Fuzzy Logic for Diabetes Predictions: A Literature Review

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Abstract: The use of methodologies based on machine learning is being increasingly used in health systems today, addressing different areas such as food, society, health and others. In terms of health, different techniques were applied to classify different diseases. In this sense, diabetes is an important and silent disease that deserves special attention and care. Individuals often do not know they have it, and, therefore, seeking alternatives to predict this disease is an important contribution to the health area. Thinking about it, in this work we present a systematic review of the literature with the objective of observing which strategies are currently being used to predict and classify diseases using fuzzy logic, in particular, diabetes. For this, 6 works were selected and analyzed, where the technique for obtaining the considered information is the blood test, in order to understand the current state of the art.

1 INTRODUCTION

Health has always been and will be an extremely important subject to be debated. Either through the incessant search for new methods that can mitigate the risks of getting diseases, or through the search for new strategies that can somehow contribute to the improvement of the health system.

The use of machine learning techniques (Bonaccorso, 2017) has been increasingly used in several areas of society, including medicine. For example, in (Saleck et al., 2017) the authors used a clustering algorithm to detect tumors in mammography images. In (Bergquist et al., 2017), the authors used machine learning to classify lung cancer patients receiving chemotherapy into early-stage versus advanced-stage cancer.

Diabetes is a disease caused by insufficient production or poor absorption of insulin, a hormone that regulates blood glucose and provides energy for the body (Grillo and Gorini, 2007). Diabetes can cause increased blood glucose and can lead to complications in the heart, arteries, eyes, kidneys and nerves. In more severe cases, diabetes can even lead to death.

According to the Brazilian Society of Diabetes [1], at the end of 2021, Brazil had more than 13 million people living with diabetes, which represents about 6.9% of the Brazilian population. Diabetes can present itself in different ways and has several different types, with type 2 diabetes being the one that most affects people, about 90% of people with diabetes have type 2. Depending on the severity, diabetes can be controlled with physical activity and dietary planning, but in other cases, it requires the use of insulin and/or other medications to control glucose (Lyra et al., 2006).

One of the tasks most used by machine learning techniques refers to the prediction problem. Predictive analysis basically consists of applying algorithms to understand the existing data structure and generate ways to help predict new cases. According to (Dos Santos et al., 2019), in the health area, predictive models can be used to estimate the risk of a given outcome occurring, considering a set of characteristics, such as: socioeconomic and demographic aspects, related to lifestyle and health conditions, among others. In addition, the correct use of prediction models can result in positive implications in terms of cost reduction and the effectiveness of interventions, such as treatments and preventive actions.

Considering the severity and consequences that diabetes can have on people's lives, it was understood

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[1] https://diabetes.org.br/

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that monitoring the variables involved in the detection of diabetes could be a way of mitigating the risks for those people who already have the disease, or even prevent the disease from manifesting itself in new people. In addition, the need to control several variables that can aggravate or even cause diabetes also led to the need not only to monitor, but also to control such variables.

For this, however, it was necessary to know the state of the art with regard to methodologies used in the health area in the classification and prediction process that could help in understanding the problem and in the elaboration of a new methodology.

In order to try to map which techniques are being most used in the prediction of diseases and, mainly, in the prediction of diabetes, it was decided to carry out a systematic review, so that one could find what is currently state-of-the-art in what concerns related to disease prediction.

In addition, the idea is also to find, from the systematic review, how fuzzy logic (Zadeh et al., 1996) is being used in this area, since it is an approach that uses linguistic terms and therefore manages to return interpretable results. We pointed out that fuzzy logic allows the possibility of modeling such linguistic terms according to the domain expert, which can be an advantage over other methods. Therefore, fuzzy logic based questions were included in this review.

Then, a systematic review of the literature was carried out, in 4 bibliographical sources (BS), considering 4 research questions.

The general objective of this work is to identify the prediction and classification methodologies, mainly involving fuzzy logic, which are being used in the health field, in particular, in relation to diabetes.

