logic.	a. Difficult to choose the hidden layer for managing features. b. Require sufficient dataset to train the neural network.
[45]	Machine learning and different classifier	a. Simple multilevel feature extraction technique. b. Cognitive approach and require less number of parameters.	a. Require desirable amounts of dataset. b. Require sufficient training for better performance.
[30]	Choquet fuzzy integral and the convolutional neural network (CNN)	a. Dynamically train the machine learning model b. CNN is used to thoroughly analyses each parameter.	a. Require appropriate justification for creating the CNN architecture b. Require sufficient training set. c. Spend extra time during the training phase.
[50]	Deep Learning	a. Considers less number inputs and takes less amount of time in the training section.	a. Difficult to manage if image sizes are different. b. Performance may be degraded due to lack of datasets.
[31]	Flower Pollination Algorithm	a. Manage the overlapping image segmentation and generate an impressive performance	a. Requires trial testing before implementation in real life.

Table 1: (continued)

Cite	Methodology	Advantage	Disadvantage
[41]	Advanced Cuckoo Search	a. Analysis the CT scan images according to clinical significance and broadly classify the images	a. To prepare an accurate initial dataset for greater accuracy.
[33]	Artificial Neural Network based Classification models	a. Simple and easy to use in medical settings. b. Input features affect in judgments to make the end decisions. c. Input features are evaluated using fuzzy logic and artificial neural networks.	a. Require appropriate data to train the network. b. Require proper justification for developing the ANN architecture. c. Spend extra time during the training phase.
[46]	Classification models	a. Trains the system dynamically. b. Uses CNN for deeply analyzing the individual parameters.	a. Require proper justification to develop the CNN architecture. b. Require adequate dataset to train the network. c. Take more time during the training section.
[38]	Fuzzy Inference system	a. Simple and easy system. b. Input parameters are classified according to importance.	a. Does not explore rule conditions. b. No learning approaches for maintaining rule-based systems.
[39]	Fuzzy Rule-base system	a. Manage the relevant steps of the COVID-19. b. Manage the multi-dimensional datasets by HIFN.	a. May arose the problem for interfacing between two phases.
[40]	Fuzzy Rule-base system	a. Analyzed the parameters step by step. b. Manage the uncertain inputs.	a. Properly synchronize the input datasets.
[43]	Fuzzy based optimal control model	a. Manage the dynamic nature of the pandemic. b. Analyzed the control parameters efficiently.	a. Undecided the maximum capacity of the system.
[48]	Optimized the algorithm using CNN	a. Reduce useless components b. Manage the uncertain inputs	a. Require the sufficient dataset during the training.

3. ANALYSING THE FACTORS RELATED TO COVID-19

The affected persons are the only source of the COVID-19 infections [57]. The virus is transmitted to other persons when the infected patients sneezes, speaks or coughs. Additionally, the infection unintentionally occurred when a person touches the contaminate objects with the virus and then touches his mouth, nose and eyes. The infection has been transmitted one human to another one by contract from the beginning of the COVID-19 invention (mid December, 2019) [29]. The virus is transmitted rapidly. Based on the opinion of the health experts, researchers and survey reports, there are different factors which played active role to transmit the virus. Various transmission factors are logically represented in Figure 2. Figure 2 also depicts the protection techniques and how the common people overlook the COVID-19 protocol intentionally or by forcefully. This section has discussed some of the relevant fuzzy sets theory-based articles which are used for analysis the factors related to COVID-19. A brief summary of the approaches which considered the various COVID-19 spreading factors are shown in Table 2.

Table 2: Literature review on factor analysis for spreading COVID-19

Cite	Methodology	Advantage	Disadvantage
[55]	Artificial Intelligence	a. Deeply analysis the inputs parameters b. Identify the region wise effects of factors.	a. Not provide any strong recommendation.
[56]	Mathematical Model	a. System of fuzzy fractional ordinary differential equations with Mittag-Leffler law. b. Ambiguity of differential equations and partial differential equations is handled by this method.	a. Critical to implement.
[57]	FAHP and HFS-TOPSIS	a. Deeply analysis of the risk factors. b. Consider future risk assessments with more variables c. Sensitivity analysis measure the impact of the parameters.	a. unable to make precise decisions like location of quarantine centers, lock down norms and isolation planning b. Requires extensive scientific investigation.
[60]	Fuzzy Model	a. Simple and easy method. b. Imprecise parameters represent accurately using fuzzy system.	a. No precaution or solutions has not provide.
[61]	Mandani based Fuzzy Model	a. Discuss broadly about the relevant factors. b. Measure the role of risk factors and preventive factors.	a. Not consider the stochastic factors.
[76]	Adaptive network-based fuzzy inference system and Virus optimization algorithm	a. Machine learning technique performed better and accurately forecast how different variables affect the infection rate. b. Importance of parameters are measured using sensitivity analysis.	a. Required long range data set instate of one month case study.
[63]	Exponential distance based Fuzzy Partitioning	a. Justified the potential and frequent presence of outlier time series. b. Regularization has used to eliminate superfluous data.	a. Require adequate datasets.
[62]	Weighted fuzzy soft set matrix	a. Clear, straightforward and incorporate crucial parameters. b. Fuzzy soft set accurately represents the observation.	a. No overt recommendations.

3.1. Factor analysis using fuzzy based Artificially Intelligence

A group of researchers developed the various type fuzzy models to analyse the functionalities of the natural parameters for transmitting the virus among communities. Initially, we considered the article [58], which was developed by Chowdhury et al. to find out the impact of the environmental parameters in order to spread the COVID-19 among the communities. In [58], the authors have developed a fuzzy based artificial intelligence system for measuring the effective role of various environmental circumstances to spread the COVID-19. They considered the relative humidity (RH), temperature, and UV index (UVI) as input parameters of some affected countries where the output variable denoted the total number of infected people. The existing data was converted was into linguistic variables and plotted for creating the relationship between input and output variable.

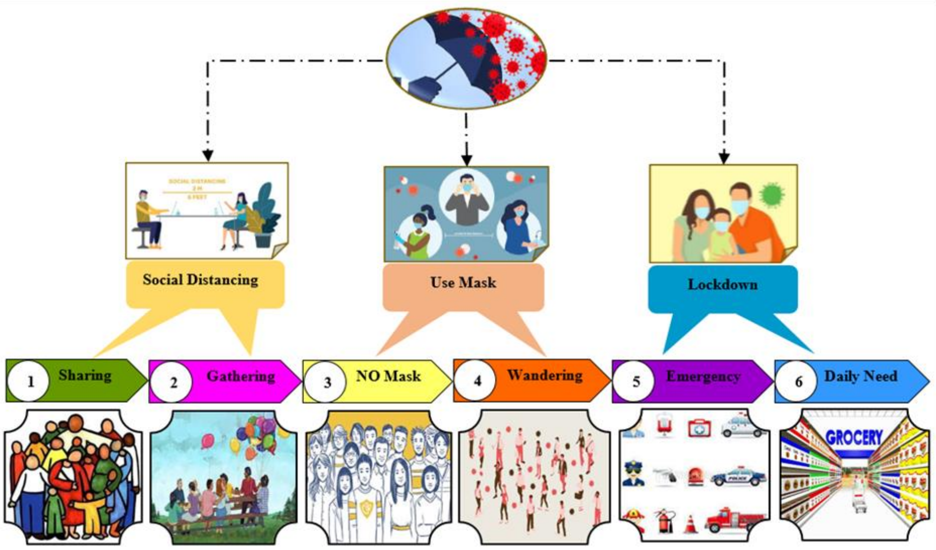

Figure 2: Important factors to spread the COVID-19 within the community

3.2. Fuzzy logic based factor analysis of COVID-19

Alderremy et al. [59] presented the numerical analysis of fractional mathematical simulation for studying the related factors for spreading the COVID-19 using fuzzy environment. The authors [59] derived the statistical approximation of fractional derivative of polynomial function and applied this approximation for developing the operational matrix of fractional differentiation and solved COVID-19 model by using Legendre operational matrix. Similarly, Ghorui et al. [60] investigated the most important risk factors related with spreading the COVID-19 disease with the help of FAHP and HFS-TOPSIS method[61]. The opinion of the health experts, literature survey and media reports were considered as the three imperative criteria for choosing the significant risk factor. The criteria's weights were estimated by FAHP[62]. The most significant risk factor identified using HFS-TOPSIS technique. Some additional factors of the COVID-19 were considered in [63] to explore the spreading around the globe. A simple fuzzy inference system was studied to diagnose the COVID-19 patients considering the six input factors such as; Ethanol, Body Temperature, Atmospheric Temperature, Cold, Cough and Breath Shortness. Next the system classified the patients into three levels such as high, medium and low based on the input parameters and the inference system for denoting the severity level of the infected patients. The impact of the factors related to the COVID-19 was considered in [64], where the authors developed a Mamdani based Fuzzy inference model to understand and evaluated the impact of epidemiological and clinical factors which led to the spread of COVID-19. This model considered nine factors and classified them into either risk factors or preventive factors. The parameters such as immunity, virulency, population density, temperature, and ventilation belong into the risk factors. Similarly, personal hygiene and social distancing are considered as the preventive factors. The susceptibility index of COVID-19 was estimated according to the inference of risk and preventative values which indicated the effect of spreading. The effect of factors was changed according to change of region. In [65], a novel approach to order the risks related to COVID-19 was studied which measured the relative level of risk within regions. Fuzzy soft set was used to represent the COVID-19 status of the region by set of factors. Another region-based factor analysis method was studied in D'Urso et al. [66], where the region base effect of the COVID-19 of the affected country was predicted by analysing the important variables related to COVID-19 pandemic. The proposed fuzzy clustering model used the interval wise collected information of the selected regions.

