Informatics in Medicine Unlocked 2 (2016) 12–37

Contents lists available at ScienceDirect

Informatics in Medicine Unlocked

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

Ebinformatics: Ebola fuzzy informatics systems on the diagnosis, prediction and recommendation of appropriate treatments for Ebola virus disease (EVD)

Olugbenga Oluwagbemi [a,*], Folakemi Oluwagbemi [b], Oluyemi Abimbola [b]

[a] *Department of Computer Science, Faculty of Science, PMB 1154, Federal University Lokoja, Nigeria*
[b] *Software Engineering Unit, Department of Computer and Information Sciences, College of Science and Technology, Covenant University, Ogun State, Ota, Nigeria*

ARTICLE INFO

Article history:
Received 19 June 2015
Received in revised form
11 December 2015
Accepted 11 December 2015
Available online 21 February 2016

Keywords:
Ebola
Informatics
Fuzzy
Diagnosis
Recommender

ABSTRACT

Ebola Virus Disease (EVD) also known as the Ebola hemorrhagic fever is a very deadly infectious disease to humankind. Therefore, a safer and complementary method of diagnosis is to employ the use of an expert system in order to initiate a platform for pre-clinical treatments, thus acting as a precursor to comprehensive medical diagnosis and treatments. This work presents a design and implementation of informatics software and a knowledge-based expert system for the diagnosis, and provision of recommendations on the appropriate type of recommended treatment to the Ebola Virus Disease (EVD).

In this research an Ebola fuzzy informatics system was developed for the purpose of diagnosing and providing useful recommendations to the management of the EVD in West Africa and other affected regions of the world. It also acts as a supplementary resource in providing medical advice to individuals in Ebola – ravaged countries. This aim was achieved through the following objectives: (i) gathering of facts through the conduct of a comprehensive continental survey to determine the knowledge and perception level of the public about factors responsible for the transmission of the Ebola Virus Disease (ii) develop an informatics software based on information collated from health institutions on basic diagnosis of the Ebola Virus Disease-related symptoms (iii) adopting and marrying the knowledge of fuzzy logic and expert systems in developing the informatics software. Necessary requirements were collated from the review of existing expert systems, consultation of journals and articles, and internet sources. Online survey was conducted to determine the level at which individuals are aware of the factors responsible for the transmission of the Ebola Virus Disease (EVD). The expert system developed, was designed to use fuzzy logic as its inference mechanism along with a set of rules. A knowledge base was created to help provide diagnosis on the Ebola Virus Disease (EVD). The Root Sum Square (RSS) was adopted as a fuzzy inference method. The degree of participation of each input parameter was shown using the triangular membership function and the defuzzification technique used is the Center of Gravity (CoG).

The resulting software produced a user-friendly desktop-based, Windows-based, application and the tools used were explained in the results section in three (3) separate phases. First, a comprehensive online survey was conducted over a period of about 3–9 months. 100 Participants participated in the survey on the perception and knowledge analysis of different individuals about Ebola Virus Disease (EVD) transmission factors. 31% of the participants didn't know that there is presently no cure for Ebola. 28% believed that there is presently a cure for Ebola. 43% agreed that Ebola is both air-borne and water-borne, while 33% disagreed, 24% do not know. 23% believed that insects and mosquitoes can help in transmitting the Ebola Virus Disease (EVD), while 30% were completely ignorant. We noticed that ignorance was a major limiting factor among some participants.

Second, a test was conducted among 45 people. Results from a comprehensive testing of the Ebinformatics software by allowing users to operate and use the software, revealed that 60% of them were satisfied, while 16% were not satisfied with the software, while 24% were indifferent. 69% of the users were in agreement that Ebinformatics was supportive, 20% disagreed, while 11% were indifferent. 67% found the software easy to use, 13% disagreed, while 20% were indifferent. Third, the output of the

* Corresponding author. Tel.: +234 8066533717.
E-mail addresses: gbemiseun@yahoo.com, olugbenga.Oluwagbemi@fulbrightmail.org (O. Oluwagbemi).

http://dx.doi.org/10.1016/j.imu.2015.12.001

software, showing the various diagnosis and recommendations interfaces were presented. Recommendations were also given with respect to how the system can be extended, and further improved upon.

1. Introduction

The deadly, scary spate and debilitating effects of the Ebola Virus Disease (EVD) in the West African sub-region, especially in 2014, left terrifying, untold hardships and discrimination mostly among the affected West African countries [1–3]. Many are yet to fully recover from the Ebola scare and the psychological trauma it generated. It is a known fact that the Ebola Virus Disease (*henceforth*, EVD), is a very contagious and deadly disease. Presently, there is no globally recognized or known cure for the disease. Other problems associated with the disease are lack of proper knowledge in diagnosing and managing the disease especially among countries in Sub-Sahara Africa. In some cases, lack of proper training for medical experts to effectively and efficiently manage the disease constitutes a problem. With these in view, there is need for a practical implementation of a complementary system that can diagnose and provide excellent recommendations to individuals in order to curb the spread of the disease. Such system will also act as a supporting tool for medical experts and resident doctors in training. The aim of this research is to develop an Ebola Fuzzy Informatics system for the purpose of diagnosing and providing useful recommendations for the management of the EVD in West Africa and other affected regions of the world. It will also help in providing medical and health advice to individuals in Ebola – ravaged countries. In order to achieve the specified aim, the following objectives will be achieved. They are (i) Gather facts by conducting a comprehensive preliminary survey to determine the perception of the public about factors responsible for the spread of the Ebola virus (ii) develop a system based on modeled facts for the basic diagnosis and provision of recommendations on the Ebola Virus Disease (iii) adopt the knowledge of fuzzy logic and expert systems concept developing the proposed system. As a result of the recent pandemic and great epidemic of EVD in West Africa [1–3] in 2014, it is evident that there is an urgent need of an informatics system that can be made available to people irrespective of their geographical location or region. This will provide individuals with the necessary support in diagnosing and providing appropriate recommendations to users of the informatics software.

2. Materials and methods

2.1. Review of relevant literature

Many works have been conducted in times past with respect to developing diagnosis and predictive-related informatics applications for disease management. Eslami and colleagues [4] developed an expert system with the ability to appropriately and correctly

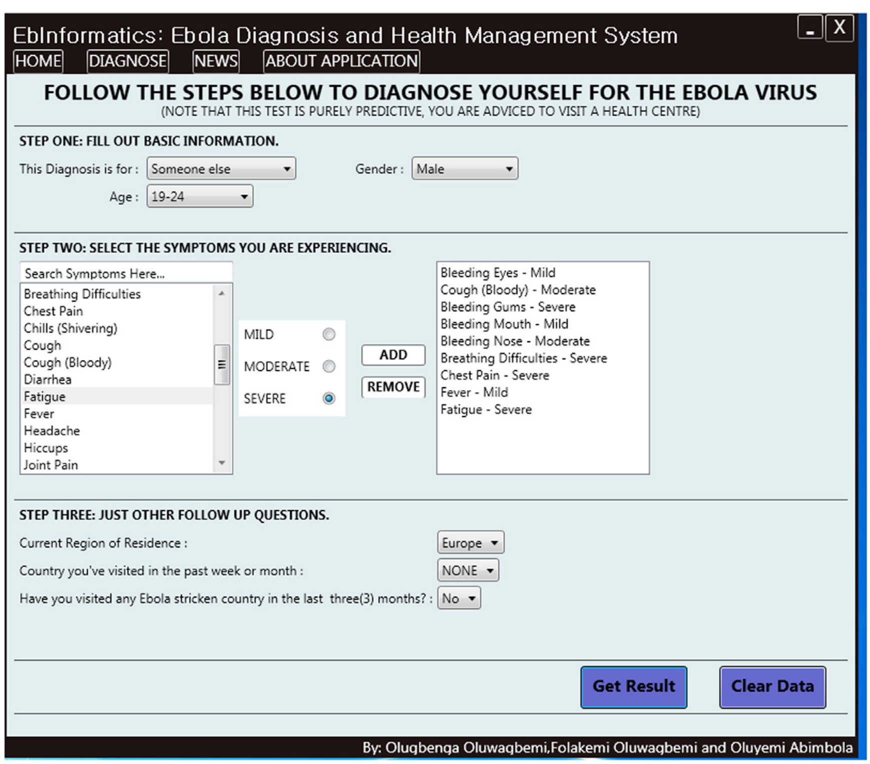


Fig. 1a. EbInformatics Software depicting the symptoms of Patient 0002. The Ebinformatics graphical user interface depicting the three different sections of the software. These are the basic information section, symptoms selection section and other follow-up question section. Here, some symptoms were selected for the diagnosis of patient 0002. Patient 0002 is a male patient, aged between 19 and 24; The symptoms selected for patient 0002 were: Bleeding Eyes – Mild; Cough (Bloody) – Moderate; Bleeding Gums – Severe; Bleeding Mouth – Mild; Bleeding Nose – Moderate; Breathing Difficulties – Severe; Chest Pain – Severe; Fever – Mild; Fatigue – Severe; Current region of residence was Europe. No country visited by the patient in the last 1 week or 1 month or in the last 3 months.

analyze the responses data collated from people with the use of questionnaires to diagnose headache. Yasnoff and Miller [5] developed a decision support system in the aspect of childhood immunization forecasting. In another study, Woolery and Grzymala-Busse [6] explored the feasibility of applying machine learning to generate predictive expert system for preterm delivery. Klausner and colleagues [7] developed a guideline software that can assist to provide health care system with optimal clinical practice. A useful fuzzy expert system was developed by Azim and colleagues [8] for the detection of fatigue among drivers in order to prevent road accidents. Alder and colleagues [9] conducted a review on different expert systems that have been developed and applied Rheumatology. Duan and colleagues [10] applied the knowledge of prefix-tree to create a Nursing care recommender system. Ati and colleagues [11] developed a hybrid recommendation system for chronic diseases by adopting the multiple classification and unified collaborative filtering methods. Shortlife [12] conducted a review on expert systems in the field of medicine and possible systems that will be useful to physicians in the future λ. Amindito and colleagues [13] developed an expert and advisory system for the prevention of stroke. Another set of scientists developed a fuzzy expert system for the diagnosis and management of male impotence [14]. Mailafiya and Isiaka [15] developed an expert system to diagnose and proffer treatment for Hepatitis B. Brasil and colleagues developed a hybrid expert system to provide diagnosis and advisory services for Epilepsy crisis [16]. In another research, Saritas and colleagues [17] developed a fuzzy expert system for the diagnosis and analysis of prostate cancer. In another study, a rule-based expert system was developed for fever diagnosis by Tunmibi and colleagues [18]. A computer-based expert system for malaria environmental diagnosis was developed by Oluwagbemi and colleagues [19]. They also went further to develop a knowledge-based data mining and secured system for the purpose of diagnosing and managing malaria cases [20,21]. Another set of researchers developed expert systems for diagnosing breast diseases [22]. Fuzzy expert systems and set theories have also been applied to the diagnosis of diseases [23–24].

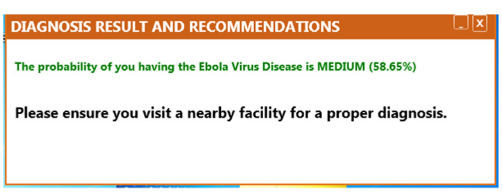


Fig. 1b. Diagnosis result and recommendation of EbInformatics Software for Patient 0002. This interface shows the results generated by Ebinformatics software about the diagnosis conducted on Patient 0002.

3. Data collation

3.1. Data gathering

First, data gathering was conducted by a preliminary survey among participants from various scientific disciplines among West African countries and South Africa. The ages of the participants ranged from 18 to 45. The participants involved both academicians with degrees and few with no formal education. The survey was conducted online by using the surveymonkey platform to ascertain the level of knowledge and perception of people about the EVD by administering questionnaires (see Supporting material 1). The responses collected from a sample of 100 people were analyzed as shown in Figs. 5.1.1–5.1.19; Tables 1 and 2.