The rest of the article is divided into four sections. The first presents the definition and steps to build a systematic review; the second presents the methodology adopted for carrying out the systematic research, as well as the discussion in each of the stages; the third presents the obtained results; and the last presents the conclusions obtained from the construction of this work.

2 SYSTEMATIC REVIEW

According to (Cordeiro et al., 2007), the Systematic Literature Review (SLR) consists of a research method that aims to identify, evaluate and interpret all relevant research on specific issues or area of interest. From the use of the SLR it is possible to sort and synthesize studies from the definition of questions and/or keywords, making the review much fairer.

A research protocol must be defined and must contain four generic steps: the first one is responsible for defining the research questions that the systematic review intends to answer and that will serve as a guideline for the study; the second defines the search strategy, including the databases and search terms that will be considered to identify and select the articles; the third defines the inclusion and exclusion criteria; and the fourth and last, is responsible for defining how to characterize the studies, which information will be extracted and how it will be synthesized and analyzed (Keele et al., 2007) (Ercole et al., 2014).

The main advantage with regard to carrying out a systematic review, according to (Ercole et al., 2014), consists in the fact that a well-defined methodology ends up making it less likely that the results of the literature are biased, that is, it tends to prevent articles from chosen by the writer are only those who support his/her point of view.

3 METHODOLOGY

The methodology used to carry out the systematic review followed the method presented by (Keele et al., 2007), and is summarized in the flowchart presented by Figure 1. In it, as the process evolves, the articles found in searches are removed from the scope of the study. Below, for each one of the four keys stages of the systematic review process, the adopted criteria will be discussed in detail.

3.1 Research Questions

The first step, to start the systematic review process, is related with the definition the research questions necessarily to be answerd. Such questions are responsible for giving rise to the search terms and combinations of keywords used during searches in the databases used.

Considering the problem previously discussed in the Introduction, four research questions were separated, namely:

- **Question 1**: What are the predictive methods used to adjust models on different blood laboratory test variables?
- **Question 2**: Which classification methods are used to fit models on different blood laboratory test variables?
- **Question 3**: What are the predictive methods used to adjust models on different health databases?