3.3. Factor analysis using Machine Learning

The machine learning based automated system was introduced in Behnood et al. [68]. The authors [68] developed a machine learning based method for investigating the effects of population density and several climate-related issues. They composed adaptive network-based fuzzy inference system based on the available data of the climate-related factors and the confirmed infected cases of the COVID-19 among the U.S counties.

4. PREVENT, CONTROL AND MANAGE COVID-19 INFECTION

The world Health Organization (WHO) has adapted various precautions to prevent, control and manage the infection of COVID-19 [69]. Those precautions are used to prevent or minimize the transmission of virus among the suspected persons. Standard precautions include hand and respiratory hygiene, the use of appropriate personal protective equipment (PPE) according to a risk assessment, wearing face masks, injection safety practices, safe waste management, avoid crowds, proper linens, and poorly ventilated spaces environmental cleaning, and sterilization of patient-care equipment. In this regard, the experts of various domains analysed the COVID-19 related factors and incidents those have active role for spreading the virus among the community. They provided different important concept and proposal such as maintaining social distance, properly using the mask most of the time and accurately following the lockdown to interrupt the new infection of COVID-19. For this purpose, Al-shami et al. [28] used Mα-neighbourhoods to categorise the community (such as patients, medical staff, school employees, etc.) based on whether COVID-19 infection was suspected in them or not. Figure 2 represents the probable precaution of the COVID-19 infection. Despite of all the precautions and safety measurements, some group of people are unable to follow the precaution appropriately and at the same time some irresponsible persons intentionally violate given rules. Figure 3 shows the hierarchical structure to control and managed the newly spread of COVID-19 infection [70]. The most effective control is Elimination which indicates the removal of exposure of COVID-19. Substitution replaces the hazard by redesigning the physical structure. Engineering and administrative control reduces the exposure of COVID-19, isolates from hazard, and change the work culture that people work. Personal Protective Equipment (PPE) used to safeguard the worker from the hazards or COVID-19 infection. The researchers analysed the COVID-19 situation and published important articles based on this control structure and the associate parameters. We have analysed some of the fuzzy set theory based novel concepts proposed by the researchers to prevent, control and manage the COVID-19 patients and situation.

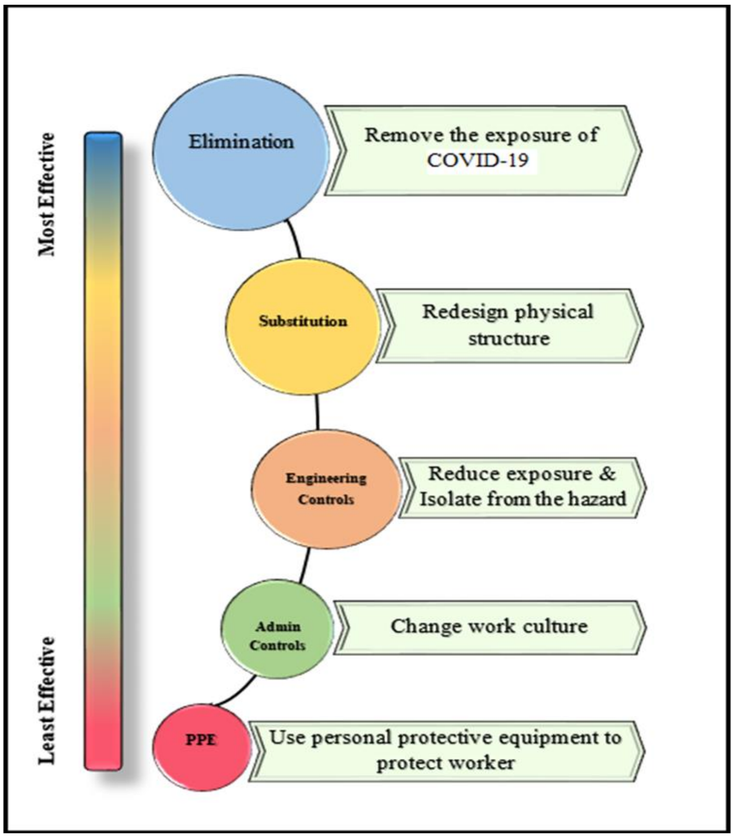

Figure 3: Hierarchical structure of COVID-19 control tragedy

4.1. Managing COVID-19 using fuzzy set based model

For taking any decision-making action to control or manage the pandemic situation of COVID-19, understanding the whole environment and representing it in a suitable format is necessary so that it would be easy to recognize and execute any operation efficiently. For this purpose, Rahman et al. [71] considered the insignificant order of the fuzzy dynamical system for modelling the COVID-19 pandemic situation. The model used the fixed-point theoretical approach to analyze the exactness and uniqueness of the solution. In [72], the authors simulated the COVID-19 situation based on the intensity level of the infected patients. A model for replicating the COVID-19 expanding using the multi-agent system and FSs was developed in [72]. The simulation concentrated on the intensity of severity of disease such as mild, severe and criticalness for patients and two general risk factors like age and body mass index.

4.2. MCDM methods to manage COVID-19

Multi Criteria Decision Making (MCDM) methods play an important role to manage and control the COVID-19 with uncertain factors which are represented by fuzzy information [73]. Gül et al. [74] provided more flexibilities to the decision maker for specifying their thoughts, preferences, and expertise with the help of FFSs. The author introduced the new multi-criteria decision-making method based on FFSs which studied the COVID-19 situation and extended the three well-known multi-attribute evaluation methods such as ARAS, SAW, and VIKOR under the FFS environment. Those three decisions making approaches handled the uncommon information. A group decision making method was used for managing emergency situation in [75]. The researchers in [75] proposed a multi-attribute emergency group decision-making method to choose the optimal humanitarian rescue scheme precisely and sensible manner of emergency that can reduce the huge loss and save the human life and health. The preferences of decision maker are represented by the IVIFSs. Next the ideal solution of the TOPSIS method was used to calculate the weight of the decision maker. Finally, appropriate interval intuitionistic fuzzy operators are considered to summarize the preferences of decision-makers in group decision-making.

4.3. Fuzzy set based prevention of COVID-19

The future treads and probable infection rate of COVID-19 is very essential for providing better service and smoothly managing the uncontrolled situation. In [49], the authors applied dynamical modeling approach denoted as Fuzzified Richards Growth Model for understanding the dynamic behavior of the COVID-19 based on available the real data and tried to predict possible future scenarios using fuzzy concepts. The fuzzy system was used to manage the uncertain, incomplete information related to COVID-19 infection. An another way for predicting the future trend of COVID-19 was analyzed in [76], where the authors used the modified software approach based on intuitionistic fuzzy factor ANOVA (2-D IFANOVA) for exploring the probable quantity of COVID-19 cases in Europe based on surrounding environment like density and climate zone. They used intuitionistic fuzzy sets (IFSs) for managing the missing, unclear or imprecise information and generated the index matrices (IMs) based on infection cases for certain period. Similarly, in [67], the authors tried to predict the infection rate of COVID-19 based on related factors, where they considered the fuzzy logic model with Mamdani method to calculate the rate of increasing of COVID-19 positive cases. The four stages Mamdani method used four inputs which are indicate the rate of change of the people in supervision, people without symptoms, patients in supervision, and positive COVID-19 cases. Here, the nonlinear infection of the COVID-19 was denoted as wave. Clin et al. [77] introduced a novel model to predict and forecast probable infection tendency of COVID-19 according to past infection scenario of China. The proposed model modified the adaptive neuro-fuzzy inference system with the help of enhanced flower pollination algorithm through the salp swarm algorithm.