Articles, research papers, journals and news updates were consulted in the data gathering process of this project and helped in constructing stimulating questions for the questionnaires. However, due to time constraints and logistics, we could not administer questionnaire to inhabitants of core local communities and villages. From the survey conducted, an appreciable number of people are aware and knowledgeable of the symptoms and factors responsible for the transmission of EVD. However, some sets of people lack that knowledge especially in other parts of the West African region. It is therefore pertinent that an Ebola informatics and support system be developed to provide advisory and recommender services to people. (Fig. 5.1.20 and Fig. 4)

3.2. Brief description of the demographics of the participants

100 participants, from two major African regions, (West Africa and South Africa), took part in this survey. Out of the 100 people, 98 were from West African countries, while only 2 were from South Africa. 69(69%) Males and 31(31%) females participated in the knowledge and perception survey about the transmission factors responsible for the spread of Ebola Virus Disease (EVD). The people that participated in the survey were from four major divisions namely the Physical Sciences (Maths, Physics, Computer Sciences, Statistics, Chemistry, Geology, Geophysics), the Biological Sciences (Health Sciences, Medicine, Pharmacy, Biology, Biochemistry, Microbiology, Botany, Physiotherapy, Anatomy), Others group (Law, Engineering, Arts, Social Sciences, Business) and

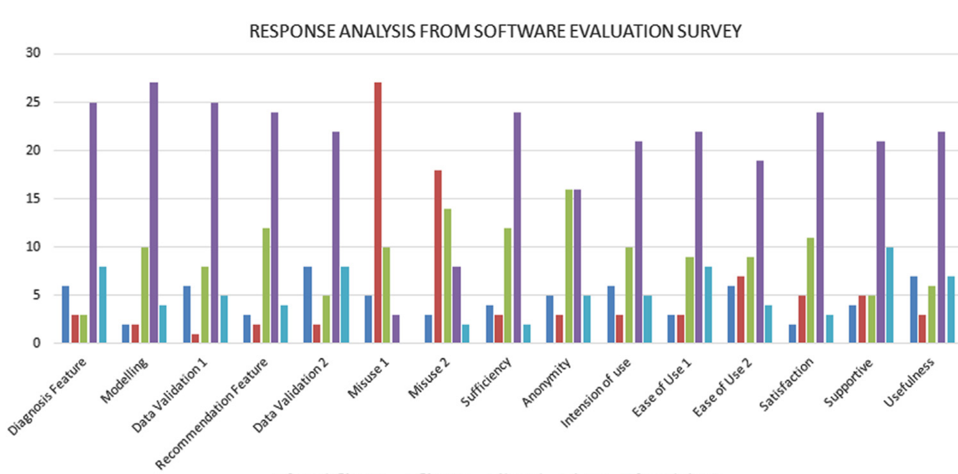


Fig. 2. Response analysis from Ebinformatics user evaluation survey. Result of responses collected from a sample of 45 people, the *y*-axis represents the population and the *x*-axis represents the features and functionalities of the *Ebinformatics* software.

finally, the Unlearned group. 91% of the participants were from the Physical Sciences, while 4% are respectively from Biological Sciences, and the other group like Law, Engineering, Social Sciences, and Business. 1% represents the unlearned group. The highest academic qualification of the survey participants are as follows: 78 (78.79%) were BSc degree holders or undergraduates, 4(4.04%) were MSc degree holders or Masters students or Mphil/PhD students. 3(3.03%) were PhD degree holders. 12(12.12%) were high school students or adult education or literacy classes. 2(2.02%) had no formal education (see Tables 1 and 2).

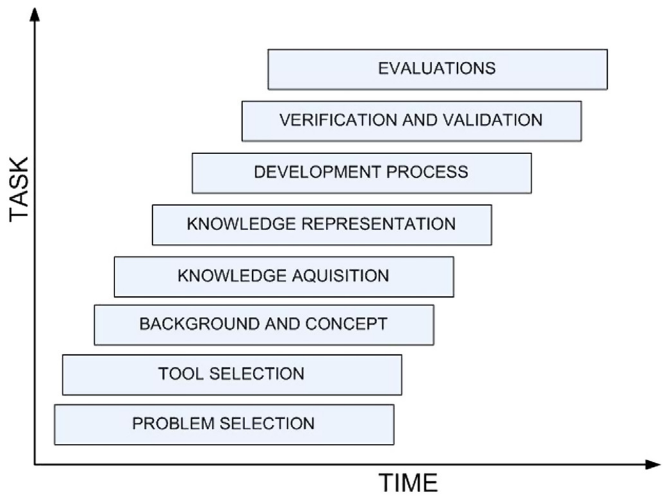


Fig. 3. Design methodology used in the development of the *Ebinformatics* software.

3.3. Architecture of Ebinformatics

Second, information that was sourced from different scholarly literature were used to develop an expert system (*Ebinformatics*) by adopting fuzzy logic techniques for the diagnosis of and the provision of useful advice and recommendations on how to contain Ebola (see Fig. 2). The expert system (*Ebinformatics*) was developed to be able to diagnose, suggest or predict an individual's probability of having the EVD. It also provides useful advice to the individuals. Prediction is based on user's input of symptoms and other catalyst factors. The two main components of this system are the Knowledge base and the Inference engine. The knowledge base consists of fuzzy rules and facts on the Ebola Virus Disease. The inference engine revolves around the concept of fuzzy logic; it performs the major functions of fuzzification, fuzzy inference and defuzzification to arrive at the final predictions. The architecture and flowchart of *Ebinformatics* is depicted in Fig. 1a and 1b respectively.

The knowledge base of *Ebinformatics* was developed through effective knowledge engineering of data and facts gathered from different sources. It contains a well-defined representation of the knowledge on the Ebola virus. It also consists of a set of rules for the symptoms which are used by the inference engine to make

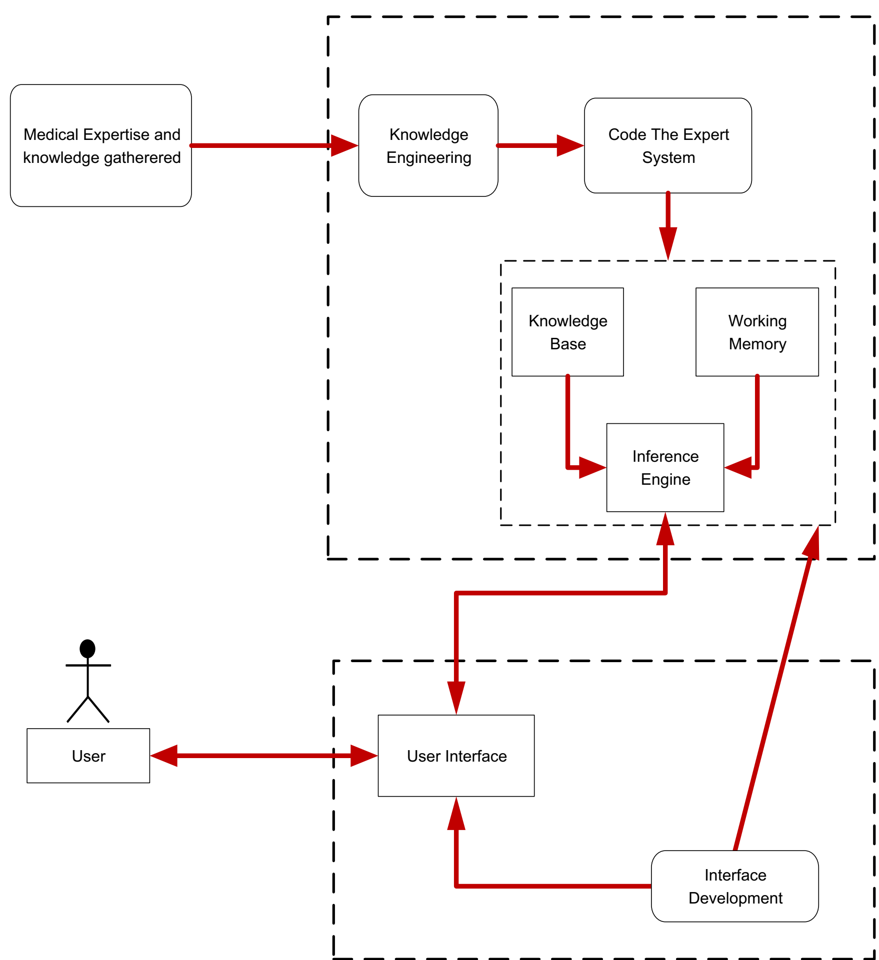


Fig. 4. Architectural design of the Ebinformatics system. The rectangles represent some of the system components and the rounded rectangles represents some processes involved in the system development.

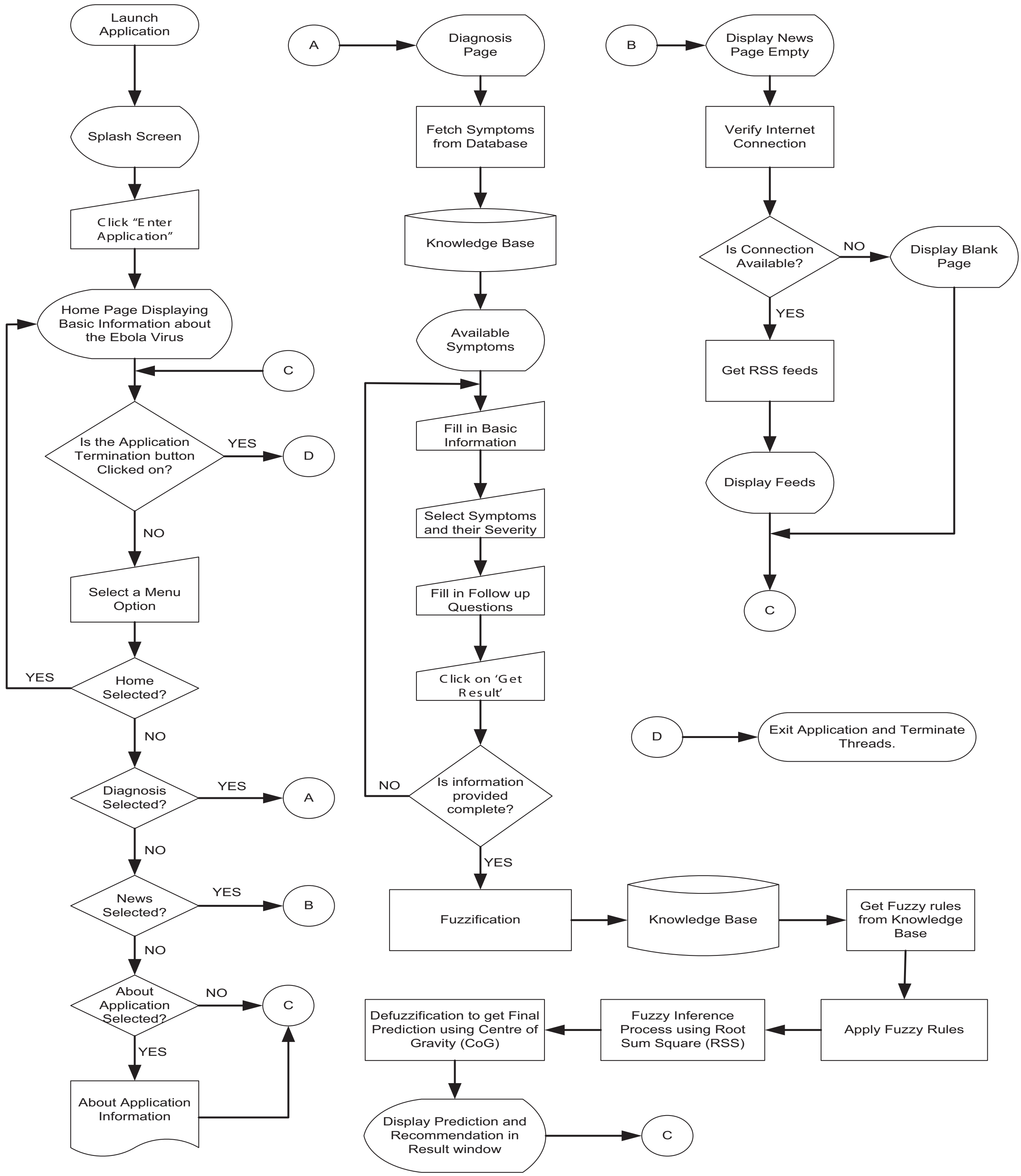


Fig. 5. The Flowchart of *Ebinformatics*. This diagram represents the general work flow and basic usage of the system.

predictions and facts which represent symptoms, risk factors and actual advices stored in a database.

The inference engine of Ebinformatics is where the prediction takes place using the concept of Fuzzy logic. The inference engine acts as interpreter which analyzes and processes the rules in the knowledge base [25]. It does this first by fuzzification, then the fuzzy inference and lastly defuzzification to produce final predictions. Fuzzification helps to convert crisp quantities to fuzzy values. The fuzzy inference helps to map inputs into corresponding outputs by applying the theory of fuzzy sets. Finally, the defuzzification process helps to transform the output into a crisp result [26]. The inference engine technique adopted by the Ebinformatics system is the Root Sum Square (RSS). The defuzzification technique used in the system is the Center of Gravity (CoG). The Ebinformatics inference engine used the rule in the knowledge-base to derive conclusions based on the rule and also made use of the forward chain inference mechanism, so as to gather facts before arriving at conclusions. The Ebinformatics software was implemented as a Windows desktop application by programming in C# .Net and the database used was the SQL server.

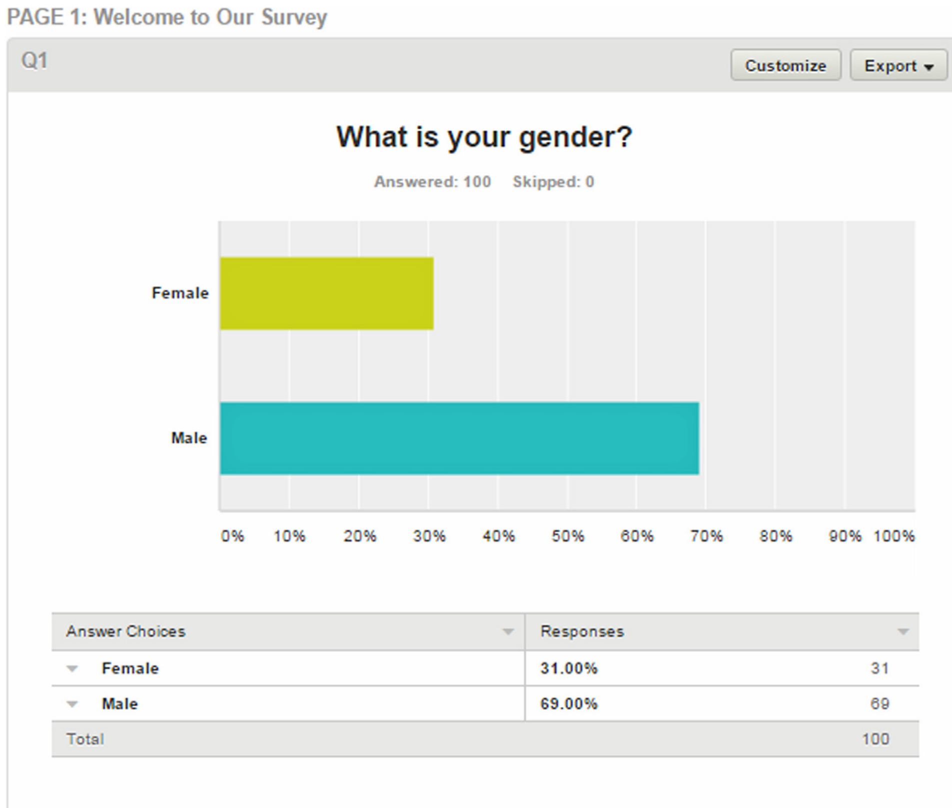


Fig. 5.1.1. Gender Classification of participants in Survey. This figure shows the responses of survey participants by gender classification. 69% of males and 31% of females participated in the survey.