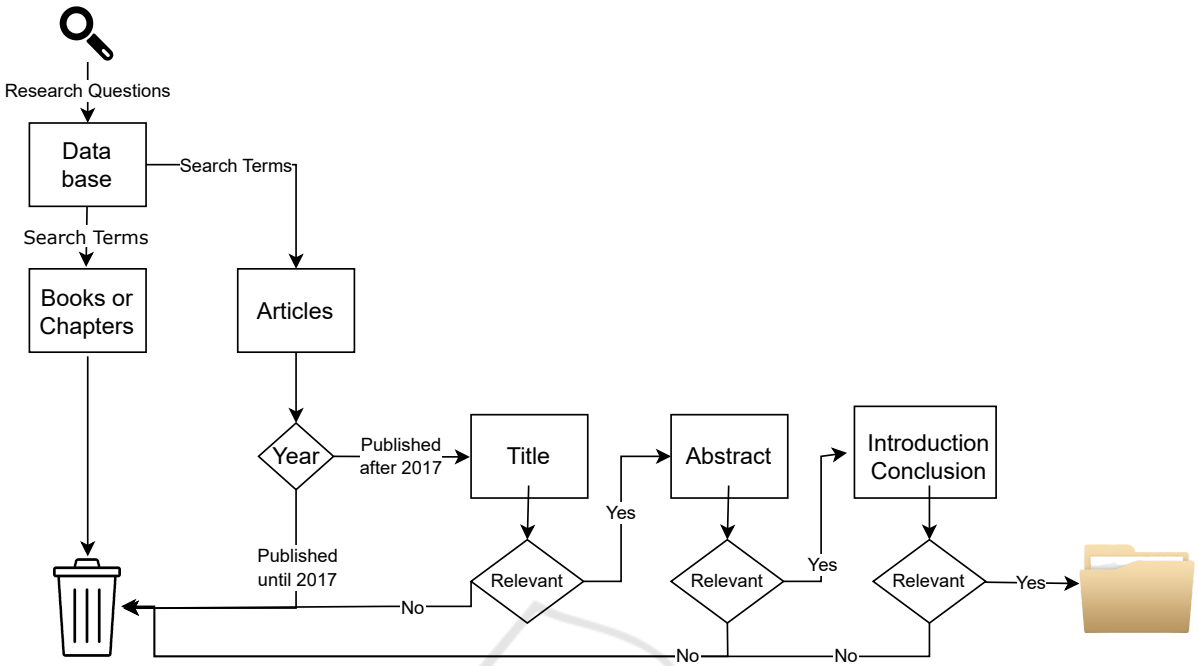

Figure 1: Flowchart of the theoretical review methodology (Source: Elaborated by the author).

- **Question 4**: Which classification methods are used to fit models on different health databases?

It should be noted that for each of the planned surveys, the existing fuzzy logic related to predictive methods was also analyzed, since the idea of the work is to use fuzzy logic to predict diabetes based on information extracted from blood tests.

3.2 Search Terms

The search terms were defined from the four research questions previously presented. We highlight the fact that we chose to consider the search terms only in English.

The search terms considered for the construction of combinations of keywords were: blood test, health database, classification, prediction and fuzzy. From these selected search terms, some combinations of keywords were elaborated that were used in the systematic research in the selected databases. In Table 1, the relation of keywords (K) used are presented.

3.3 Considered Data Bases

To perform a complete and more robust search, different digital libraries were considered. Precisely, the queries were performed in:

- IEEE Xplore[2];

[2]https://ieeexplore-ieee-org.ez40.periodicos.capes.gov.br/Xplore/guesthome.jsp

Table 1: Keyword combinations used.

K	Combination
1	“blood test” and “prediction”
2	“blood test” and “classification”
3	“blood test” and “prediction” and “fuzzy”
4	“blood test” and “classification” and “fuzzy”
5	“health database” and “prediction”
6	“health database” and “classification”
7	“health database” and “prediction” and “fuzzy”
8	“health database” and “classification” and “fuzzy”

- ACM Digital Library[3];
- Scopus[4];
- SpringerLink[5].

3.4 Exclusion/Inclusion Criteria

Exclusion Criteria (EC) are defined as aspects of the study that meet the inclusion criteria, but have additional characteristics that could interfere with the success of the study or increase the risk of obtaining unnecessary information for the study. The considered ECs were:

- EC 1: Articles published before 2017, because

[3]https://dl-acm-org.ez40.periodicos.capes.gov.br/

[4]https://www-scopus.ez40.periodicos.capes.gov.br/search/form.uri?display=basic#basic

[5]https://link-springer-com.ez40.periodicos.capes.gov.br/

Table 2: Total articles returned for each of the steps described.