4.4. Hybrid model to prevent COVID-19 infection

The researchers used some mathematical tools and statistical analysis methods for predicting the COVID-19 infection. The introspective fuzzy correlation technique based on the parameters of the COVID-19 patients was developed by Sharma et al. [48]. The proposed meditative fuzzy correlation technique provided the relation between the increments of COVID-19 positive patients in terms of the passage of increment with respect to time. The maximum infection of COVID-19 cases were estimated with the help of related conditions and their current magnitudes. The meditative fuzzy logic is the mathematical model which is used for finding the good fit or a contradictory model for any pandemic model. The proposed approach predicted the COVID-19 infection in the continuous contradictory situation. Kumar et al. [78] experimented to predict the future trends of the COVID-19 infection as well fatality rate. It is very important to take the proper precaution and plan future actions to manage the uncertainty situation due to unpredicted pandemic of novel COVID-19. In this regards, they proposed a hybrid fuzzy time series model to predict the upcoming COVID-19 infected cases and deaths in India by using modified fuzzy C-means clustering technique. The available COVID-19 data set was used to measure the performance of the proposed model based on mean square error, root mean square error, and average forecasting error rate. This method predicted COVID-19 infected cases and deaths for upcoming 31 days.

4.5. Fuzzy set based methods to control COVID-19

Castillo et al. [86] tried to implement the nonlinear behavior by an alternative way and introduced the novel concept known as fuzzy fractal control method to control the COVID-19 pandemic by the hybridized technique of fractal theoretical constructs and fuzzy logic concepts. The fractal theory which is known as the fractal dimension was used to measure the complexity of the active activities of the nonlinear plant whereas the fuzzy logic theory was considered for representing and capturing the opinion of the expert in control plant. Fuzzy logic was used to control the ambiguity present during the decision-making process. Kumar et al. [84] provided an analytical approach about the COVID-19 pandemic for estimating the most acceptable number and length of intervals according to fuzzy order of fuzzy time series forecasting of COVID-19 applying the concept of PSO (Particle Swarm Optimization) algorithm. Fu et al. [80] analyzed the household medical products regarding COVID-19 prevention, control and observation using fuzzy logic. They proposed and designed the anti-epidemic products for the passage by the household anti-epidemic status, economic and environmental benefits. The fuzzy logic programming managed the difficulties of the adaptable design method.

The uncertainty and vagueness within the health situation measurement smoothly managed using fuzzy inference system. The authors in [79] developed fuzzy assisted system to evaluate the safety of dental care which is connected to the sets of patient status and environmental conditions. The assessment of the proposed system was conducted based on the patient’s body temperature, dental care ventilation rate, travel history, and disinfection frequency. The fuzzy system was used to evaluate patient and environmental factors for predicting the safety of dental care. Dhandapani et al. [90] developed a novel stiff fuzzy model for studying the transmission variance of 14 day life span of COVID-19 affected patients. They introduced a special variable, the average transmission number, which was used to study the average spread of infection instead of basic reproduction number. The goal of this model was to control the spread of disease and deaths by estimating the threshold value, where increment of the threshold value can increase the spread of infection and number of deaths due to COVID-19. Ghosh et al. [82] developed a fuzzy inference system based computational methodology to quantify the present condition of the regions which were affected by COVID-19. They considered the related factors of

COVID-19 such as population density, number of COVID-19 tests, confirmed cases of COVID-19, recovery rate, and mortality rate as the input parameters.

The COVID-19 pandemic badly affected the high population country like India. Government of India introduced complete lockdown to maintain the COVID-19 protocol. However some people suffered much during the lockdown due to financial crisis and lack of socio-economical activities. In this aspect Khatua et al. [43] studied and developed an optimal control model to control the impacts of COVID-19 pandemic by using fuzzy dynamical system based on granular differentiability. The infection rate of COVID-19 changed according to the region with others factors like population density, average contact hours per day and necessary daily activities. The authors [81] considered these factors and introduced a model to represent and analyse the region-based trend of COVID-19 in Malayisa, which was the fuzzy graph related concept.

4.6. Hybrid models to control COVID-19

The restriction rules for controlling the new infection of COVID-19 are implemented based on infection rate. In this context, the authors of Castillo et al. [89] introduced a novel hybrid approach for the classification of countries based on the data complexity of the COVID-19. The proposed approach consisted of two concepts which are fractal theoretical constructs and fuzzy logic concepts for classifying the countries according to their complexity of the time series data. Fuzzy logic was used to represent and manage the inherent uncertainty of the classification problem. The classification information of countries according to the COVID-19 data was used to forecast the time series and tracking accurate control actions depending on present condition of the countries. The COVID-19 pandemic had destructive impact on the community basically on health sectors, global economy, education systems, cultures, politics, and other related fields. As an extension of [82], Castillo et al. [85] measured the effects of COVID-19 and developed a hybrid technique by merging the fractal theory and fuzzy logic for forecasting COVID-19 confirmed cases and country wise death cases according to complexity of their COVID-19 time series. The fractal theory was used to measure the complexity and fuzzy logic was used to managed the uncertainty. Ahmad et al. [91] developed the novel concept known as fuzzy cloud-based diagnosis assistant to provide the service to the COVID-19 effected patients in this pandemic. They aimed to reduce the causalities of COVID-19 by the early detection of COVID-19 effected patients. Mardani et al. [83] considered two techniques under hesitant fuzzy set to control the COVID-19 outbreak. They used SWOT (Strengths, Weaknesses, Opportunities, Threats) framework to identify the challenge of COVID-19. The authors [92] introduced the policies and plans for estimating the relation of the COVID-19 distribution among the various countries. They considered the increase rate of COVID-19 with in countries like Unites States America, Spain, Italy, Germany, United Kingdom, France, and Iran for comparing and clustering with the help of fuzzy clustering technique.

The proposed approaches, discussed in the preceding six subsections, which are used to control and manage the COVID-19, are enlisted in Table 3.

Table 3: Literature review to prevent the COVID-19 infection

Cite	Methodology	Advantage	Disadvantage
[76]	Correlation technique	a. Manages the conflicting situation among the parameters. b. Analyses the interconnecting nature of parameters. c. Use different fuzzy systems for point to point analysis.	a. Not specify the proper direction of positive or negative correlation.
[82]	Differential equations in fuzzy system	a. Analyses the spreading intensity into different levels. b. Generated threshold number is very useful in decision making.	a. No specific discussion in the transition points where infection rate changes from positive to negative or vice-versa.
[74]	Fuzzy model	a. Simple and easy to implement. b. Input parameters are well organized in a domain of fuzzy systems.	a. Due to rigidness, the defined rules are not update according to case history.
[71]	Fuzzy MCDM	a. Simple and easy MCDM method to manage the crisis of COVID-19. b. Weight of factors are estimated using entropy.	a. The choice of a humanitarian rescue plan based on insufficient information. b. The issues of information asymmetry and incompleteness have not yet been resolved.
[81]	Fuzzy inference system	a. Determine the risk factors that are most important to spread COVID-19. b. Analyzes the risk factors comprehensively.	a. Does not provide any strong recommendation.
[48]	Fuzzy SEIAHRD model	a. Managed the uncertain parameters. b. Deeply analyzes the whole process in different directions to the infection rate.	a. Basically, lengthy process and used a number of terminologies.
[61]	Fuzzyfied Richards Growth Model	a. Analyzes the dynamic nature of COVID19 in a fuzzy domain for managing the uncertainty.	a. No sensitivity analysis of the assign constants.
[38]	Inference system of adaptive neuro-fuzzy	a. Utilize and improved existing methods and trained by the standard model to optimize its parameters. b. Intermediate three layers used to learn properly and adjust the weights of input parameters.	a. Unable to manage the local optimal, especially in complex and multi-modal datasets.
[49]	Intuitionistic fuzzy two factor ANOVA	a. Detect the dependence of relevant factors. b. Properly judged the factors by the IFIM.	a. ANOVA is sensitive to outliers, however the data preprocessing has not use to clear dataset.
[16]	Multi-Agent System	a. Simple and easy method. b. Use multiple agents to properly classify the factors.	a. Not consider the relevant parameters other than age and Body Mass Index.

Table 3: (continued)

Cite	Methodology	Advantage	Disadvantage
[85]	Fuzzy rules based system and Fractal dimensions	a. Managed the complex behavior of times series through the concept of fractal dimension and fractal dimension change by dynamic nature of class of country.	a. Difficult to manage the different fractal dimensional iterations.
[28]	SAW, ARAS, and VIKOR	a. Generate the accurate decision matrix using various fuzzy terminology. b. Validity of the final output justified by the different MADM methods.	a. Aggregation processes were not illustrated. b. Direct provision of positive and negative membership degrees. c. Absence of linguistic word proposal
[84]	Chemo-metrics fuzzy autocatalytic set	a. Analyzed the complex, large dataset and interrelated factor by c-FACs.	a. Not process the dataset of other countries except Malaysia.
[89]	Fuzzy clustering and Pearson correlation	a. Each symptom of the patient analyzes independently and measures the severity level. b. Health experts get more flexibility during treatment.	a. Not consider the dynamic nature of symptoms.
[77]	Fuzzy C-means clustering	a. Realized the relation between spreading intensity and population's size using Pearson correlation. b. Reduces the effect of the population's size by rescaling the datasets.	a. No data cleaning method included.
[80]	Fuzzy logic programming	a. Use to measure level of household anti-epidemic products and give proposals to improve the usability. .	a. Critical to measure actual utilities of anti-epidemic products.
[87]	Fractal theory and fuzzy logic	a. Easily manages the uncertainty of the input parameters and handles involved complexity. b. Applied the standard dataset in proposed method for the experiments	a. Difficult to construct actual fuzzy rules for the hybrid model and manage different versions of the fractal dimension.
[79]	Particle Swam Optimization	a. Considered the fluctuated dataset and improved the accuracy b. Estimate the minimum partitions for the gray area.	a. Complex to prepare the accurate initial dataset.
[67]	Caputo as well as Attangana-Baleanu and Caputo fractional type derivative.	a. Investigated the qualitative aspect. b. Manage the uncertainty related to the datasets.	a. Complex to understand. b. Use a large number of various types of variables.