3.4. Design methodology of Ebinformatics software

The design methodology employed in developing the Ebinformatics software was patterned according to the approach depicted by Kulani [27] in a graphical and schematic view of the tasks involved in the development of the system with time.

Fig. 3 below illustrates the design methodology used in the development of the Ebinformatics software. In this methodology, the programmer can go back to previous phases of design from any phase at any time.

The diagram shows a graphical view of the tasks involved in the development of the system with time (Source: Kulani, 2012) [27].

Third, a comprehensive user-testing of the software (*Ebinformatics*) was conducted after the software had been developed. Another questionnaire for evaluating Ebinformatics software's performance was prepared (see Supporting material 2). and administered to 45 people. The questionnaire for evaluation was evaluated on about 20 different parameters. The results for this are presented in the results section (see Fig. 2).

4. Decision support mechanism in Ebinformatics

4.1. Knowledge base

The Knowledge base helps to allocate memory to store transformed information about decision variables in the diagnosis of Ebola. The database, fuzzy logic serve as a repertoire for data that are to be processed.

4.1.1. Database

The Ebinformatics database presents data about facts and the established rules in the field of medicine focusing on the possible diagnosis of Ebola Virus Disease (EVD). These facts comprise of signs and symptoms of EVD, while the rules represent patterns to draw deductions from, based on available information. The database consists of Disease-Physical-Signs, Disease-Symptoms, results of diagnostic tests and Patient Diagnosis.

4.1.2. Fuzzy logic

The Ebinformatics diagnosis process takes advantage of the strength of fuzzy logic component in the following progression:

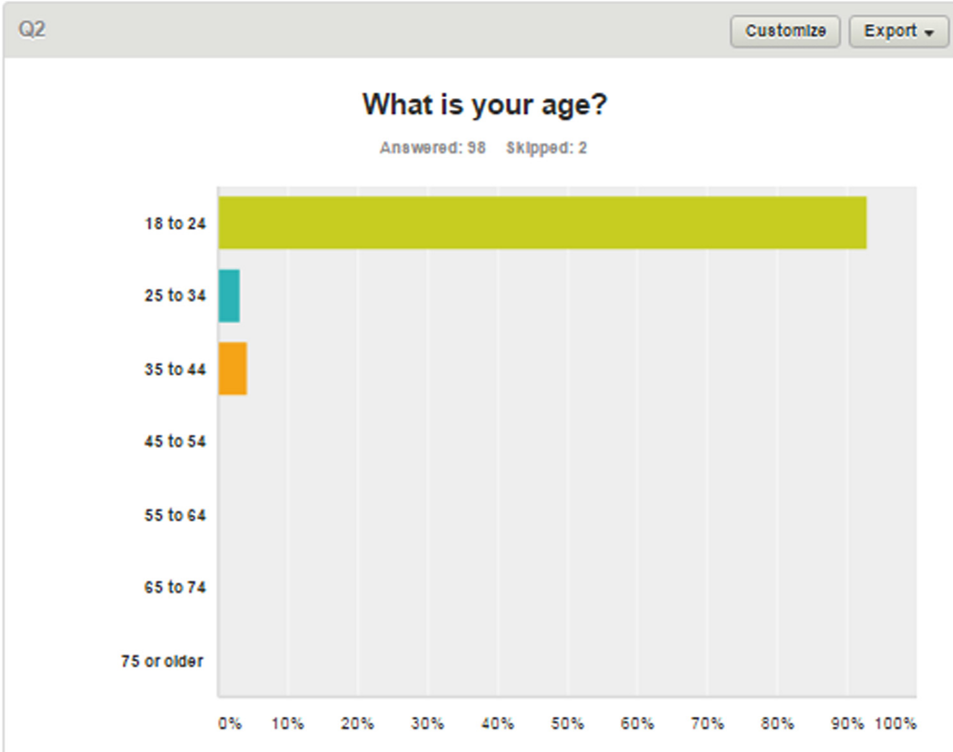
4.1.2.1. Fuzzification of input variables into Ebinformatics. Given a fuzzy set B, defined in (Eq. (1)), representing Ebola Virus Disease diagnosis variables with element denoted by y_i, the fuzzification process involves translating raw input value of each variable into a fuzzy term obtained from set $\{mild, \text{mod}\, erate, severe\}$ defined over the variables. Such values are derived from functions defined to determine the degree of membership of each variable in the fuzzy set (Eq. (1)).

$$B = \{(y_i, \mu_B(y_i)) \mid y_i \in V, \mu_B(y_i) \in [0, 1] \quad (1)$$

Fuzzification is actually done using the function defined in Eq. (2)

$$\mu_B(y_i) = \begin{cases} 1 & \text{if } y_i < a \\ \frac{y_i - a}{b - a} & \text{if } a \le y_i < b \\ \frac{c - y_i}{c - b} & \text{if } b \le y_i < c \\ 0 & \text{if } c < y_i \end{cases} \quad (2)$$

where $\mu_B(y_i)$ is the MF (Membership Function) of y_i in B using triangular MF while μ_B is the degree of membership of y_i in *B*. *a*, *b*, and *c* are parameters of the MF which governs its triangular shape and each attribute is described with lingual terms.



Answer Choices	Responses	
18 to 24	92.86%	91
25 to 34	3.06%	3
35 to 44	4.08%	4
45 to 54	0.00%	0
55 to 64	0.00%	0
65 to 74	0.00%	0
75 or older	0.00%	0
Total		98

Fig. 5.1.2. Age classification of participants in Survey. This figure shows the responses of survey participants by age classification.

4.1.2.2. Establishment of fuzzy rule base. The rule base for Ebola diagnosis in Ebinformatics is characterized by a set of IF-THEN rules in which the IF parts and THEN parts involve linguistic variables.

The rules were formulated and constructed with the help of medical and research professionals in the management of Ebola and on consultation with existing standard scientific literature.

A rule is executed if the precedence parameters such as mild, moderate and severe evaluate to TRUE, otherwise, no action is performed.

4.1.2.3. Fuzzy inference engine. The fuzzy inference engine is an engine that controls the logic that governs decision making. It achieves this by applying operations from rule base to values of variables input received. Here, the Root Sum Square (RSS) is applied to combine the effects of executed rules in order to draw meaningful inference.

$$RSS = \sum_{s=1}^{n} R_s^2 \tag{3}$$

where R_s is a fired rule where $s \forall 1, \ldots\ldots\ldots n$ is the identifier of rules that have been executed,where Eq. (3) *can be expanded into* Eq. (4) *as shown below:*

$$\sqrt{\sum R^2} = \sqrt{R_1^2 + R_2^2 + R_3^2 + R_4^2 + R_5^2 + R_6^2 + R_7^2 \ldots\ldots\ldots R_n^2} \tag{4}$$

Here, $R_1^2 + R_2^2 + R_3^2 + R_4^2 + R_5^2 + R_6^2 + R_7^2 + \ldots\ldots\ldots R_n^2$ represent the strength values of different rules which share the same results.

R is the value of having a rule executed. This RSS method integrates the effects of all applicable rules, scales the functions of such rules at their respective magnitude and finally computes the fuzzy centroid of the composite area.

This method was chosen above all other methods because it provides the best weighted influence to all rules that are being executed.

4.1.2.4. Defuzzification of output values. The output values can be defuzzified by translating the results of the inference engine into compact values. These compact values provide assistance in efficient diagnosis. The development of the operations of the Ebinformatics software employs Center of Gravity (CoG) or Centroid of

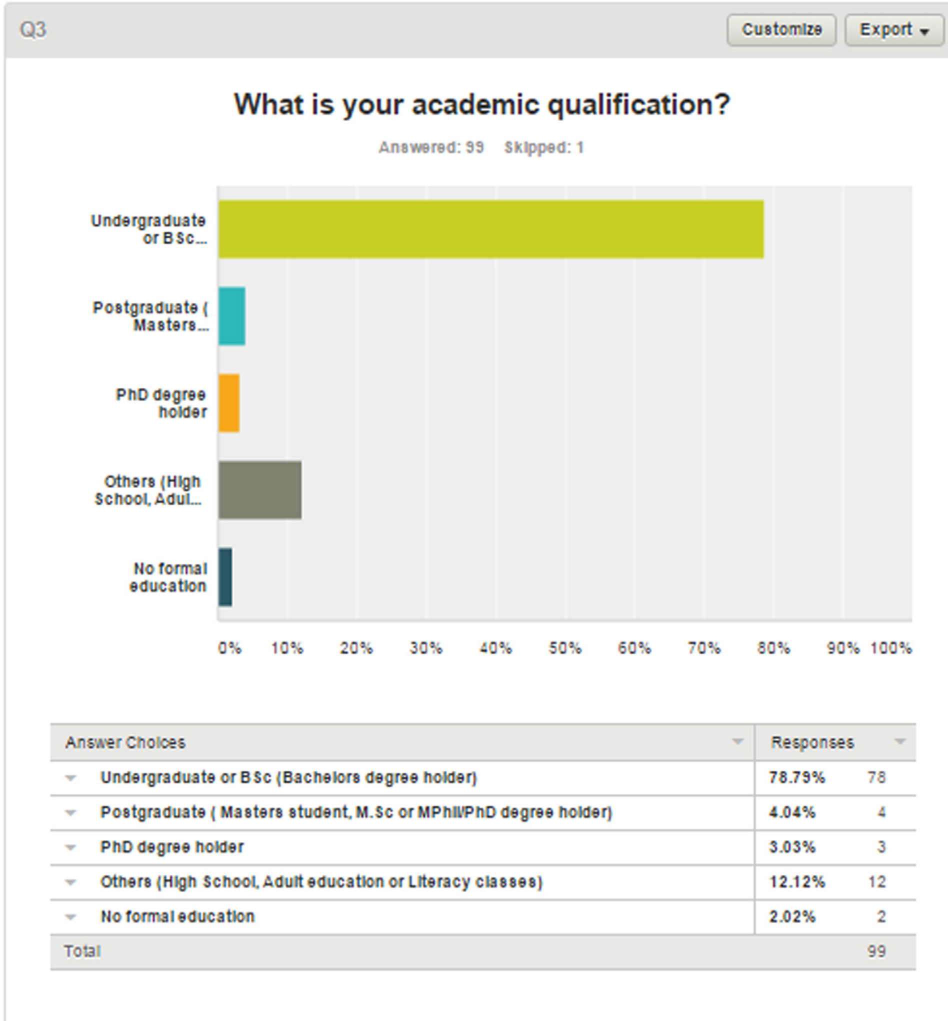


Fig. 5.1.3. Academic classification of participants in Survey. This figure shows the responses of survey participants by academic classification. The various academic classifications are (undergraduate or BSc/BS holders); (MS/MSc students or MS/MSc degree holders, MPhil/PhD students/holders) (others: high school, adult education and Literacy classes); (no formal education) and PhD degree holders.

Area (CoA) method for its defuzzification by applying Eq. (5).

$$CoA = \frac{\sum_{j=1}^{n} \mu Y(y_j) y_j}{\sum_{j=1}^{n} \mu Y(y_j)} \quad (5)$$

where $\mu Y(y_j)$ is the degree of j in a membership function, while y_j is the center value in the function.

What informed our choice of this methodology is the computational flexibility, ease and intuitive plausibility that this approach provides.

4.1.2.5. Fuzzification process. Different types of fuzzifiers can be used to achieve fuzzification which involves transforming a real scalar value into a fuzzy value. Of the four (4) types of fuzzifiers namely: Singleton, Gaussian, Triangular and Trapezoidal fuzzifiers [47], the triangular fuzzifier was adopted for the purpose of this research. Fuzzification process occurs through the selection of input parameters into horizontal axis and vertical projection to obtain the membership degree.

For the purpose of this research, the description of the input and output parameters was based on three linguistic variables (mild, moderate, and severe). The fuzzy value range for these variables is described in Table 4 below. Fuzzy sets are constructed for parameters as shown in [Eqs. (6) –(8)]. The range of fuzzy value for each linguistic is shown in Table 4 below:

$$\mu_{Mild}(Y) = \begin{cases} 0 & if\ y \le 0.1 \\ \frac{y-0.1}{0.2} & if\ 0.1 \le y \le 0.3 \\ \frac{0.2-y}{0.1} & if\ 0.2 \le y \le 0.3 \\ 0 & if\ y \ge 0.2 \end{cases} \quad (6)$$

$$\mu_{Moderate}(Y) = \begin{cases} 0 & if\ y \le 0.3 \\ \frac{y-0.3}{0.3} & if\ 0.3 \le y \le 0.6 \\ \frac{0.45-y}{0.15} & if\ 0.45 \le y \le 0.6 \\ 0 & if\ y \ge 0.45 \end{cases} \quad (7)$$

$$\{\mu_{Severe}(Y) = \begin{cases} 0 & if\ y \le 0.5 \\ \frac{y-0.6}{0.2} & if\ 0.6 \le y \le 0.8 \\ \frac{0.7-y}{0.1} & if\ 0.7 \le y \le 0.8 \\ 0 & if\ y \ge 0.8 \end{cases} \quad (8)$$

It should be noted that the region of residence of a patient, and whether the patient has visited any recently hit Ebola country in West Africa, or whether the patient had previously visited any Ebola stricken country collectively influence the prediction of the intensity of possible individual Ebola infection (as shown in Table 5 above).