BS	Initial		EC 1		EC 2 e 4		EC 3	
IEEE Xplore	K1: 30	K5: 4	K1: 20	K5: 4	K1: 18	K5: 4	K1: 18	K5: 4
	K2: 32	K6: 1	K2: 20	K6: 1	K2: 19	K6: 1	K2: 19	K6: 1
	K3: 2	K7: 0	K3: 2	K7: 0	K3: 2	K7: 0	K3: 2	K7: 0
	K4: 2	K8: 0	K4: 1	K8: 0	K4: 1	K8: 0	K4: 1	K8: 0
	Total: 71		**Total: 48**		**Total: 45**		**Total: 45**	
SpringerLink	K1: 9251	K5: 596	K1: 5052	K5: 374	K1: 2902	K5: 190	K1: 2892	K5: 190
	K2: 17494	K6: 1355	K2: 8812	K6: 766	K2: 5549	K6: 527	K2: 5345	K6: 526
	K3: 861	K7: 106	K3: 624	K7: 81	K3: 123	K7: 9	K3: 123	K7: 9
	K4: 991	K8: 116	K4: 679	K8: 87	K4: 143	K8: 13	K4: 143	K8: 13
	Total: 30770		**Total: 16475**		**Total: 9456**		**Total: 9241**	
Scopus	K1: 1321	K5: 67	K1: 698	K5: 44	K1: 672	K5: 41	K1: 636	K5: 41
	K2: 974	K6: 148	K2: 488	K6: 75	K2: 475	K6: 65	K2: 441	K6: 65
	K3: 7	K7: 0	K3: 6	K7: 0	K3: 6	K7: 0	K3: 6	K7: 0
	K4: 7	K8: 1	K4: 2	K8: 0	K4: 2	K8: 0	K4: 2	K8: 0
	Total: 2525		**Total: 1313**		**Total: 1261**		**Total: 1191**	
ACM	K1: 92	K5: 13	K1: 66	K5: 6	K1: 45	K5: 4	K1: 45	K5: 4
	K2: 152	K6: 18	K2: 69	K6: 6	K2: 49	K6: 5	K2: 49	K: 5
	K3: 16	K7: 2	K3: 12	K7: 0	K3: 7	K7: 0	K3: 7	K7: 0
	K4: 23	K8: 3	K4: 12	K8: 0	K4: 8	K8: 0	K4: 8	K8: 0
	Total: 319		**Total: 171**		**Total: 118**		**Total: 118**	
Total by K	K1: 10694	K5: 680	K1: 5836	K5: 428	K1: 3637	K5: 239	K1: 3591	K5: 239
	K2: 18652	K6: 1522	K2: 9389	K6: 848	K2: 6092	K6: 598	K2: 5854	K6: 597
	K3: 886	K7: 108	K3: 644	K7: 81	K3: 138	K7: 9	K3: 138	K7: 9
	K4: 1023	K8: 120	K4: 694	K8: 87	K4: 154	K8: 13	K4: 154	K8: 13

the idea is to observe what is newest being developed and studied by scholars and researchers in the area;

- EC 2: Books and book chapters, because the idea is to find what is being developed by other researchers in recent years and not the concepts and definitions related to the subject addressed in the work;
- EC 3: Works that are not in English;
- EC 4: Works that are not fully published. Ex. drafts;
- EC 5: Articles returned in combinations that do not involve fuzzy logic.

Inclusion Criteria (IC) are defined as the key characteristics of the population or research being carried out. The ICs are used to answer the research questions and are presented below:

- **Title**: Does the paper deal with machine learning with diabetes or prediction or classification using fuzzy logic for diabetes?
- **Abstract**: Does the article explain the use of fuzzy logic in predicting blood test data? Does the paper explain about the use of fuzzy logic in classifying blood test data? Does the paper describe methods of predicting or classifying blood test data? Does the paper present prediction or classification in a blood test database?
- **Introduction and Conclusion**: Are the objectives clearly defined? Are the prediction or classification methods clearly defined? Does the study present the idea of using fuzzy logic in predicting or classifying blood tests? Does the study present the blood test database used?

3.5 Selecting Works

In this subsection, the data related to exclusion and inclusion criteria are presented, as well as the number of articles that were returned from the application of each of the previously listed criteria.

The first step consisted of carrying out a search for each of the previously highlighted keyword in the considered databases, without considering, at first, any exclusion criteria. In Table 2, the total number of articles returned for each search order. By line, the digital libraries are considered and by columns, the stages of the review process (see Figure 1).

Then, it was decided to apply the exclusion criterion related to the year of publication of the returned results. For this case, therefore, only the results published from 2017 to the present were considered. This exclusion criterion reduced the total number of returned results, as shown in column “EC 1” of Table 2.

The next steps consisted of applying the other exclusion criteria. The column “EC 2 e 4” of Table 2 presents the results after excluding books and book

chapters and also articles that were not fully published, while the column "EC 3" of Table 2 presents the results after the application of the EC referring to the language in which the article was published.

In short, Table 2 presents for each of the bibliographic sources the total number of articles returned for each K, as well as the total number of articles returned per database. In addition, through Table 2 it can be observed that with each EC applied, the total number of articles returned, not only by K, but also by bibliographic source, decreased.