Table 3: (continued)

Cite	Methodology	Advantage	Disadvantage
[78]	Fractal theory	a. Effectively controls nonlinear dynamic systems and assesses the degree of dynamic behavior complexity. b. The ambiguity inherent in the decision-making process can be managed by using fuzzy logic.	a. Have a challenge to create practical fuzzy rules for the hybrid model and control various fractal dimension iterations.
[83]	Fuzzy inference system,	a. Analyze the uncertainty before processing. b. Importance of the inputs is evaluated independently.	a. Difficult to manage the situation out of bound rules.
[88]	Weighted Aggregated Sum Product Assessment and Stepwise Weight Assessment Ratio Analysis	a. Easily tackles the relevant complexity of MCDM problems. b. Manages the key challenges of digital technologies of health science.	a. No specific instruction to manage if some information is missing or out of bound.
[97]	Fuzzy Cloud	a. Cloud based technique diagnosis remotely without physical contact.	a. Difficulty to develop the initial dataset. b. Required sufficient technological support. c. Justify the information which is provided by patient.

5. ANALYSIS OF COVID-19 TREATMENT

Initially there was no approved specific treatments for the COVID-19 affected persons [93]. Numerous therapies or tentative treatments are permitted to manage the COVID-19 infection and recovering from COVID-19. At the beginning, the health department approved few medicines for the treatment of the corona positive patients. The treatment of the COVID-19 patients is done according to patients' conditions like mild cases (without symptoms), moderate cases (with symptoms) and severs cases (critical condition) treatment. Presently, health department temporarily approved and use these therapies as the available evidence is limited [94]. Based on the circumstances and obtained data, the evidence can be included and recommendations degree can be upgraded. A set of researchers from various domain, have developed the various fuzzy methods to measure the performance of the approved therapies and their effectiveness. Similarly, numerous researcher groups have developed the several models to select the medicine of various type of virus affected patients [95]. In this section, we study some collected articles based on fuzzy set theory for the said purpose. In the following sub-sections, we have analysed some of the fuzzy set theory based novel concepts proposed by the researchers to analysis the COVID-19 treatment.

5.1. Fuzzy logic based concepts to analyse COVID-19 treatment

During the peak of COVID-19, many infected persons were critically affected and quality treatment from the health centre system was required. But the available quantity of high-quality treatment is limited, so suitable admission procedure might be considered for proper patient admission [96]. In this aspect the authors [97], developed a type-2 fuzzy expert system and an adaptive neuro-fuzzy inference system for predicting of ICU admission. They used the Mamdani inference system, where the antecedents and consequent are type-2 fuzzy sets which contain a fixed mean and an interval value assigned for the uncertain standard deviation. Various classification methods such as Naive Bayes, Decision Tree, Case-Based Reasoning, and K-Nearest Neighbour were considered and implemented for estimating the performance of these fuzzy systems. The authors in [99] proposed another systematic method for monitoring and analyzed the COVID-19 affected patients based on their current medical and psychological conditions within the hospital and quarantine centers. The proposed method identified the medical status and psychological condition according to the intensity of current symptoms and mental activities by the model of the fuzzy context-aware reasoning engine.

Fuzzy reasoning engine generated the decisions with the help of linguistic rules based on inference mechanisms that helped to identify the condition of the patients. The relationships between the attributes were identified by the fuzzy semantic rules and the reasoning engine was used to ensure precise real-time context interpretation and current evaluation of the situation. The health department faced a big challenge to provide the quality treatment for the large scale sever case patients. The governments of the most affected COVID-19 countries found it difficult to allocate beds equipped with modern health instruments. Thereafter, selecting the patients became an important issue to provide quality treatment to the severe case patients and reduce the causality. Geetha et al. [101] studied about hospitalization of severe case COVID-19 patients. In this regard, they developed an algorithm to evaluate COVID-19 admission within the hospitals. They considered eight key factors for determining the priorities of the patients and analyzed all these factors separately to check the effectiveness and practicability of the proposed algorithm. Another study for selecting appropriate patients for the proper treatment of the COVID-19 infected patients was found in [98], where the authors proposed a novel concept for selecting the suitable list of COVID-19 patients to provide the treatment within the health centers. They considered AI based approaches using ANN to identify the death or the recovery of COVID-19 infected patients.

5.2. Evidence based medicine selection

Treatment procedure, proper therapies and correct medicine are considered as important factor to recover from COVID-19. For choosing the appropriate treatment, Si et al. [95], introduced an evidence-based medicine selection approach that belongs to the probabilistic based uncertainty for the treatment of COVID-19 patients. They used picture fuzzy set to represent the uncertain information. The probabilistic based uncertainty of the neutral membership degree of picture fuzzy set was measured by the D–S theory, and GRA used for measuring the performance among the set of conflict and contradiction parameters. They also proposed the FUSH operation for aggregating the PFNs. The proposed method was used to find the superior medicine for the treatment of COVID-19 patients. For the high mutation capability of the COVID-19 virus, no approved drugs and medicines are found so far for better treatment. Similar type of concept was considered for selecting medicine in Ren et al. [102], where the authors proposed a multi-criterion decision-making method for selecting the medicines of the mild COVID-19 infected patients using the concepts of Dempster-Shafer (DS) theory and generalized Z-numbers. In continuation of the concept of hesitant fuzzy linguistic term set, they extended the Z-number into a generalized form that can manage the human expression more accurately. The created a connection between the knowledge of Z-numbers and the DS evidence theory to integrate Z-valuations. The related evidence of the DS theory was used to represent the generalized Z numbers and reduced the ambiguity accordingly.

5.3. MCDM methods for analysis of COVID-19 treatment

Figen et al. [100] introduced the multi-criteria decision-making method to evaluate the tentative COVID-19 treatments. They used the fuzzy PROMETHEE and VIKOR methods to evaluated the eleven number of current treatments of COVID-19 such as Plasma exchange, Favipravir, Tocilizumab, Remdesivir, Interferon, Hydroxychloroquine etc. The main objective of Mishra et al. [103] was to elect the superlative antiviral therapy to treat the mild symptom of COVID-19 among the available numerous antiviral therapies. For this purpose, the authors developed Additive Ratio Assessment (ARAS) approach to clarify the affectivity of the antiviral therapies. They introduced a novel hesitant fuzzy set based divergence measuring method for assessing the relative importance of the criteria. Throughout the COVID-19 pandemic, the health department and healthcare centers faced various challenges due to high infection rate of COVID-19. The authors [104] evaluated the criteria of SERVPERF (the performance component of the Service Quality scale) standard for health services to measure the customer perceptions of service quality. They considered the connecting relationships between the criteria using Fuzzy Cognitive Maps (FCMs) and Z-Number theory, and analyzed the importance of these criteria in the prevalence of infectious diseases.

A summary of the various approaches used for analysis of the probable treatment of COVID-19 infected patients is depicted in Table 4.

Table 4: Literature review on treatment of patients infected by COVID-19

Cite	Methodology	Advantage	Disadvantage
[43]	Z-Number theory and Fuzzy Cognitive Maps	a. Evaluate the relationship of the criteria of the health service, then readjust the weight of the criteria. b. The uncertainty during calculation of unreliable numbers handle by Z-number.	a. Arise the inconsistencies using Z-number in different contexts. b. Not scalable for very large systems
[94]	Inference system	a. Tuning the input parameters accurately b. Use various type of classification techniques for better accuracy	a. Not highlighted which classification is suitable in which situation.
[95]	Fuzzy reasoning engine	a. The IoT based technique observe the patients remotely. b. Input parameters accurately measure by the various level of classification.	a. Difficult to manage if the situation arise out of proposed rules.