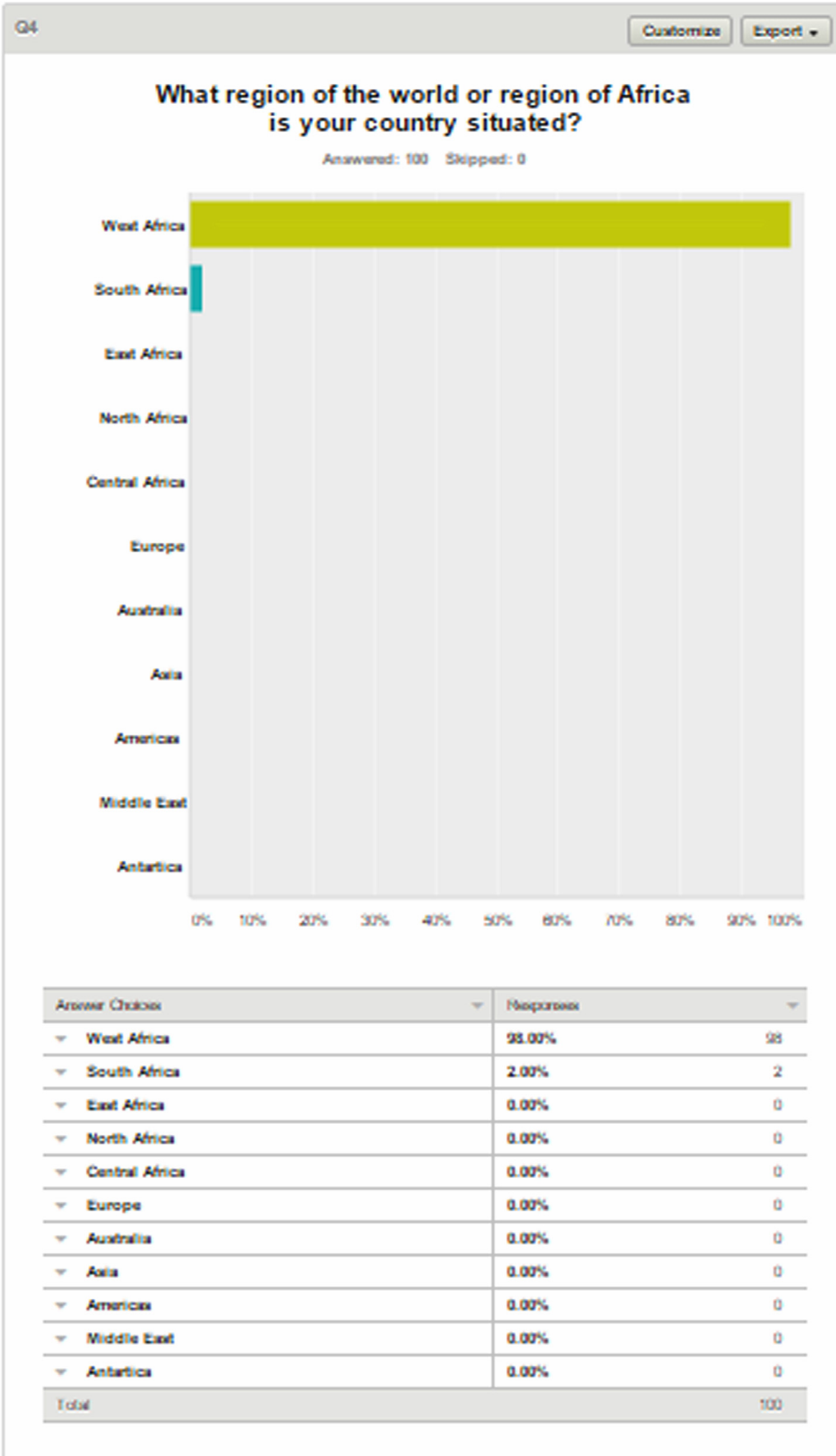
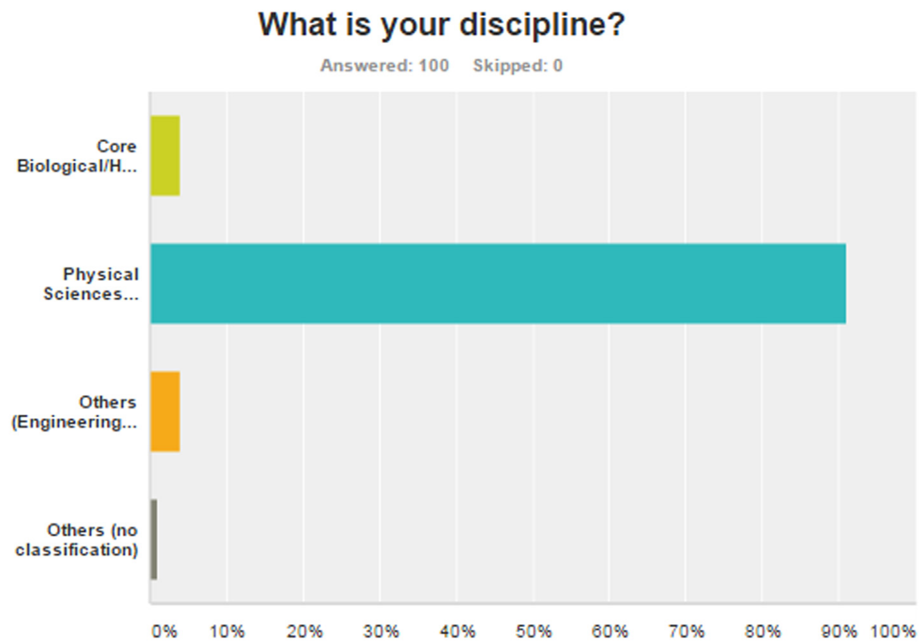


Fig. 5.1.4. World regional classification of participants in Survey. All the participants in the survey were from West Africa and South Africa.

Some of the rules (Rules 1, 3, and 11) in Table 5 can be interpreted as follows:

Rule1: IF Bleeding Eyes = mild and Bloody cough = moderate and Bleeding gums = severe and Bleeding mouth = severe and backache = moderate and Breathing difficulty = severe and Chest Pain = moderate and Fever = moderate and Fatigue = moderate and Patient resides in West Africa, and patient has lived in or visited Sierra Leone in the last week or last 1 month and patient has visited any Ebola affected country in the last 3 months THEN possibility of having Ebola Virus Disease (EVD) = **HIGH**



Answer Choices	Responses	
Core Biological/Health Sciences (Medicine, Pharmacy,Biology, Biochemistry, Microbiology, Botany, Physiotherapy, Anatomy)	4.00%	4
Physical Sciences (Maths, Physics, Computer Sciences, Statistics, Chemistry, Geology, Geophysics, etc)	91.00%	91
Others (Engineering, Law, Arts, Social Sciences, Business)	4.00%	4
Others (no classification)	1.00%	1
Total		100

Fig. 5.1.5. Disciplinary classification of participants in Ebinformatics software Survey.This figure shows the responses of survey participants by their respective disciplines. These disciplines are: Core Biological sciences; Physical sciences; others (Engineering, Law, Arts, Social sciences) and others (no classification).

Rule3: IF Bleeding Eyes = mild and Bloody cough = mild and Bleeding gums = mild and Bleeding mouth = mild and backache = mild and Breathing difficulty = mild and Chest Pain = mild and Fever = mild and Fatigue = mild and Patient resides in Europe, and patient has NOT lived in nor visited any Sierra Leone, Guinea, Mali, and Liberia, in the last 1week or last 1 month and has NOT visited nor lived in any Ebola affected country in the last 3 months THEN possibility of having Ebola Virus Disease (EVD) = **LOW**

Rule11: IF Bleeding Eyes = mild and Bloody cough = mild and Bleeding gums = severe and Bleeding mouth = severe and backache = mild and Breathing difficulty = mild and Chest Pain = severe and Fever = severe and Fatigue = severe and Patient resides in Africa, and patient has NOT lived in or nor visited Sierra Leone, Guinea, Mali and Liberia in the last week or last 1 month and patient has NOT visited any Ebola affected country in the last 3 months THEN possibility of having Ebola Virus Disease (EVD) = **MEDIUM**

4.2. EbInformatics Algorithm

The **Algorithm** for the Ebola diagnostic process is as follows:

Step 1: Enter the signs and symptoms of patient into EbInformatics software, where $s_1, s_2, s_3, s_4, s_5, s_6, s_7, \ldots s_n$ is the number of signs and symptoms.

Step 2: Knowledge-base is searched for the possible disease ***d*** from the list of diseases d_1, d_2, d_3whose signs and symptoms have been specified.

Step 3: The *weighing factors (wf)* are gotten. In this case wf = 1, 2, 3 where *Mild* = 1, *Moderate* = 2 and *Severe* = 3.

Step 4: Fuzzy rules are applied.

Step 5: Degree of membership is determined by associating respective weighing factors with fuzzy inputs through mapping.

Step 6: Rule base are determined.

Step 7: Execution strength of the rules are determined.

Step 8: Determine each rule's degree of truth through the non-zero minimum evaluation.

Step 9: Calculate the intensity of Ebola Virus Disease by factoring whether a patient has lived in or visited an Ebola endemic country before presenting the final intensity of the disease.

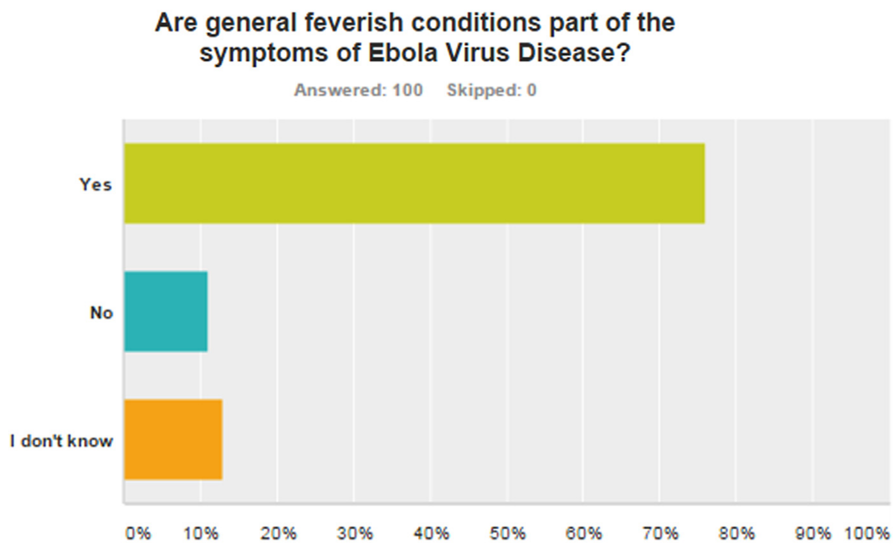
Step 10: Provide the output of the diagnosis.

Step 11: Provide the appropriate recommendation.

4.3. Experimental sample on Ebola Virus Disease (EVD)

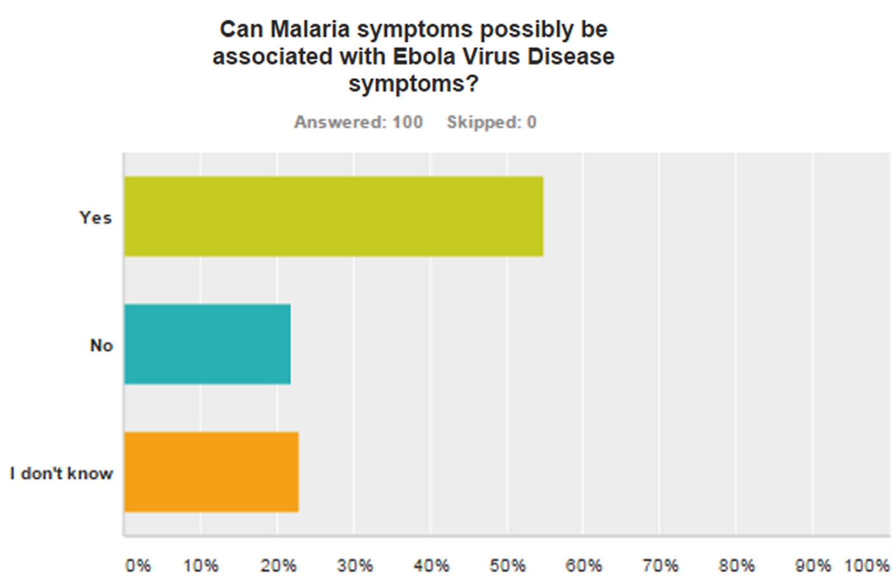
Some paradigms are true about EVD. (i) The chances of survival become increased especially through an early identification of the disease. (ii) Sharing common symptoms with other infectious diseases can make it tedious to identify the specific disease in question.