After evaluating the returned results, it was found that a very large number of results had been returned in combinations of words that did not include the word "fuzzy". Thus, it was decided to remove such combinations from the analysis, since the main focus of this work was to find studies that used fuzzy logic in the process of predicting or classifying health problems. Thus, instead of 8 Ks, only 4 were considered, as shown in Table 3.

Table 3: Total articles selected from the application of all exclusion criteria.

K	IEEE Xplore	Springer Link	Scopus	ACM Dig. Lib.	Total
3	2	123	6	7	138
4	1	143	2	8	154
7	0	9	0	0	9
8	0	13	0	0	13
Total	3	288	8	15	314

Analyzing Table 3, it can be seen that the IEEE Xplore library was the one that returned a smaller number of articles considering all Ks. On the other hand, SpringerLink was the library that returned the highest number of results. In addition, the K that returned the most articles was K4, which considered the relationship of "blood test" and "classification" and "fuzzy".

After applying all the previously listed exclusion criteria, the next step is to apply the inclusion criteria. In this case, the title of all pre-selected works is initially evaluated. If the title did not meet the established criteria, the article was rejected, if it did, it moved on to the next analysis. After checking the title of the 314 articles that had remained, 124 articles still remained. It is noteworthy that, at that time, they were not yet being analyzed whether the same article was appearing in more than one combination or in more than one database.

The next step consisted of analyzing the abstract and the idea was similar to that of the title, if the abstract did not present the desired information, the work was discarded, otherwise, the introduction and conclusion of the work were evaluated. Figure 2 presents the summary of the number of articles excluded from the application of each exclusion and inclusion criteria considered in this systematic review.

Therefore, after applying all the inclusion criteria, the total number of selected articles was equal to 6, whose title information, authors and year of publication are presented in Table 4.

Next, the 6 selected articles will be briefly discussed, using each of the considered research questions as a guide. It should also be noted that a certain study can answer one or more questions.

4 RESULTS

In this section, each of the selected articles is briefly presented, highlighting the questions that each one of them answers, as well as highlighting their main points.

However, before starting such an analysis, it was decided to create a word cloud from the six selected articles. The cloud was generated from the full text of all articles, that is, all sections of each article were considered and not just any specific one. The purpose of creating a word cloud is to observe which words appear more frequently in the analyzed articles. For the construction of the cloud presented by Figure 3 the words/terms that appear more than fifty times were considered.

Thus, it can be concluded that the words that appear most frequently are precisely those words that form the scope of study of this work, that is, those words that formed the queries. In addition to these, words such as patients and diabetes also appear frequently, since even though they were not part of the queries, they were terms that were part of the general scope of the work and were even used as inclusion criteria for the selection of articles.

The study presented by (Goldar et al., 2020) arises as an answer to research questions 1 and 2, since it works with a prediction system for laboratory tests. The prediction techniques used were Takagi-Sugeno zero order fuzzy modeling and sequential direct selection method. The authors proposed a prediction approach in order to predict values of laboratory tests of patients admitted to the ICU with gastrointestinal hemorrhage.

A study that helps answer research question 2 and 4 is presented (Wedagu et al., 2020). The study disregards the question of blood tests, since it aims to propose a recommendation method called DIMERS (Diabetes Medicine Recommendation System, which combines a previous medical knowl-