Table 4: (continued)

Cite	Methodology	Advantage	Disadvantage
[98]	Generalized Z-numbers and Dempster-Shafer (DS) theory	a. Ambiguity of criteria manage by the Z-numbers and considers the evidence using basic probability assignment.	a. Cannot evaluate the levels in the identification framework are not mutually exclusive. b. Dependency among the criteria was not considered
[96]	Case-Based Reasoning Approach	a. Use to measure the severity of patients and prescribed treatment according to this.	a. Analysis of comorbidities and justification of symptom level are crucial.
[100]	Additive Ratio Assessment and Divergence measure	a. Use a unique criteria weights determination technique to measure the significance of criteria. b. Successfully eliminate the impact of decision experts' opinions on the results of the evaluation.	a. Essential physical level trail before implementation.
[97]	Fuzzy hybrid concept	a. It is a two phase hybrid model to reduce death case rate. b. Initially, measured infection level of patient using ANN then proposed suitable treatment.	a. Consider only the maximization function.
[92]	Evidence based system	a. Smoothly managed the neutral part of the parameters.	a. Require practical experiment before implementation
[99]	Fuzzy PROMETHEE and VIKOR	a. Fuzzy scale based on fuzzy logic use to express qualitative data like applicability, side effects and compliance. b. Expressing opinion of experts by the degrees of importance easily.	a. Lack of the method for calculating the weight of the criteria. b. Expert judgement is used to determine the weights of the criteria in this model.

6. AFTER EFFECTS OF COVID-19

The COVID-19 pandemic has infected millions of peoples and among them five percent people lost their life globally. It has a great impact for creating the economic crisis and recession in the near future. Most of the industrialist, businessman, policymaker and government authorities are in fear for the upcoming situation [109]. COVID-19 protocols such as social distancing, home quarantine, self-isolation and travel restrictions may reduce the workforce across all economic sectors and lead to huge jobs loss. Educational sector has been badly affected due to shut down of the institutes from very beginning of the pandemic, and the demand of essential related commodities and manufactured products has been dropped. Alternatively, the demand of medicine and medical equipment are increased drastically. The scenario in food sector is dangerous due to panic-buying and stockpiling of food products. These activities create the temporary shortfall of the food products in the market. In this background, the researchers analyzed and summarized the socioeconomic effects of COVID-19 on individual aspects of the world economy. The rest of this section deeply investigates the published articles regarding the after effect of COVID-19 pandemic in different directions.

6.1. After effect of COVID-19 in Production System

During the COVID-19 pandemic, the demand of various medical equipment increased exponentially. Then various electro-mechanical or other domain of industries were introduced to develop various type of medical equipment to manage the high demand of the current situation. Ahmad et al. [88] introduced a model and optimization framework for sustainable production and waste management (SPWM) decision-making model for COVID-19 medical equipment under uncertainty. They used intuitionistic fuzzy set theory to quantify the present uncertainties within parameter values. Additionally, they developed a novel interactive intuitionistic fuzzy programming approach to solve the proposed SPWM model in fuzzy environment. They used three criteria like savings from baseline, co-efficient of variations, and desirability degrees to measure performance of the proposed method. COVID-19 pandemic reduced the market place and natural hazard like super cyclone “Amphan” destroyed the agricultural field and left a huge impact on the farmer of the state of West Bengal in India. Goswami et al. [105] deeply studied the related impact of the COVID-19 pandemic and the super cyclone “Amphan” on smallholder agricultural systems. The authors conducted thematic analysis based on in-depth responses of the multiple stakeholders in region of Sundarbans areas in eastern India for identifying the probable present and future systems outcomes of the current situation. They developed the multi-stakeholder mental models based on the Fuzzy-Logic Cognitive Mapping tool for the smallholder agricultural systems of the region.

6.2. After effect of COVID-19 in Education Sector

The educational institute and universities were closed due to COVID-19 pandemic and the educational organizations had to shift the teaching and learning system into the online mode for continuing educational activities based on COVID-19 protocol. There was an obvious need to measure the qualities of online education system. Tang et al. [108] applied an integrated approach known as FCE-AHP (Fuzzy Comprehensive Evaluation-Analytic Hierarchy Process) for the evaluation purpose. This approach evaluated the impact of COVID-19 in online courses.

6.3. After effect of COVID-19 in Insurance Sector

The common people realized the importance of health insurance companies during this COVID-19 pandemic as the health expenses increased exponentially and it is essential to tactically manage the COVID-19 infection and protect from the casualty basically for the aged population. In this context, Ecer et al. [112] analyzed the performance of the health insurance companies by the developing a decision support tool. They used intuitionistic fuzzy sets and the Measurement of Alternatives and Ranking according to the Compromise Solution (MARCOS) method to develop a decision tool for measuring the performance of the insurance companies in health services. After the COVID-19 outbreak, most of the countries around the world have suffered badly in the health sector as well as other fields of the community. Government implemented several policies to recover from the effects of pandemic. The authors [110] proposed a multi-criteria decision-making process in the domain of q-rung orthopair FSs for measuring the performance of implemented policies. The decision maker considered the q-rung orthopair FSs for large scale assessment and managing ambiguous information.

6.4. After effect of COVID-19 in Tourism

The COVID-19 pandemic totally hampered the most of the business sectors. The ecotourism centers were badly affected. A group of researchers tried to develop some action plans to improve and recover the relative activities in this pandemic period. Hosseini et al. [111] provided a set of appropriate action plans for ecotourism centers. For implementing the suggested action plans, they considered four criteria such as time, effectiveness, cost and necessity. Next they used fuzzy DEMATEL method to estimate the weights of individual criterion and fuzzy VIKOR method was used to rank the criteria. Due to the pandemic scenario, finding a suitable visiting place by maintaining the travel restriction was difficult. In [106], Chen et al. introduced a fuzzy multi-criteria decision-making method denoted as the calibrated piecewise-linear fuzzy geometric mean (FGM) approach for recommending the travel destination after reducing the COVID-19 restriction within the bounded region. The proposed method managed the complexity for choosing the desirable visiting place. It is very important to know the infection status of COVID-19 outbreak over the world for having travel restriction and any socio-economical issues. The authors [107] used coloring the fuzzy direct graph to represent the COVID-19 infection among the various countries for maintaining the updated Interpol activities. For these purpose, they introduced novel fuzzy graph coloring approach based on influence value of edges and chromatic index. This method managed incomplete information in the Interpol activities.

6.5. After effect of COVID-19 within Society

Throughout the COVID-19 pandemic period, many persons have suffered due to financial crisis. In this context, the authors [113] developed a model to assess the donor system, evaluate the progress of development and measure the effectiveness in terms of preserving the health of citizens in Russia. The model was based on fuzzy environment, considered 12 input, 3 output variables, and 3 rule blocks for assessing the development and effectiveness of donation in the various regions. The authors trained the system based on the collected rules and tested on specific data of COVID-19, and then generate the categorical output of the donor system like high, average and low. Ashraf et al. [114] introduced spherical fuzzy environment based emergency decision support techniques to provide quality treatment, hospitality and enhance the quality life styles of peoples. They managed the ambiguity and uncertainty present in decision-making problems using fuzzy structure of spherical fuzzy set. A set of aggregation methods according to the Einstein operational laws were familiarized to combine the uncertainty of decision making problems. They proposed two approaches known as AHP and spherical fuzzy entropy for estimating the attributes weights. Then they considered two spherical fuzzy decision support techniques using TOPSIS and GRA methods to manage the emergency situation of COVID-19. Three algorithms were designed based on these three different techniques. Bahuguna et al. [115], a unified deep neuro-fuzzy approach has been developed for Covid-19 twitter sentiment classification. In this method incorporating fuzzy logic for analyzing the twitter data due to the merely obnoxious of the spelling and grammar in tweets.

The information given in Table 5 represents the summary report of published articles for the after effects of COVID-19 pandemic.

Table 5: Literature review on the after effect for the COVID-19 pandemic

Cite	Methodology	Advantage	Disadvantage
[112]	AHP and spherical fuzzy entropy	a. Managed the unknown weight information using entropy calculation b. Tackle the uncertainty related to the decision making process.	a. Incorporated a numbers of mathematical tools for the final decision.
[105]	Fuzzy Comprehensive Evaluation-Analytic Hierarchy Process	a. Evaluate the online courses based on criteria and their different level.	a. Unable to determine how crucial a set of criteria.
[111]	FuzzyTECH environment	a. Perfectly measure the input parameters by the different level b. Technically manage the incomplete information.	a. Computational complexity depend on the parameter levels.
[110]	Fuzzy graphs colouring	a. Successfully manage the inter-dependence of the region. b. Introduced two constants chromatic index and strong chromatic index and accurately represent the situation.	a. Complex situation arises when a region bounded with large number of regions.
[106]	Ranking according to the Compromise Solution and Measurement of Alternatives	a. Useful, efficient, easy to use, flexible, and robust decision tool. b. Sensitivity analysis states and identifies the effect of criteria in decision-makers for evaluation.	a. Lack of adaptability capability.
[103]	Optimization Technique	a. Convexity property use to measure working efficiency of the proposed SPWM model. b. Tuning the various parameters to generate the wonderful solution.	a. All crucial aspects has not cover. b. Require additional modification for multi-choice and stochastic random variables
[104]	Fuzzy-Logic Cognitive Mapping tool	a. Use various type of fuzzy terminology for detail analysis of contradictory situations.	a. Has not consider the neutral membership parts of the parameters.
[108]	Fuzzy DEMATEL and fuzzy VIKOR	a. Calculate the weight of the criteria in uncertainty domain using Fuzzy DEMATEL b. Prioritize criteria efficiently by the Fuzzy VIKOR.	a. Lengthily process b. No proper justification for multiple satisfiable option.
[109]	Linear Fuzzy Geometric Mean	a. Manage the critical factors by the calibrated piecewise-linear fuzzy geometric mean.	a. Dynamic nature of the factors change the final outcome.
[107]	TOPSIS method	a. Manage the uncertainty of MCDM deeply using q-ROFSs b. Elaborately increase evaluate space.	a. No specific instruction for the interval numbers.
[113]	Deep neuro-fuzzy approach	b. Manage the incomplete twitter. c. Justify the social impact of our community.	a. Dose not properly check the output of the approach.