In such a situation, fuzzy algorithm plays a very important role. Suppose for instance we considered a set of three diseases **D**, and



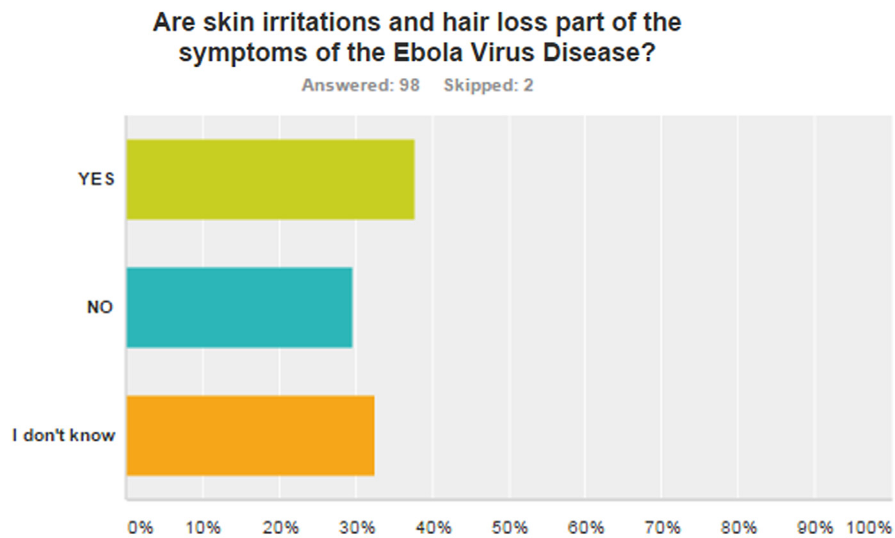
Answer Choices	Responses	
Yes	76.00%	76
No	11.00%	11
I don't know	13.00%	13
Total		100

Fig. 5.1.6. Survey response of participants to know if general feverish conditions are parts of the symptoms of Ebola Virus Disease (EVD). This figure highlights the responses of survey participants to know if general feverish conditions are parts of the symptoms of Ebola Virus Disease (EVD).



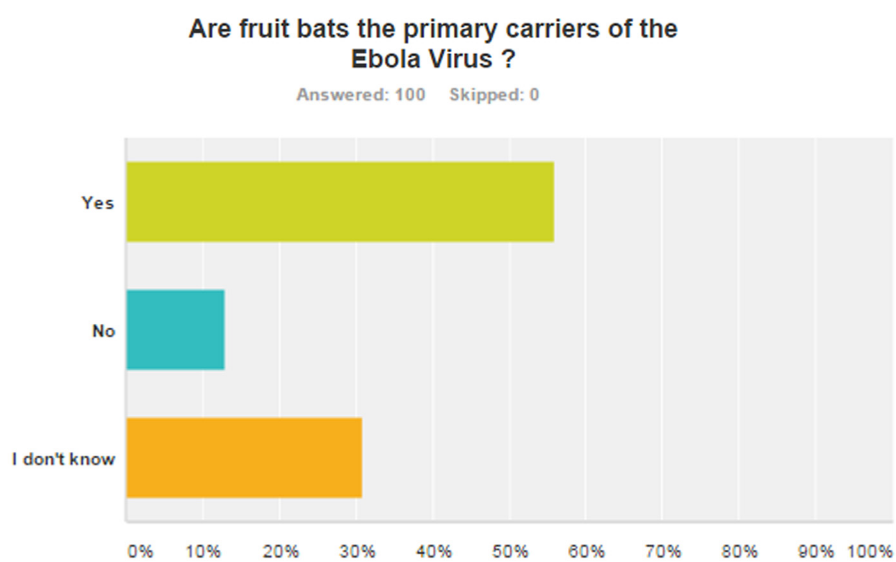
Answer Choices	Responses	
Yes	55.00%	55
No	22.00%	22
I don't know	23.00%	23
Total		100

Fig. 5.1.7. Survey response of participants to know if Ebola Virus Disease (EVD) presently has a cure. This figure highlights the responses of survey participants to know if Ebola Virus Disease (EVD) presently has a cure.



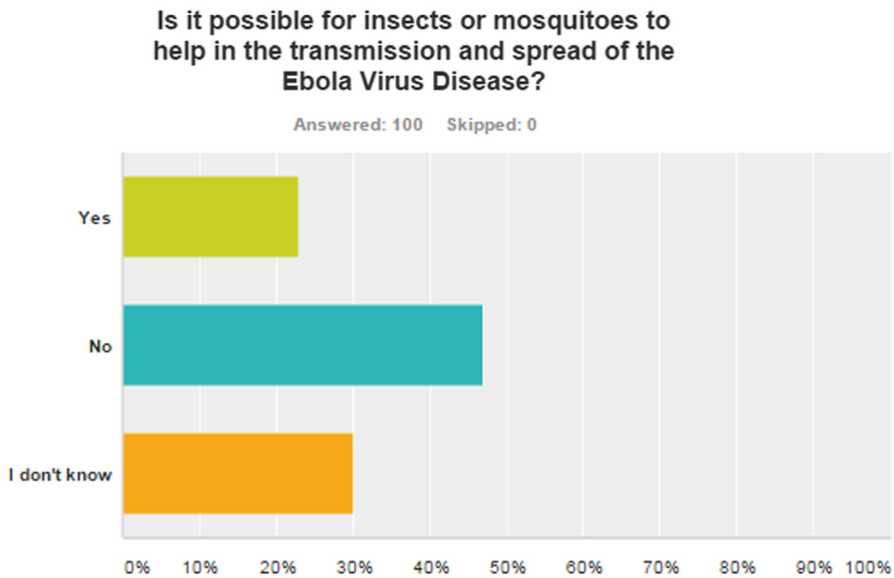
Answer Choices	Responses	
YES	37.76%	37
NO	29.59%	29
I don't know	32.65%	32
Total		98

Fig. 5.1.8. Survey response of participants to know if Ebola Virus Disease (EVD) can be transmitted by touching infected dead bodies. This figure highlights the responses of survey participants to know if Ebola Virus Disease (EVD) can be transmitted if an uninfected person touches a dead person who died as a result of Ebola infection.



Answer Choices	Responses	
Yes	56.00%	56
No	13.00%	13
I don't know	31.00%	31
Total		100

Fig. 5.1.9. Survey response of participants to know if fruit bats are the primary carriers of Ebola Virus Disease (EVD). This figure highlights the responses of survey participants to know if fruit bats are the primary carriers of Ebola Virus Disease (EVD).



Answer Choices	Responses	
Yes	23.00%	23
No	47.00%	47
I don't know	30.00%	30
Total		100

Fig. 5.1.10. Survey response of participants to know if Ebola Virus Disease (EVD) can be transmitted and spread by insects or mosquitoes. This figure highlights the responses of survey participants to know if Ebola Virus Disease (EVD) can be transmitted by illegal hard drug administration among users that share syringe with an infected individual.

medical professionals defined sets of signs and symptoms **S** relevant to a particular infectious disease (say Ebola Virus Disease (EVD)).

$D=\{d_1,d_2,d_3\}$ where d_1,d_2,d_3 represents the three different infectious diseases.

$S=\{s_1,s_2,s_3,s_4,s_5,s_6,s_7,\ldots\ldots\ldots s_n\}$ where $s_1,s_2,s_3,s_4,s_5,s_6,s_7,\ldots..s_n$ represents the signs and symptoms of a particular infectious disease.

In order to specify the intensity of the signs and symptoms for a specific patient, weighing factors were applied to the set S, thus assigning fuzzy values to the signs and symptoms. Fuzzy values were derived from the fuzzy set:

$$\{Mild(1), Moderate(2), Severe(3)\}$$

The patient's health state with respect to Ebola Virus Disease (EVD), was evaluated based on signs, symptoms and personal investigations. We rated the intensity of signs and symptoms as mild(1), moderate(2) and severe(3).

From Table 6 above, it is ambiguous to say a patient has low or moderate fever, low chest pain, low bleeding nose, and moderate bleeding gums. It is thus essential to specify the degree to which one can actually say a sign and symptom is low, moderate and severe. A fuzzifier helps with these. The fuzzifier employed for this purpose is the triangular fuzzifier (see Eq. (2)).

Table 7 defines the degree to which we can say signs and symptoms are mild, moderate and severe. For instance if a patient tells a medical doctor that he or she has a severe chest pain, the doctor assigns 3 (out of 3) value to the chest pain. Thus, the system will evaluate the degree of the chest pain as $(3-1)/3=2/3=0.6667\approx0.67$ by applying triangular fuzzifier to derive the triangular fuzzy numbers.

Derived triangular values for Ebola Virus Disease (EVD) signs/symptoms are as shown in Table 7.

From the 14 rules executed in Table 8, only 11 of the rules generated non-zero minimum values.

By applying the RSS inference technique, the output membership function strength for each variable (*mild, moderate, severe*) was computed from possible rules (R1-R14).

$$\begin{aligned} \text{Mild} &= \sqrt{R_{12}{}^2} \\ &= \sqrt{0.33^2} \\ &= 0.33 \end{aligned}$$

$$\begin{aligned} \text{Moderate} &= \sqrt{R_2{}^2+R_9{}^2} \\ &= \sqrt{0.33^2+0.33^2} \\ &= \sqrt{R_2{}^2+R_9{}^2} \\ &= \sqrt{0.1089+0.1089} \\ &= \sqrt{0.2718} \\ &= 0.1359 \end{aligned}$$

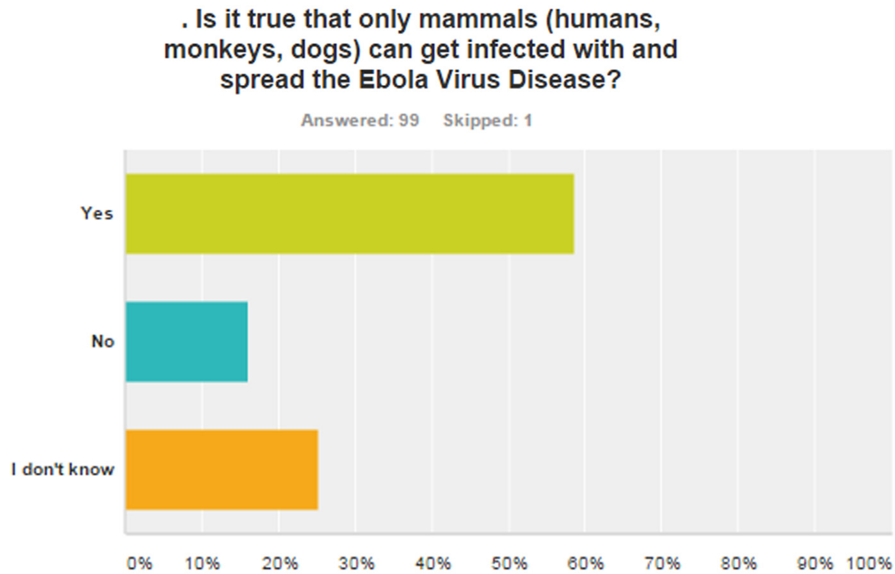
Severe = Rules 4,5,6,7,8,10,11, and 14

$$= \sqrt{R_4^2+R_5^2+R_6^2+R_7^2+R_8^2+R_{10}^2+R_{11}^2+R_{14}^2}$$

$$= \sqrt{0.67^2+0.67^2+0.67^2+0.67^2+0.67^2}+0.67^2+0.67^2+0.67^2$$

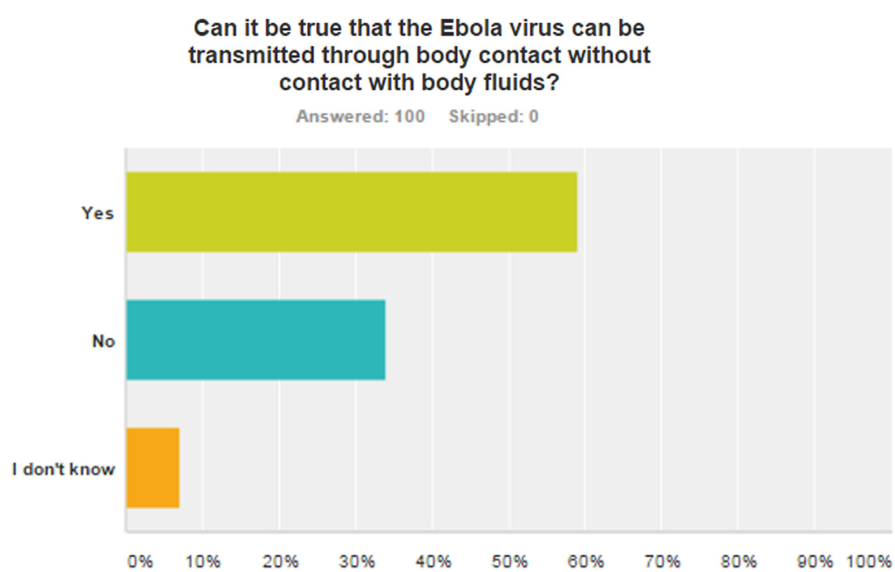
$$= 3.5912^{\frac{1}{2}} = 1.7956$$

This fuzzy set as highlighted above is now defuzzified into produce compact outputs.



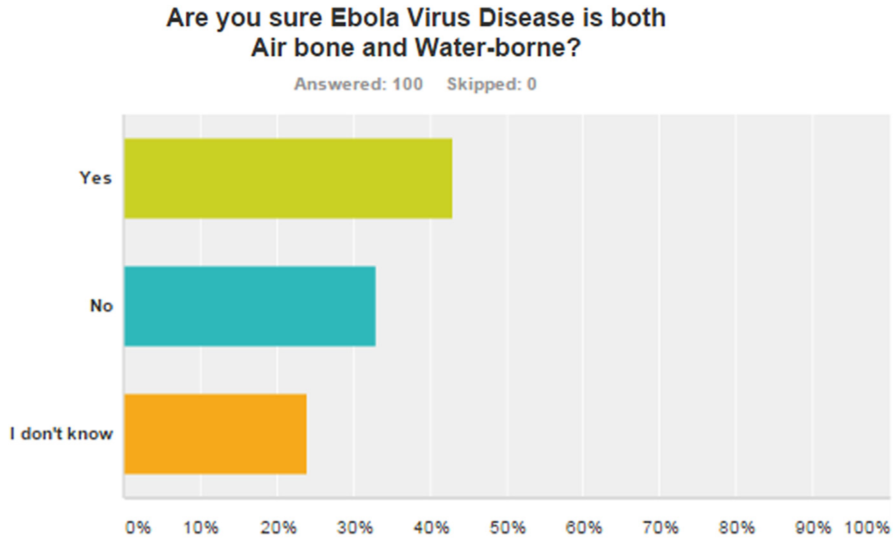
Answer Choices	Responses	
Yes	58.59%	58
No	16.16%	16
I don't know	25.25%	25
Total		99

Fig. 5.1.11. Survey response of participants to know if only mammals can get infected with and spread the Ebola Virus Disease (EVD). This figure highlights the responses of survey participants to know if only mammals can get infected with or spread Ebola Virus Disease (EVD).