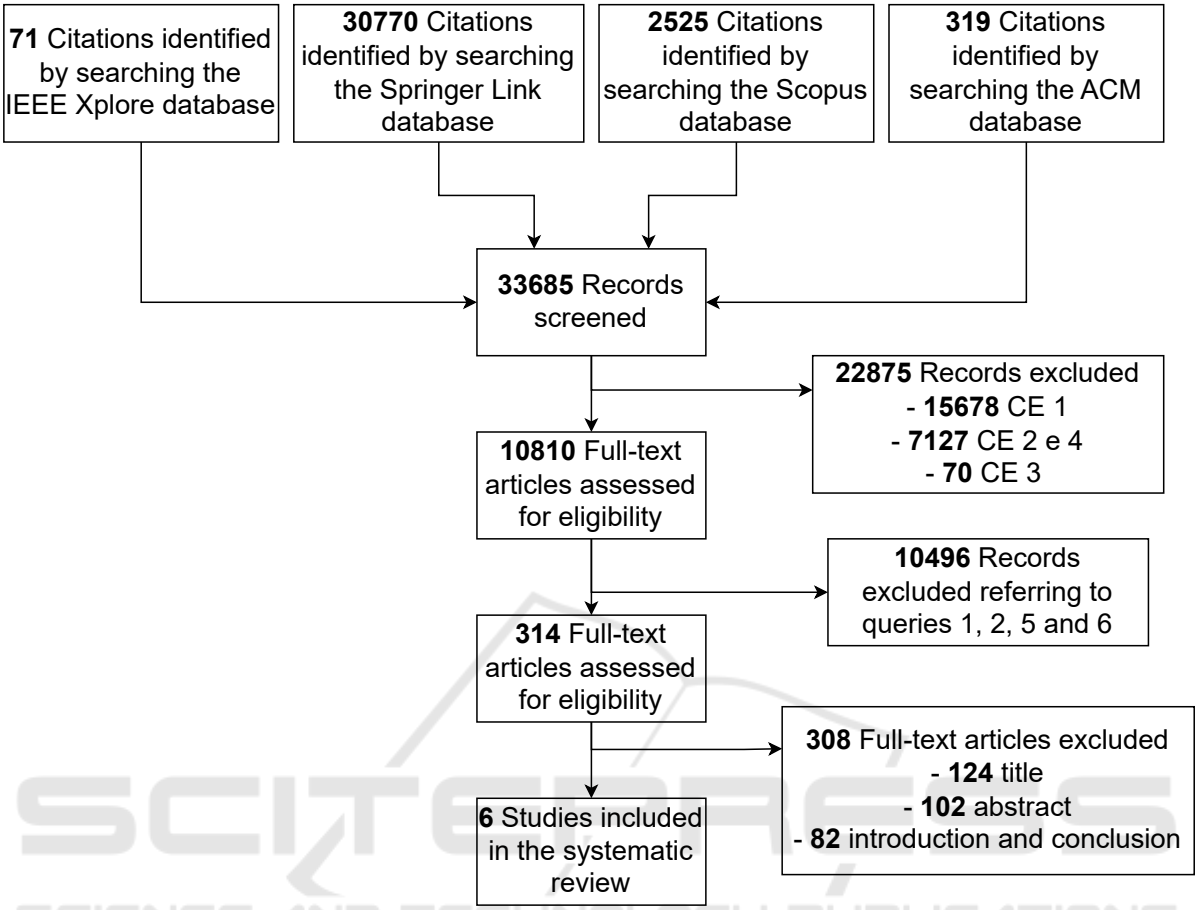

Figure 2: PRISMA Flow Diagram (Source: Elaborated by the author).

edge of doctors with bidirectional long-term memory (BiLSTM), in order to correctly recommend medications for diabetes. Also, according to this study, more than 250,000 people die from medication errors, which makes it necessary to use machine learning approaches to correct such problems. However, most of the approaches adopted do not consider prior medical knowledge, meaning that they do not have a result as satisfactory as what is being proposed in the study.

The study presented by (Deif et al., 2021), despite not meeting the inclusion criteria IC1, was considered as it aims to use an Adaptive Neuro-Fuzzy Inference System (ANFIS) to quickly detect cases of COVID-19 from commonly available laboratory tests . Thus, this study answers research question 1, since it uses the fuzzy methodology to predict, from blood tests, whether or not the patient has COVID-19.

Fasting blood glucose is considered one of the most important indicators of diabetes, but its testing is not feasible for the public and requires prior preparations before implementation. Thus, the study presented by (Faraji-Biregani and Nematbakhsh, 2019) aims to present a model for predicting fasting blood sugar from other factors in blood tests. For this, the sine-cosine optimization algorithm and neural networks (RNN) are used to perform the prediction. The study was the one of that best answered the research questions, being able to answer the four questions simultaneously.