7. DISTRIBUTION OF COVID-19 VACCINE

The WHO (world health organization) and alliance organization are struggling to manage the present pandemic situation of COVID-19 [29]. They announced various types of instructions to take as the precaution for preventing the infection of COVID-19 like wash hands and face frequently with soap and water, maintain the social distance from the people having coughing or sneezing, avoid touching face, cover mouth and noise with mask etc. Those prescribed instructions and various strong decisions can reduce the chance of being exposed to the virus or spreading it to others but these are not enough to stop the infection permanently [93]. The world famous virologists deeply investigated and proposed that the vaccination should be ultimate solution. The genetic sequence of COVID-19 was published in January, 2020. After that various research groups have developed a dozen of the probable vaccines. Various countries like China, Russia United Kingdom's, Bahrain, UAE and United States started the vaccination officially of various COVID-19 vaccines like BNT162b2, Pfizer–BioNTech, BBIBP-CorV from June 2020 [117]. Transportation of vaccine was a crucial issue because delivering billions of doses of a vaccine and storing in a deep-frozen state required hugely complex logistical challenges across the supply chain [118]. Air cargo for long distance and medicine van for local area transportation played an important role to distribute the manufactured vaccines in normal times based on temperature-sensitive distribution systems. Apparently, vaccine allocation is very much complex. For instance, there is a strong agreement that healthcare workers need to be prioritized. Moreover, vaccine allocation elevates a number of ethical issues. Figure 4 show the way of vaccine transportation from manufacturing site to vaccination centres/nodes through the various phases and allocation among the people according to priority [119]. For the universal aspect, the benefit of the vaccine should be provided to lower category countries along with scientifically developed countries, which raised an issue about the global allocation of vaccine during the final phase testing of vaccine [120]. At present there are no predefined protocols to force the countries to share their excess vaccines. The Coalition for Epidemic Preparedness Innovations reported that still now there are no clear agreements for the principles of the fair allocation system. In this context, Matrajt et al [87] introduced a mathematical model to manage the vaccine crisis during the vaccination. The model consisted of a pair of optimization algorithms based on four various metrics. In the next section, we discuss some proposed vaccine distribution techniques briefly.

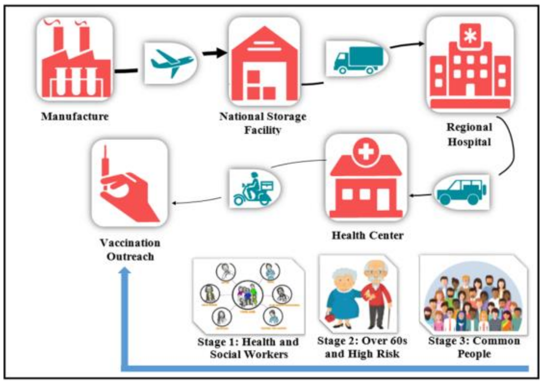

Figure 4: Vaccination distribution and stage wise vaccine allocation

The trial reports of the vaccines have shown that it can reduce the new infection and protect the community. It was considered that the vaccination of whole population was the effective way to recover from the COVID-19 pandemic. There are various challenges in the vaccination process like developing the genetic sequence, manufactured vaccines, distributing among the health centers, and appropriate administration for proper control. One of the most important factors is the selection of right amount of vaccine to be delivered to the right place at the right time. In this regard, Alam et al. [121] explored the related challenge of the COVID-19 vaccine supply chain through the merging of DEMATEL (decision-making trial and evaluation laboratory) method with the help of intuitionistic fuzzy sets for identifying right place and needy persons for vaccination. The authors identified 15 challenges of the COVID-19 vaccine supply chain and ranked those challenges. Hezam et al. [45] proposed another vaccine distribution method for identifying the priority groups for allocating the COVID-19 vaccine doses. They recognized four main criteria and fifteen sub criteria of the person like age, health status, status of woman health and job responsibility. They used neutrosophic Analytic Hierarchy Process to evaluate those main and sub criteria. They applied neutrosophic TOPSIS method for ranking the COVID-19 vaccine alternatives. The health worker, edged person, person with high-risk health, workers of emergency service, pregnant and lactating mothers are considered as the most prioritized group to take the vaccine dose first. The rigidness of the fixed point vaccine distribution center can be overcome by the moveable clinics to reduce the travel as well as waiting time of the citizen basically for physically challenge and edged persons. In this regards, Cakır et al. [116] studied an assignment problem to locate the movable vaccination clinics with in three cities (Istanbul, Ankara, and Izmir) of Turkey. Vaccination centers were determined and their weights were estimated by the spherical bipolar fuzzy MCDM based on identified criteria according to decision makers. The General Algebraic Modelling System was used to solve the location problem with multiple facility for COVID-19 vaccination.

A brief summary of the approaches, used to distribute the vaccine among the people is depicted in Table 6.

Table 6: Literature review on vaccine distribution among the peoples

Cite	Methodology	Advantage	Disadvantage
[119]	Evaluation laboratory method by the decision-making trial	a. analyze the difficulties to distribute the vaccine b. Find the relation among the criteria accurately.	a. Stakeholders' quantity in this study is low. b. Has not check the validity, feasibility, reliability, and sensitivity of this method.
[120]	The neutrosophic Analytic Hierarchy Process (AHP) and neutrosophic TOPSIS method	a. Produce the order sequence by the analysis of criteria of criteria.	a. Incorporated less number of criteria and sub criteria.
[121]	Spherical bipolar fuzzy MCDM	a. used multi-facility location selection technique with heuristic algorithm to find the location properly	a. Observation perform within narrow region.

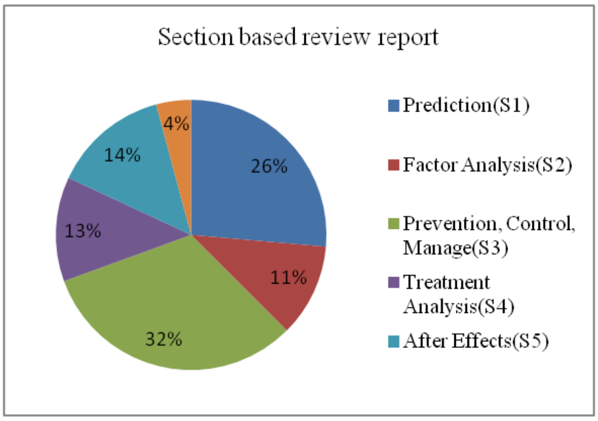

Figure 5: Utility of fuzzy set theories in various domains of COVID-19

8. DISCUSSIONS AND LIMITATIONS

The COVID-19 pandemic has hampered the entire nation. This type of pandemic needs to be dissolved as early as possible for re-establishing the normal human culture. Sensing the need, many researchers from various domains have contributed their thoughts to recover from the current pandemic. To explore the outline of the COVID-19 related research works, a comprehensive survey of COVID-19 articles was very much necessary. We have categorized the research activities into six relevant groups that will assist the researchers to understand and solve the COVID-19 related problems more efficiently. According to the survey report, we have realized that the researchers prominently considered the fuzzy set theories to find the probable solution for the current pandemic situation and developed various models and proposed numerous concepts to manage the pandemic. During the analysis of various proposed methods, we have found that researchers have adopted different approaches to solve similar types of problems, which finally resulted in approximately similar outcome.