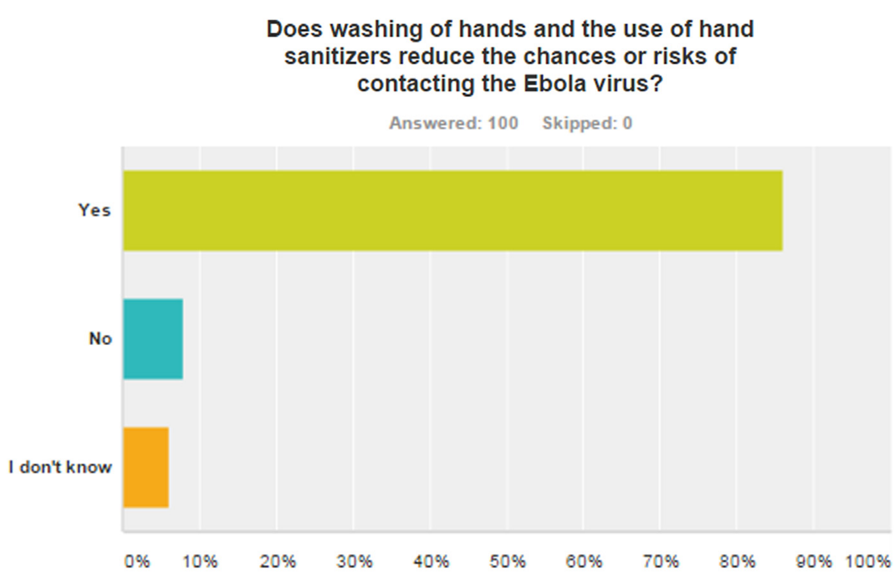
Answer Choices	Responses	
Yes	59.00%	59
No	34.00%	34
I don't know	7.00%	7
Total		100

Fig. 5.1.12. Survey response of participants to know if the Ebola Virus Disease (EVD) can be transmitted through body contacts without contact with body fluids. This figure highlights the responses of survey participants to know if Ebola Virus Disease (EVD) can be transmitted through body contacts without contact with body fluids.



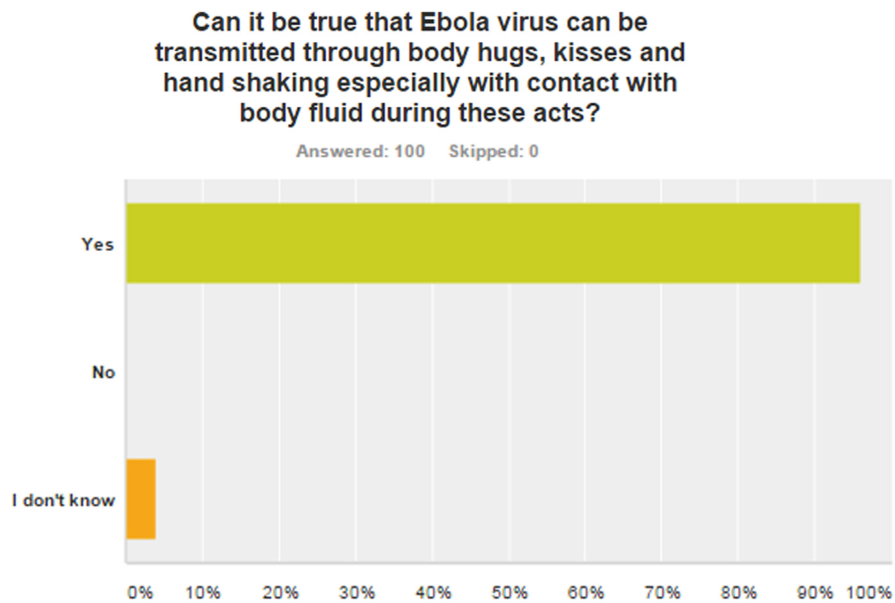
Answer Choices	Responses	
Yes	43.00%	43
No	33.00%	33
I don't know	24.00%	24
Total		100

Fig. 5.1.13. Survey response of participants to know if the Ebola Virus Disease (EVD) is both Air-borne and water borne. This figure highlights the responses of survey participants to know if Ebola Virus Disease (EVD) is both air-borne and water borne.



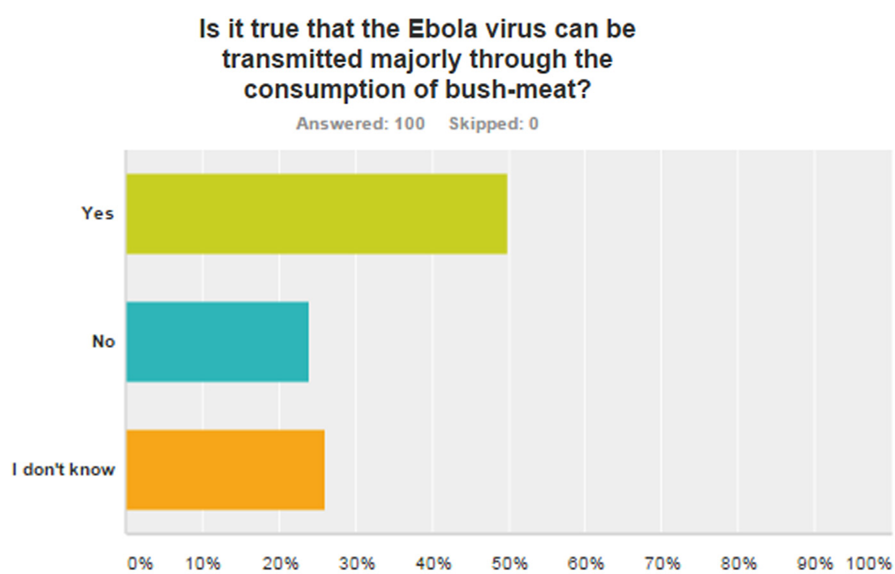
Answer Choices	Responses	
Yes	86.00%	86
No	8.00%	8
I don't know	6.00%	6
Total		100

Fig. 5.1.14. Survey response of participants to know if washing of hands reduces the risk of contacting the Ebola Virus Disease (EVD). This figure highlights the responses of survey participants to know if washing of hands and the use of hand sanitizers can reduce the chances or risks of contacting the Ebola Virus Disease (EVD).



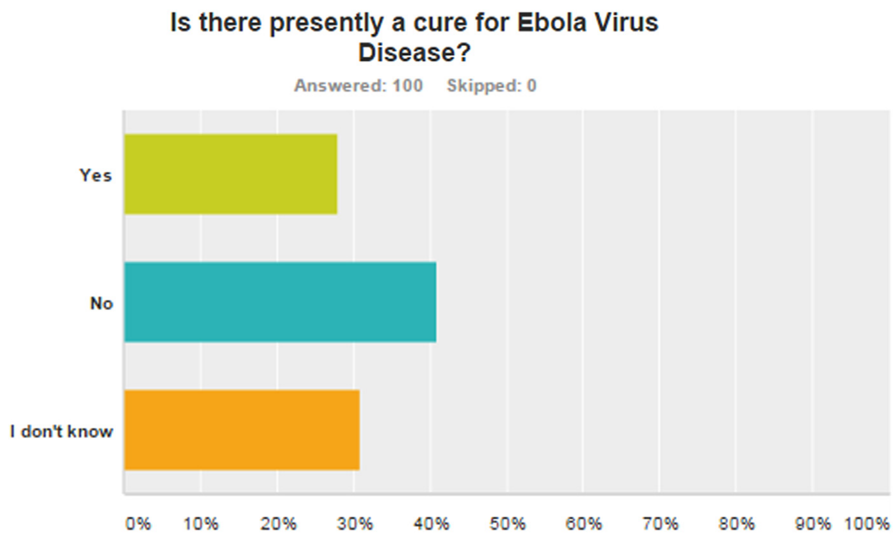
Answer Choices	Responses	
Yes	96.00%	96
No	0.00%	0
I don't know	4.00%	4
Total		100

Fig. 5.1.15. Survey response of participants to know if the Ebola Virus Disease (EVD) can be transmitted through body hugs, kissing and hand shaking. This figure highlights the responses of survey participants to know if the Ebola Virus Disease (EVD) can be transmitted by body hugs, kissing, and hand shaking especially with contact with body fluids during these acts.



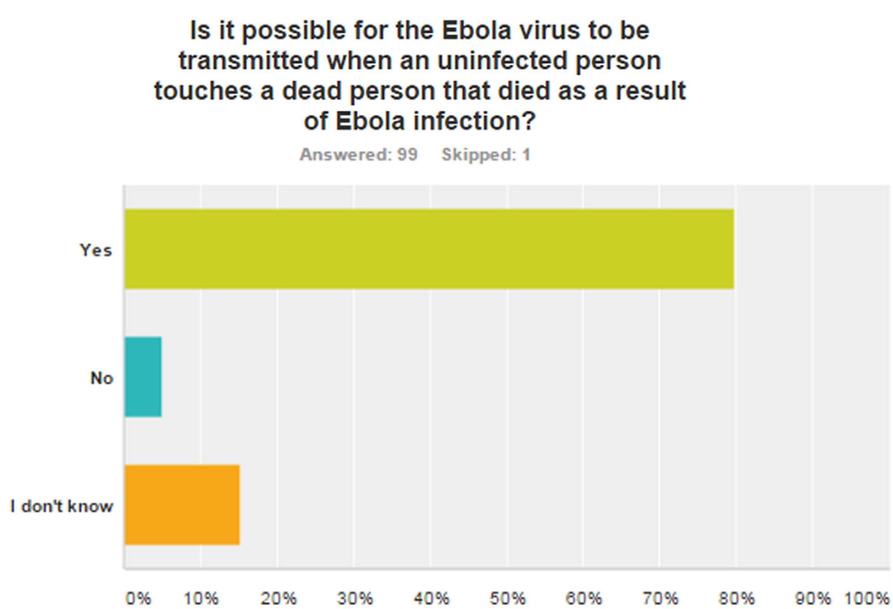
Answer Choices	Responses	
Yes	50.00%	50
No	24.00%	24
I don't know	26.00%	26
Total		100

Fig. 5.1.16. Survey response of participants to know if Ebola can be transmitted by consuming bush meat. This figure highlights the responses of survey participants to know if Ebola can be transmitted by consuming bush meat. 50% of the respondents selected YES.



Answer Choices	Responses	
Yes	28.00%	28
No	41.00%	41
I don't know	31.00%	31
Total		100

Fig. 5.1.17. Survey response of participants to know if Ebola symptoms and Malaria symptoms share certain things in common. This figure highlights the responses of survey participants to know if malaria symptoms can be associated with Ebola symptoms.



Answer Choices	Responses	
Yes	79.80%	79
No	5.05%	5
I don't know	15.15%	15
Total		99

Fig. 5.1.18. Survey response of participants to know if skin irritations and hair loss are symptoms of Ebola Virus Disease (EVD). This figure highlights the responses of survey participants to know if skin irritations and hair loss are symptoms of Ebola Virus Disease (EVD).

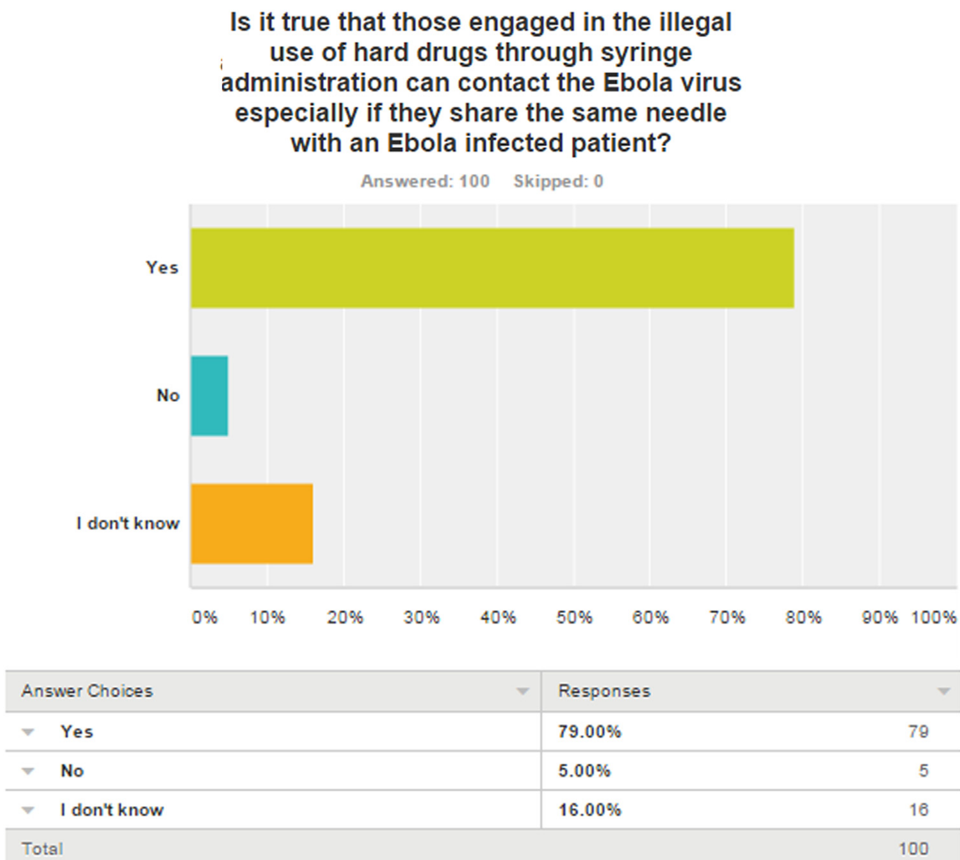


Fig. 5.1.19. Survey response of participants to know if Ebola Virus Disease (EVD) can be transmitted by illegal syringe for drug administration among individuals. This figure highlights the responses of survey participants to know if Ebola Virus Disease (EVD) can be transmitted by illegal hard drug administration among users that share syringe with an infected individual.