Different machine learning techniques, such as the Adaptive Neuro-Fuzzy Inference System (ANFIS), K-Nearest Neighbors (KNN) and Decision Tree (DT) were applied in (Kalaiselvi et al., 2022). Such techniques can help in decision making of the physician's decision in the process of predicting liver disease. This study answers questions 1 and 2, since, based on blood tests, it uses machine learning techniques to help physicians predict and classify liver diseases. In addition, one of the techniques presented by the study makes use of fuzzy logic, which is also of interest to be analyzed. Together with the study presented in the previous paragraph, this work was classified as one that best answered the listed research questions.

In (Jamuna and Mohan Kumar, 2020), it is pre-

Table 4: Basic information of selected articles.

Title	Authors	Year	Total Citations	Diabetes	Fuzzy
Predicting lab values for gastrointestinal bleeding patients in the intensive care unit: A comparative study on the impact of comorbidities and medications	Mahani, Golnar K and Pajoohan, Mohammad-Reza	2019	2	No	Yes
Medicine Recommendation System For Diabetes Using Prior Medical Knowledge	Wedagu, Mulubrhan Ayalew and Chen, Dehua and Hussain, Muhammad Ather Iqbal and Gebremeskel, Tsegay and Orlando, Mayugi Tanguy and Manzoor, Arslan	2020	0	Yes	No
Adaptive neuro-fuzzy inference system (ANFIS) for rapid diagnosis of COVID-19 cases based on routine blood tests	Deif, Mohanad and Hammam, Rania and Solyman, Ahmed	2021	9	No	Yes
Diabetes Prediction Recommender System based on Artificial Neural Networks and Sine-Cosine Optimization Algorithm	Faraji-Biregani, Maryam and Nematbakhsh, Nasser	2019	1	Yes	No
Liver Disease Prediction Using Machine Learning Algorithms	Kalaiselvi, R and Meena, K and Vanitha, V	2021	1	No	Yes
Prediction of Diabetes and Clustering Based on its Levels using Fuzzy C Means Algorithm	S. Jamuna, K. Mohan Kumar	2020	1	Yes	Yes

Figure 3: Word cloud assembled from the six selected articles (Source: Elaborated by the author).

sented a study that aims to classify patients according to three levels of diabetes: non-diabetic, pre-diabetic or diabetic. For this, it makes use of the Fuzzy C−Means algorithm. The information used by the algorithm comes from blood tests of patients. Like the last two works, this study was also considered one of the three that best answered the research questions, since it answers all the items of research question 2, since it is based on blood test data, uses fuzzy techniques, performing the classification of patients according to the level of diabetes.

Finally, we highlight the fact that the questions that were best answered are related to the prediction and classification methodologies used in the health area. In summary, it can be concluded that of the 6 selected articles: 4 of them answered research question 1, 5 papers answered question 2, 1 answered question 3 and 2 answered question 4.

5 CONCLUSION

Methodologies based on machine learning are increasingly being used to solve problems associated with healthcare. Diabetes is a disease that needs special care because it is a silent disease, making many

individuals not even know they have such a disease.

Considering the problems mentioned above, the objective of this work is to identify forecasting and classification methodologies, mainly involving fuzzy logic, used to help the health area.

To this end, a systematic review was carried out with the objective of finding prediction and classification methods for diabetes or even for other diseases, but that could help in understanding the state of the art, that is, that could facilitate the understanding of which techniques, currently, are being used to predict or classify health problems.

In order to carry out the systematic review, inclusion and exclusion criteria were considered so that the works found could be filtered and, at the end, those that best met the pre-established conditions could be studied.

Thus, at the end of the work, it was possible to observe that techniques using fuzzy logic, such as: Fuzzy C−Means, ANFIS and Takagi-Sugeno zero order fuzzy modeling are being used and from that it can be observed which is the best way to contribute in the area proposing techniques that can improve the quality/perfomance/explainability/interpretability of the existing related methods.

The next step, therefore, consists of implementing a fuzzy methodology for predicting diabetes based on blood test variables and also on information provided by the patients themselves, such as: sleep, physical activity and diet.

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