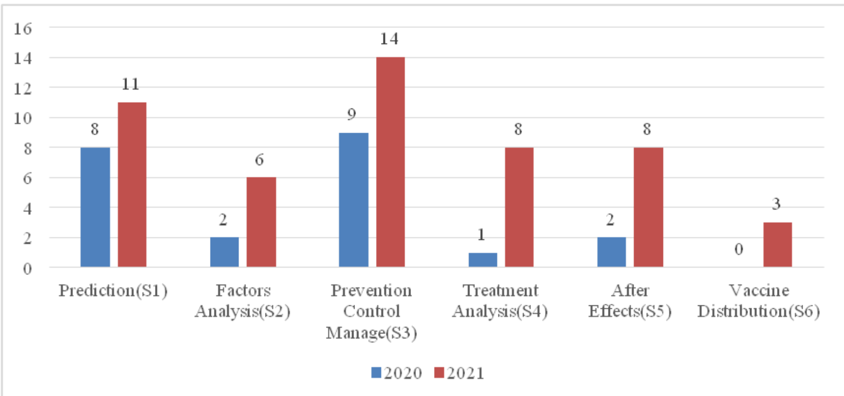

Figure 6: Year wise publication in various fields of COVID-19

After the invention of COVID-19, the whole community was unable to understand the harmfulness of it. Some of the scientists concentrated regarding this problem but found it difficult to draw any conclusion at the very beginning of the pandemic. According to the Figure 6 and Table 8, we observe that the quality research article related to COVID-19 in fuzzy domain were published at the end of first quarter of 2020. At that time, the scientist observed the malicious behaviours of it and deeply investigated to find the suitable solution to reduce the loss of the society with the help of modern technology and procedure. Initially in the first quarter of 2020, most of the researchers and scientists were helpless and disoriented due to lack of experience and concrete information regarding the pandemic. During this session, they studied and observed the whole environment for gathering the knowledge and collecting the relevant information. After having the required information and knowledge, they prepared various types of roadmaps for investigation in different domains. At the very beginning of the pandemic, the health worker faced some problems to correctly identify the infected patients due to the common symptoms of normal flu. To rectify this problem, the researchers investigated in depth regarding COVID-19 symptoms and proposed various concepts. According to Fig. 5, 26% articles were published for predicting the COVID-19 patients. These articles provided analytical as well as experimental approaches that can help the health workers for predicting the infected patients by the alternative ways. The experts diagnosed the role of various parameters to spread the COVID-19 within the communities. The researchers concentrated on this domain of COVID-19 infection and analysed multiple ways to measure the role of the natural and environmental factors for spreading the COVID-19 in different direction. It is very important to know individual role regarding the factors to control COVID-19 and manage the new infection. Afterwards, the experts realised that the prevention and control of the COVID-19 are more important than that of the factor's analysis. In this context, researchers proposed various novel concepts and developed acceptable models to manage the situation. The patients were classified into various categories according to their infection levels and the corresponding treatment was prescribed. However initially there were no proper evidence of the COVID-19 treatment. Later the recovery rate was improved based on the performance of the medicine which are applied according to patient's conditions. This study explores that researchers applied different types of approaches, technique and methodises which is shown in Table 9. Some researchers used the more than one approaches to manage the situation and investigated the hidden information to control the infection rate directly or indirectly [95, 65, 47].

During the last two years, the whole communities around the world suffered from mental and physical pressure and financial crisis [122]. A lot of skill workers and daily wages workers lost their job and entered into a stagnant situation [123]. The vaccination was considered the only option along with other necessary precautions to recover from this pitiable situation by creating hard immunity within human body. The priority-based vaccination was started from January, 2021 and the performance of the vaccine were satisfied. According to virologist, the COVID-19 pandemic can be controlled when the vaccination rate above 60%. Feeling the need of urgency, the researchers started investigation to managing the vaccine crisis, vaccine distribution technique and identifying the needy person for vaccination. Moveable vaccination camps were proposed and optimization method was developed to reduce the harassment and successfully execute the vaccination processes among the selected and needy persons. In the post pandemic situation, when the rate of COVID-19 infection was reducing, a big challenge was raised to restore the normality among the affected person and communities. Researchers took this challenge and provided future direction to recover from this uncertainty. According to Figure 5, sixteen percentage of researchers considered about post COVID-19 activities like role of manufacturing industries, activities of educational institution, travel and tourism sector and IT industry.

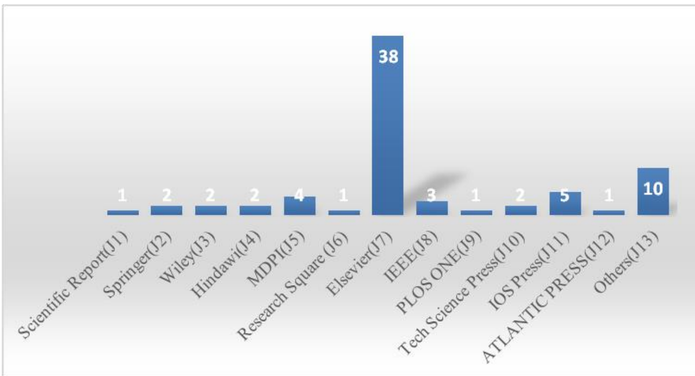

Figure 7: Journals wise collected articles

Figure 7 shows the total number of journals/articles published according to various domain of the COVID-19 related activities. Year wise publication of the collected article are shown in Figure 6. The actual investigation started slowly at the time of invention of COVID-19. Then it was accelerated after the first quadrant of 2020 in the domain of patient's detection and control as well as managing COVID-19 situation. In 2021, a huge number of researches regarding treatment analysis, after effects and vaccine distribution were published. Journal wise collected articles are shown in Figure 9, where most of the available articles are collected from Elsevier and rest are from other reputed libraries like Springer, MPDI, IOS press and well-known IEEE conferences. Figure 8 highlights the approaches of the published articles. Initially some algorithm based procedural approaches were considered to evaluate the scenario. After that machine learning based experimental concepts was used for predicting the future trends. Similarly, analytical based concepts were applied for estimating the upcoming situation according to collected information from the reliable sources.

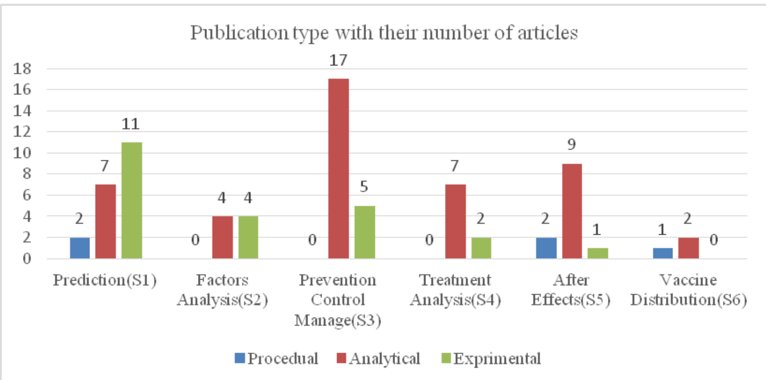

Figure 8: Domain wise published articles

The researcher used various type of fuzzy set theries to repreent COVID-19 relatated information in different way for acurately managing the situation. The collected articles those considered the various types of fuzzy theories are enlisted in Table 7, which shows that 54 articles out of 69 used the core fuzzy sets concepts and remaining 20 articles applied specified fuzzy version for indepth investication of COVID-19 in alternatives ways. We found that some of the authors used more than one types of fuzzy set theories in their article for implementing the proposed concepts.

Table 7: Fuzzy categorized wise published articles

Type of FSs	No. of articles	Domain	Article
FSs	53	Prediction	[30], [32], [35], [36], [37], [38], [39], [41], [42], [43], [45], [46], [47], [50], [52], [53], [54], [55], [77], [87], [96]
		Factor analysis	[58], [59], [60], [62], [64], [65], [92]
		Prevention	[50], [60], [63], [71], [76], [78], [79], [80], [81], [83], [84], [85], [86], [89] , [90], [117],
		After Effects	[88], [106], [107], [110], [111], [112]
		Treatment Analysis	[43], [97], [98], [99], [101]
		Vaccine Distribution	[121]
IFSs	5	Prediction	[34]
		Vaccine Distribution	[120]
		Prevention	[49]
		After Effect	[108], [105]
HFSs	4	Factor Analysis	[57]
		Treatment Analysis	[98], [100]
		Prevention	[88]
Type 2 Fuzzy Sets	3	Prediction	[31], [40]
		Treatment Analysis	[94]
NFSs	2	Treatment Analysis	[94]
		Vaccine Distribution	[120]
MFL	1	Prevention	[76]
FSSs	1	Factor Analysis	[62]
PFSs	1	Treatment Analysis	[92]
IVIFSs	1	Prevention	[71]
SFSs	1	After Effects	[112]
FFSs	1	Prevention	[28]
q-rung orthopair FSs	1	After Effects	[107]

The researchers published number of articles related to COVID-19 pandemic in the various journals or library. The domain wise published articles of each journal are shown in the Fig 9. We find mainly three types of articles which are shown in Table 10. Initially, most of researchers investigated to understand the nature of COVID-9 and observed the probable solutions. Then the proposed solutions were implemented through the experimental or procedural methods.