Table 1
Comprehensive survey about knowledge and perception.

S/N	Survey Questions	Agreed (yes)	Disagreed (no)	Neutral (I don't know)	Remarks
1	Are general feverish conditions part of the symptoms of Ebola Virus Disease?	76 (76%)	11 (11%)	13 (13%)	
2	Can malaria symptoms be possibly associated with Ebola Virus Disease symptoms?	55 (55%)	22 (22%)	23 (23%)	
3	Are skin irritations and hair loss part of the symptoms of Ebola Virus Disease?	37 (37.76%)	29 (29.59%)	32 (32.65%)	2 Skipped
4	Are fruit bats the primary carriers of Ebola virus?	56 (56%)	13 (13%)	31 (31%)	
5	Is it possible for insects or mosquitoes to help in the transmission and spread of the Ebola Virus Disease (EVD)?	23 (23%)	47 (47%)	30 (30%)	
6	Is it true that only mammals (humans, monkeys, dogs,) can get infected with and spread the Ebola Virus Disease (EVD)?	58 (59.59%)	16 (16.16%)	25 (25.25%)	1 Skipped
7	Can it be true that Ebola Virus Disease can be transmitted through body contact without contact with body fluids?	59 (59%)	34 (34%)	7 (7%)	
8	Are you sure Ebola Virus Disease is air bone and water borne?	43 (43%)	33 (33%)	24 (24%)	
9	Does washing of hands and the use of hand sanitizer reduce the chances or risks of contacting the Ebola virus?	86 (86%)	8 (8%)	6 (6%)	
10	Can it be true that Ebola can be transmitted through body hugs, kisses and hand shaking, especially with contact with body fluids during these acts?	96 (96%)	0 (0%)	4 (4%)	
11	Is it true that Ebola can be transmitted majorly through the consumption of bush meat?	50(50%)	24 (24%)	26 (26%)	
12	Is there presently a cure for Ebola Virus Disease?	28 (28%)	41(41%)	31(31%)	
13	Is it possible for the Ebola virus to be transmitted when an uninfected person touches a dead person that died as a result of Ebola infection?	79 (79.8%)	5 (5.05%)	15 (15.15%)	1 Skipped
14	Is it true that those engaged in illegal use of drugs through syringe administration can contact the Ebola virus especially if they share the same needle with an Ebola infected patient?	79 (79%)	5 (5%)	16 (16%)	

Using the CoG technique, we defuzzify as follows

$$\text{Output} = \frac{(0.33 * 0.2) + (0.1359 * 0.45) + (1.7956 * 0.7)}{0.33 + 0.1359 + 1.7956}$$

$$= \frac{0.066 + 0.061 + 1.257}{0.33 + 0.1359 + 1.7956}$$

$$= \frac{1.384}{2.2615} = 0.611 = 0.61$$

$= 61\%$ possibility which is falls into the MEDIUM intensity

Entering the symptoms of Patient 0002 into EbInformatics software, it yielded a MEDIUM intensity $= 58.65\% \cong 60\%$ (See

Table 2
Demographic Information about users that participated in the knowledge and perception survey of Ebola Virus Disease (EVD) transmission factors.

Demographic information about survey participants				
Participants	**Region of participants**	**Types of participants [field of study]**	**Age [bracket]**	**Gender [M=male and F=female]**
Undergraduates or BSc degree holders 78 (78.79%)	West African countries 98 (98%)	Physical Sciences 91(91%)	18–24	Male 69 (69%)
MSc students, MSc degree holders, Mphil/PhD degree holders 4 (4.04%)		Biological Sciences 4(4%)	25–34	Female 31 (31%)
PhD degree holders 3 (3.03%)	South Africa 2 (2%)	Other fields (Law, Engineering, Business, Social Sciences) 4(4%)	35–44	
High School students, Adult Education, Literacy class products 12 (12.12%)		Others (unlearned) 1(1%)		
No formal education 2 (2.02%)				

Demography on knowledge and perception survey of Ebola Virus Disease transmission factors.

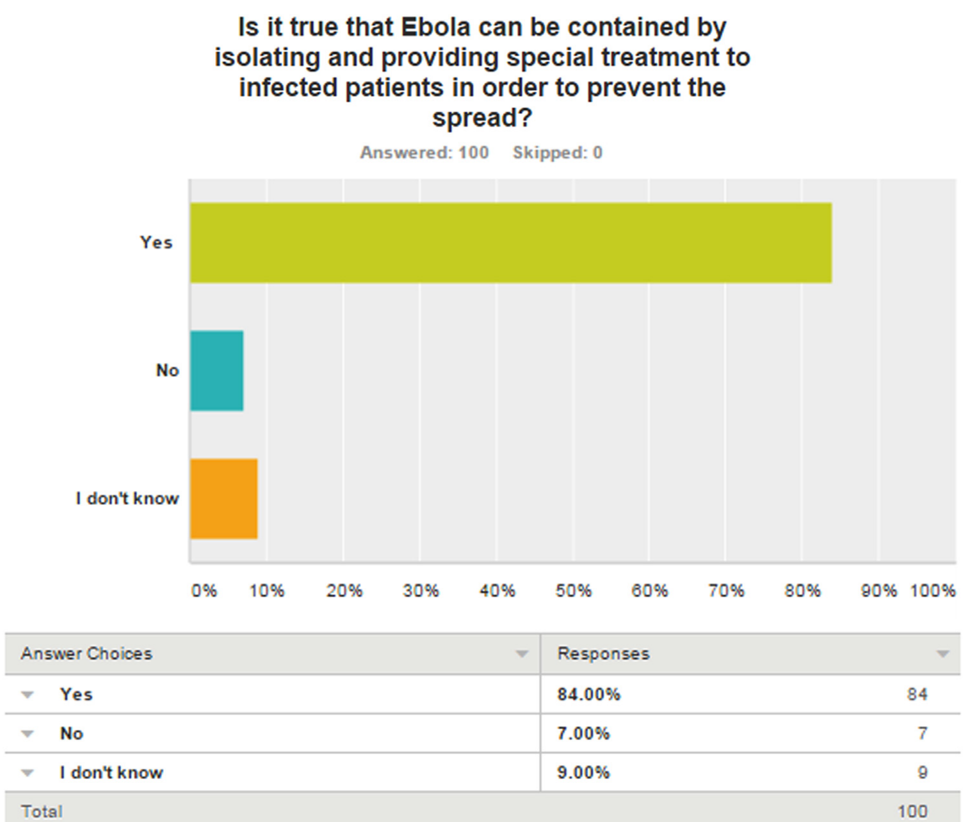


Fig. 5.1.20. Survey response of participants to know if Ebola Virus Disease (EVD) can be contained by isolating and providing special treatments to infected patients. This figure highlights the responses of survey participants to know if Ebola Virus Disease (EVD) can be contained by isolating and providing special treatments to infected patients.

Figs. 4.1 and 4.2). It was assumed that such a patient has never visited any Ebola endemic country. This helps to validate the correlation of EbInformatics prediction with the results derived from Equations (See Table 9).

We should bear in mind that the current region of residence, Ebola endemic Countries visited or lived in (Guinea, Liberia, Sierra Leone, Mali), in the last 1 week or 1 month and Ebola endemic countries visited or lived in, in the last 3 months all were designed separately but they have the tendency of influencing the intensity of predicted EVD if integrated into the results predicted by the Fuzzy-predicted method.

Fuzzy logic is a type of logic where truth values range between 0 and 1 [48]. The introduction of linguistic variables to fuzzy logic makes fuzzy logic very applicable in many artificial intelligence-related applications [49,50,51]. Fuzzy logic and Bayesian classifiers address different variations of uncertainty. Fuzzy set theory adopts and applies the concept of fuzzy set membership. Some Schools of thought showed that probability theory is a “subset” of fuzzy logic. Some went further to derive Baye’s theorem from the concept of Fuzzy subsethood, while others were able to fuzzify probability to fuzzy probability and provide a generic application of it to possibility theory [52]. Thus, we chose fuzzy logic algorithm because of its computational simplicity and the intuitive plausibility it provides as a result of its adoption.

5. Results

5.1. Survey results on Knowledge and Perception Analysis of Ebola transmission factors

First, from the survey was re-conducted on the knowledge and perception of individuals about factors responsible for the

Table 3
Criterion for Ebinformatics testing and evaluation.

(a) Detailed evaluation criterion of the user evaluation explained

S/N	Evaluation Criterion	Interpretation
1	**Ability**	This criterion checks whether EBINFORMATICS has the ability to identify or diagnose users ailments based on the symptoms they have supplied to the software.
2	**Data Validation 1**	This criterion helps to check whether EBINFORMATICS accepts appropriate data type for each field.
3	**Data Validation 2**	This criterion helps to ascertain if EBINFORMATICS prompts error message whenever wrong data is supplied or when important input fields are omitted.
4	**Sufficiency**	This criterion helps users to check if EBINFORMATICS is sufficiently robust.
5	**Security**	This criterion is profitable in ascertaining whether EBINFORMATICS possesses adequate access control (security)
6	**Intension to Use**	This criterion is profitable in ascertaining whether EBINFORMATICS will act as a complementary resource for supplementary healthcare support
7	**Ease of Use 1**	This Ease of Use 1 criterion helps to check if EBINFORMATICS software is very easy to use.
8	**Satisfaction**	This criterion helps to ascertain if users are actually satisfied with the services provided by EBINFORMATICS.
9	**Supportive**	This criterion checks if EBINFORMATICS will be particularly supportive to developing countries with recent incidences of Ebola Outbreak.
10	**Useful**	This criterion helps to check if EBINFORMATICS would be useful as an Ebola –supporting software

(b)

S/N	Evaluation Criterion	Interpretation
1	**Modeling**	The developers of the Ebinformatics software have adequately modeled the software according to the operations of typical healthcare providers.
2	**Misuse 1**	The Misuse 1 criterion helps to check if Ebinformatics software allows every form of attempts to misuse it (Miuse1)
3	**Misuse 2**	The Misuse 2 criterion helps to check if Ebinformatics software does not have enough controls to disallow misuse (Misuse 2)
4	**Ease of Use 2**	This Ease of Use 2 criterion helps to check if EBINFORMATICS software is generally simple to navigate and explore without any difficulty.
5	**Anonymity**	This criterion helps to check if Ebinformatics software allows for anonymity in its usage.
6	**Recommender function**	This criterion helps to check if The Ebinformatics software is able to give useful advice and recommendations users

Table 4
EbInformatics Range of Fuzzy Values.

S/N	Linguistic variables	Fuzzy values
1	Mild	$0.1 \leq y < 0.3$
2	Moderate	$0.3 \leq y < 0.6$
3	Severe	$0.6 \leq y < 0.8$

transmission of EVD. The response analysis result is shown in Table 1. This result shows that there were appreciable number of people with good knowledge and perception about factors responsible for the transmission of EVD. However, there were other sets of people that had very poor knowledge and perception of factors responsible for the transmission of EVD.

23(23%) of the participants agreed that it is possible for insects or mosquitoes to aid in the transmission and spread of the Ebola Virus Disease, 30 (30%) are ignorant about this. 47 (47%) of the

Table 5
Fuzzy Rule Base for Ebola Virus Disease (EVD) in Ebinformatics – using 14 rules.

Rule no	Bleeding eyes	Bloody cough	Bleeding gums	Bleeding mouth	Backache	Breathing difficulty	Chest pain	Fever	Fatigue	Region	Countries visited	3-months visit	Conclusion-Ebola intensity
1	Mild	Moderate	Severe	Severe	Moderate	Severe	Moderate	Moderate	Moderate	West Africa	Sierra Leaone	Yes	High (82.06%)
2	Moderate	Moderate	Mild	Mild	Mild	Mild	Mild	Mild	Mild	America	None	No	High (80%)
3	Mild	Mild	Mild	Mild	Mild	Mild	Mild	Mild	Mild	Europe	None	No	Low (0%)
4	Moderate	Mild	Mild	Mild	Mild	Mild	Severe	Severe	Severe	Middle East	None	No	Medium (55.02%)
5	Mild	Mild	Mild	Mild	Severe	Moderate	Severe	Mild	Mild	Asia	None	No	Medium (54.54%)
6	Mild	Severe	Mild	Severe	Mild	Severe	Mild	Mild	Mild	Africa	Liberia	Yes	High (78.65%)
7	Severe	Mild	Severe	Mild	Severe	Mild	Severe	Mild	Severe	Australia	Guinea	Yes	High (80.32%)
8	Mild	Mild	Mild	Mild	Severe	Mild	Severe	Mild	Mild	South Africa	None	No	Medium (54.54%)
9	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Europe	Mali	Yes	High (78.65%)
10	Severe	Severe	Severe	Severe	Severe	Severe	Severe	Severe	Severe	West Africa	Sierra Leone	Yes	High (81%)
11	Mild	Mild	Severe	Severe	Mild	Mild	Severe	Severe	Severe	Africa	None	No	Medium (59.55%)
12	Mild	Moderate	Mild	Moderate	Mild	Moderate	Mild	Moderate	Mild	South Africa	None	No	Medium (56.25%)
13	Mild	Mild	Mild	Mild	Mild	Moderate	Mild	Mild	Moderate	America	None	No	Low (32.5%)
14	Mild	Mild	Mild	Mild	Mild	Mild	Mild	Mild	Mild	Asia	Liberia	Yes	High (88.33%)

Table 6
Weights assigned to patients by doctors who have interacted with such patients.