Table 8: Year wise published articles

Year	Month	No of Articles	Articles
2020	**Mar**	1	[38]
	Apr	2	[36], [60]
	May	3	[50], [55] , [98]
	Jun	4	[81], [112], [76],[51]
	Jul	2	[43], [82]
	Aug	4	[67], [87], [88], [89]
	Sep	2	[34], [80]
	Oct	3	[31], [33], [44]
	Nov	4	[32], [53], [61], [120]
	Dec	4	[48], [56], [57], [104]
	Unknown	5	[16], [49], [61], [94], [111]
2021	**Jan**	5	[37], [45], [87], [99], [100]
	Feb	3	[85], [106], [110]
	Mar	2	[62], [76]
	Apr	3	[84], [96], [41]
	May	6	[42], [63], [83], [92], [103], [119]
	Jun	7	[28], [30], [74], [79], [97], [107], [109],
	Jul	4	[48], [74], [84], [88]
	Sept	1	[54]
	Unknown	6	[38], [46], [47], [107], [97], [121],

Table 9: Different approach used in the articles

Approaches	No. of articles	Articles
Fuzzy Inference Engine	16	[16], [32], [35], [38], [53], [78], [80], [82], [85], [90], [91], [96], [97], [113], [106], [110]
Neural Network	5	[30], [32], [33], [53], [87]
Knowledge Based System	3	[37], [98], [107]
Distance Based Estimation	9	[34], [47], [48], [65], [86], [91], [102], [108], [121]
Rule Based System	5	[79], [36], [81], [39], [40]
Models Based	15	[33], [43], [46], [50], [55], [58], [62], [63], [64], [76], [95], [99], [100], [111], [112]
Optimization and Investigation	5	[42], [43], [85], [91], [105]
Algorithm Based	4	[25], [31], [41], [71],
Deep Learning	3	[47], [50], [52],
Support Vector Machine	1	[87]
Machine Learning	5	[30], [31], [41], [45], [52],
Time Series	1	[54],
Artificial Intelligence	2	[58], [76]
MCDM	9	[59], [74], [92], [101], [38], [109], [120], [87], [121]
Fractal Theory	2	[84], [72]
Cloud Base System	1	[89]

Table 10: Type of articles

Article Types	Citation	No of Articles
Investigation	[29], [34], [35], [36], [38], [39], [40], [43], [47], [48], [49], [50], [54], [55], [59], [62], [63], [64], [65], [68], [74], [75], [78], [80], [81], [82], [83], [85], [87], [89], [91], [96], [97], [98], [100], [102], [105], [106], [107], [108], [109], [110], [111], [113]	44
Experimentation	[30], [31], [37], [41], [42], [45], [48], [50] [52], [54], [56], [58], [59], [60], [67], [84], [85], [88] [90], [99], [46], [101], [113]	23
Procedural	[35], [33],[116], [115]	4

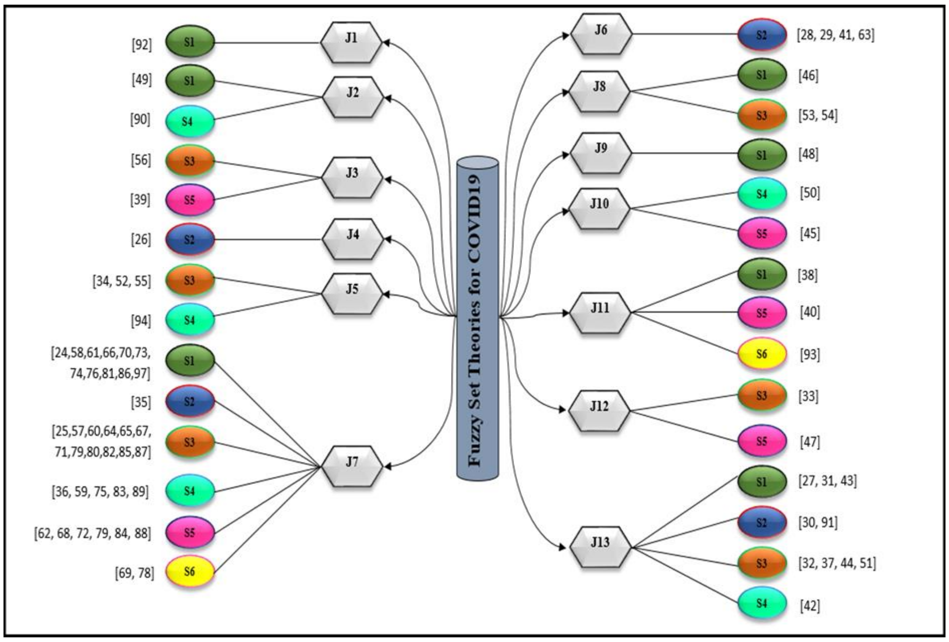

Figure 9: Domain wise citation of various journals

9. CONCLUSION AND FUTURE OUTLINE

Since December 2019, the entire world was running through a pandemic situation that has badly exaggerated the human community and the scientists or researchers found it very difficult to provide any constructive or strong measures to manage this unwanted situation. They introduced and analyzed various models for the purpose of COVID-19 predictions and proposed necessary measures required for precautions. Researchers also studied various methods to suitable distribute the vaccine among the needy people in order to mitigate the impact of COVID-19. Many of the experts proposed their models using fuzzy sets and its extensions as fuzzy set was considered to be more useful to deal with the uncertainties associated with COVID-19. Researchers applied fuzzy set theories primarily for the proposed model development and analyzing the uncertain situation to manage

COVID-19 related scenarios. In this study, we have represented and elucidated the voluminous works in the domain of fuzzy set theories for managing and controlling the effects of the COVID-19. We have reviewed the different research articles related to the pandemic in the domain of the fuzzy systems. After the invention of COVID-19 in December 2019, several fuzzy set based models, procedures and expert systems were developed by the researchers. The researchers introduced several different techniques or approaches for the purpose of predicting the infected patients of COVID-19, analyzing the role of various factors, analyzing the treatments of infected patients, preventing and controlling the situation, distributing the vaccine among the communities after final approval by regulatory bodies, and for measuring the after effect of the COVID-19 situation. In this study, we have analyzed the articles related to COVID-19 in the domain of fuzzy set theories and its extensions. The researchers have started their investigation regarding COVID-19 at the beginning of 2020 but large scale analysis was considered at the end of the first quarter of 2020 when the whole world become stagnant due to malicious virus. We observed that initially the researchers did not have sufficient information regarding the COVID-19 virus and proposed various conventional approaches to identify, prevent and control the infections. Then gradually the researchers gripped the behavior of COVID-19 and pushed research one step ahead, to prevent the infection, control intensity and minimize the penalty. Thereafter, the researchers found some relevant information to collect the strong evidence of COVID-19 and introduced the various intelligence systems to manage the COVID-19 in more scientific manner. The outcome and analysis reports of this study highlight the importance of the fuzzy system as a beneficial tool for healthcare workers and first responders' emergency professionals to face this pandemic as well as to manage the created uncertainty and its related risks.

In the future, researchers can use this article to quickly identify research gaps and address them by introducing innovative concepts. The COVID-19 pandemic affected every community, with some groups encountering challenges due to home quarantine, while others felt overwhelmed trying to provide emergency services to those in need. This situation highlighted new issues requiring researchers' attention to develop simpler and more effective approaches for managing the pandemic. As a potential future direction, research can be scientifically extended in various ways across different domains to combat the pandemic. For instance, researchers may propose isolation procedures based on fuzzy inference systems and/or machine learning for suspected patients to disrupt the virus's transmission chain. Additionally, the performance of various uncertain functionalities related to safe home practices can be assessed using multi-criteria decision-making and optimization techniques. A model for controlling the pandemic could be developed using convolutional neural networks to manage uncertain parameters more accurately. Fuzzy clustering techniques may be employed to identify suitable locations for establishing quarantine centers that adhere to COVID-19 protocols. Similarly, fuzzy matching techniques could be utilized to create a bed allocation model for COVID-19 hospitals when accurately measuring the number of infected patients proves challenging. Furthermore, a more precise fuzzy time series forecasting model may be developed to estimate the unpredictable infection rate. A closed-loop exert system could be introduced to help rehabilitate the educational sector and health insurance industry from their decline. Researchers may also propose a group multi-criteria decision-making method to formulate future work plans for affected manufacturing industries, estimating financial support, manufacturing rates, and production quality. To address the job crisis faced by daily workers and the shortage of cash flow, efficient decision-making models based on fuzzy sets and their extensions may be explored. Utilizing regression-based machine learning techniques, researchers can predict future trends in work-from-home policies in IT industries based on the companies' profit and loss. Moreover, data analytical methods such as confusion matrices and kappa coefficients might be employed to evaluate the performance of vaccines on a country-by-country basis, facilitating the development of corresponding recovery plans. Researchers could also consider extensions of fuzzy logic, such as cloud-based fuzzy systems, to collect COVID-19-related information more accurately, which would help extract relationships among uncertain parameters related to the virus, ultimately improving system performance.

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