For instance, sample of rating of patients on Ebola (EVD) diagnosis variables									
Patients no.	Bleeding eyes	Bloody cough	Bleeding gums	Bleeding mouth	Bleeding nose	Breathing difficulty	Chest pain	Fever	Fatigue
0001	3	3	2	1	3	3	3	3	1
0002	1	2	3	1	2	3	3	2	3
0003	3	1	1	1	1	1	1	1	1
0004	3	2	1	3	2	1	3	2	1

All symptoms-specified in File **EbinformaticsSymtoms.doc**
Table 6**:** above shows the weights assigned to patients by doctors who have interacted with such patients.

Table 7
Derived triangular values for Ebola Virus Disease (EVD) signs/symptoms.

Patients ID	Bleeding Eyes	Bloody Cough	Bleeding Gums	Bleeding mouth	Bleeding nose	Breathing difficulty	Chest pain	Fever	Fatigue
0001	0.67	0.67	0.33	0	0.67	0.67	0.67	0.67	0
0002	0	0.33	0.67	0	0.33	0.67	0.67	0.33	0.67
0003	0.67	0	0	0	0	0	0	0	0
0004	0.67	0.33	0	0.67	0.33	0	0.67	0.33	0

If we are to analyze and provide detail description for the entries made for the second patient for instance, from Table 7, the values entered for patient 2 (with ID=0002). Record of Patient 2 is highlighted YELLOW in the Table 7.

Bleeding Eyes	Mild	0
Bloody Cough	Moderate	0.33
Bleeding gums	Severe	0.67
Bleeding mouth	Mild	0
Bleeding nose	Moderate	0.33
Breathing difficulty	Severe	0.67
Chest pain	Severe	0.67
Fever	Moderate	0.33
Fatigue	Severe	0.67

participants disagreed. 59 (59%) of the participants agreed that it is possible that Ebola Virus Disease can be transmitted through body contact without contact with body fluids; 34(34%) disagreed; 7 (7%) were ignorant about this. 43 (43%) of the participants were sure that Ebola Virus Disease is both air-borne and water-borne. 33 (33%) disagreed, while 24(24%) were ignorant about whether EVD is both air-borne and water-borne. 50(50%) agreed that it is true that Ebola can be transmitted majorly through the consumption of bush meat. 24(24%) disagreed, while 26(26%) do not know the answer to the question. 28(28%) of the participants agreed that there is presently a known cure for EVD; 41(41%) disagreed; 31 (31%) do not know whether there is presently a known cure for EVD or not. 79(79.8%) agreed that it is possible for the Ebola virus to be transmitted when an uninfected person touches a dead person that died as a result of Ebola infection; 5(5.05%) disagreed, while 15(15.15%) were ignorant of the answer. 1(1%) person skipped and avoided this particular question during the survey. 86 (86%) agreed that washing of hands and the use of hand sanitizer can reduce the chances or risks of contacting the Ebola virus, 8(8%) disagreed, while the remaining 6(6%) were ignorant. 56(56%) of the participants agreed that fruit bats are the primary carriers of Ebola virus, 13(13%) disagreed, while 31(31%) were ignorant. (See Table 1)

5.2. Graphical User interfaces of Ebinformatics Software

Second, the output of the Ebinformatics software was captured as screenshots. Figs. 6 – 10 reveal the screenshots of the various sections of the graphical user interface of our *Ebinformatics* software. Fig. 5 revealed the splash welcome screen of *Ebinformatics.*

The homepage of the *Ebinformatics* software is depicted in Fig. 6. This figure provides an overall depiction (an overview) of the entire system. It consists of a section for diagnosing patients. There is also another section that provides information about symptoms and facts about the Ebola Virus Disease (EVD).

Fig. 7 is the diagnosis section of the *Ebinformatics* software. This section consists of a basic information section to be filled-in by the users, another section allows the user to select possible symptoms currently affecting such patients, and lastly a section of pertinent questions that will help prevent onward transmission of the EVD if the patient had already been infected.

Fig. 8 shows an example of an already filled-in diagnosis section of the *Ebinformatics* software. Fig. 9 revealed the predictive result of the *Ebinformatics* software after analyzing input data.

5.3. Results of comprehensive testing of Ebinformatics software by users

Third, a comprehensive user-testing evaluation of the Ebinformatics software produced the following results: 33 (73%) agreed that Ebinformatics diagnosis feature was very good; 9 (20%) disagreed, while 3 (6.67%) were neutral. 31 (68.89%) agreed that the Ebinformatics software was well modeled, 4 (9%) disagreed, while 10 (22.22%) were neutral. With respect to user satisfaction based on the testing of the Ebinformatics software, 27 (60%) were satisfied, while 7 (16%) were dissatisfied, while 11 (24%) were neutral. 31 (69%) agreed that Ebinformatics software was supportive and will be a complementary supportive tool for individuals, medical practitioners and patients, 9(20%) disagreed, 5(11%) were neutral. With respect to the evaluation criterion of Ease of use1 of the Ebinformatics software, 30 (66.67%) agreed, 6 (13.33%) disagreed, while 9 (20%) were neutral; concerning how well the Ebinformatics software made decisions and provided recommendations to users, 28 (62%) of the participants agreed that it was

Table 8
Rule base EVD evaluation for Patient number 0002 based on the Rule base specified in Table 5 Fuzzy Rule Base for Ebola Virus Disease (EVD) in Ebinformatics – Using 14 rules.

These values eventually generate fuzzy transcripts as shown in Table 8

Rule No	Bleeding Eyes	Bloody Cough	Bleeding Gums	Bleeding mouth	Backache	Breathing difficulty	Chest Pain	Fever	Fatigue	Conclusion	Non-Zero
2	-	0.33	-	0	-	-	-	0.33	-	Moderate	0.33
4	-	-	-	0	-	-	0.67	-	0.67	Severe	0.67
5	0	-	-	0	-	-	0.67	-	-	Severe	0.67
6	0	-	-	-	-	0.67	-	-	-	Severe	0.67
7	-	-	0.67	0	-	-	0.67	-	0.67	Severe	0.67
8	0	-	-	0	-	-	0.67	-	-	Severe	0.67
9	-	0.33	-	-	0.33	-	-	0.33	-	Moderate	0.33
10	-	-	0.67	-	-	0.67	0.67	-	0.67	Severe	0.67
11	0	-	0.67	-	-	-	0.67	-	0.67	Severe	0.67
12	0	-	-	-	-	-	-	0.33	-	Mild	0.33
14	0	-	-	0	-	-	-	-	0.67	Severe	0.67

Table 8: Rule base EVD evaluation for Patient number 0002.

Table 9
Comparison between mathematically calculated intensity and EbInformatics predicted intensity.

Patient ID	Mathematically Calculated Ebola Intensity	EbInformatics Software Ebola Intensity
0002	61% ~ MEDIUM	60%~MEDIUM

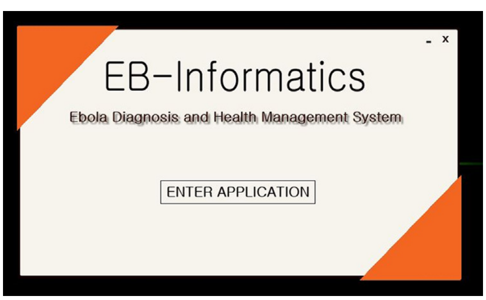


Fig. 6. Welcome section of the Graphical Interface of Ebinformatics Software. legend: This page welcomes users to the EB-Informatics software (an Ebola diagnosis and health management system).

very good, 5 (11%) disagreed, while 12 (27%) were neutral in their decision (see a comprehensive list in the supplementary material System evaluation.xls and Fig. 2).

6. Discussion

6.1. Ignorance as a major player in the promotion of Ebola Virus Disease transmission

It is evident that ignorance plays a role in the transmission of EVD. Many are still in the category of being ignorant about the transmission factors responsible for the spread of EVD. In the recent outbreak of Ebola among some West African countries in 2014, many people were infected with the disease as a result of ignorance by them with respect to the transmission factors of the disease. From the survey results as specified in Table 1, ignorance played a major role. Thus, the rapid transmission of EVD in 2014 among West African countries was as a result of lack of EVD knowledge and factors responsible for its transmission.

Medical professionals in training and researchers consistently seek effective informatics tools to complement their needs in meeting the demands of present day infectious disease like Ebola. The success of Ebinformatics illustrates the potentials of applying an informatics tool on operational and research platforms as a means of fostering critical tasks such as patient diagnosis, prediction and proffering appropriate recommendations.

However, only a handful of biomedical informatics literatures have discussed the development of informatics applications for Ebola detection, diagnosis and how it can be helpful to affected regions of the world [28,29].

Despite a slightly above average knowledge of the disease and its modes of transmissions [30], it is pertinent to keep more of the world populace well informed about Ebola and factors responsible for its transmission through the development of Ebola informatics-related tools.

Several lessons have been learnt through the interactions of users with the *Ebinformatics* software. First, users of the software desired simplicity. This is evident in the results obtained during the user-evaluation of the *Ebinformatics* software where about 70% agreed that simplicity is an essential factor in determining how readily informatics software can be accepted for use by consumers.

Second, users of the *Ebinformatics* software acknowledged and embraced the supportiveness and complementary nature of the software especially in the health industry. This is evident in the result where about 70% indicated their agreement after using the software.

Third, we found that a high percentage (over 70%) of users of the *Ebinformatics* software embraced the diagnostic feature more than anticipated and this is further corroborated by the satisfaction level expressed by users as observed in the results.

Thirdly, since the goal of the Ebinformatics software is to assist and complement users to diagnose and make an informed decision on their health status, the usability of such software in presenting acceptable results is very critical in determining its success. In *Ebinformatics* software, we implemented graphical user interface (visual aids) and also provided definitive steps to guide users in exploring the features embedded therein, the results, identify information of interest and study information around the software's environment. Based on the user feedback we received, it is our belief that the usability of the software has played a very important role in growing our user base and sustaining the interest of existing users.

6.2. Ebinformatics software as a feasible solution to complement efforts of health infrastructure in Ebola affected West African countries

An unhealthy nation is a fainting or dying nation. It was observed in 2014 that the health systems in Guinea, Liberia and

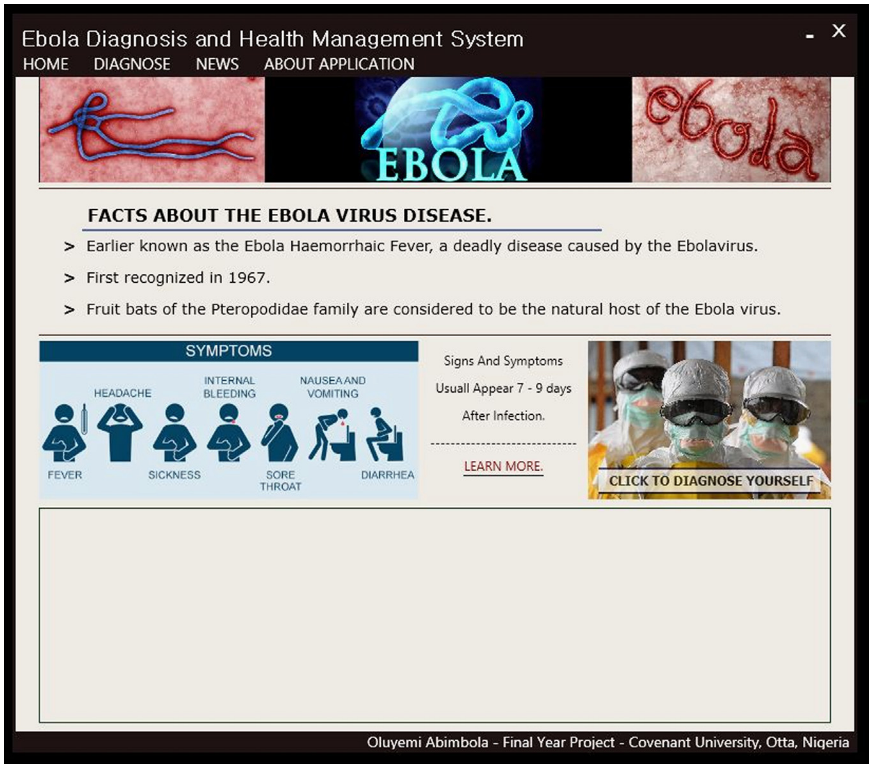


Fig. 7. Home Section of Ebinformatics software. legend: This home page of Ebinformatics software provides an overview of the entire component of the software to interested users. The home section of Ebinformatics software consists of three(3) sub-sections namely: the basic information section, symptoms selection section and other follow-up question section. All these sections are essential to making informed diagnosis, decision and recommendation by the Ebinformatics software.

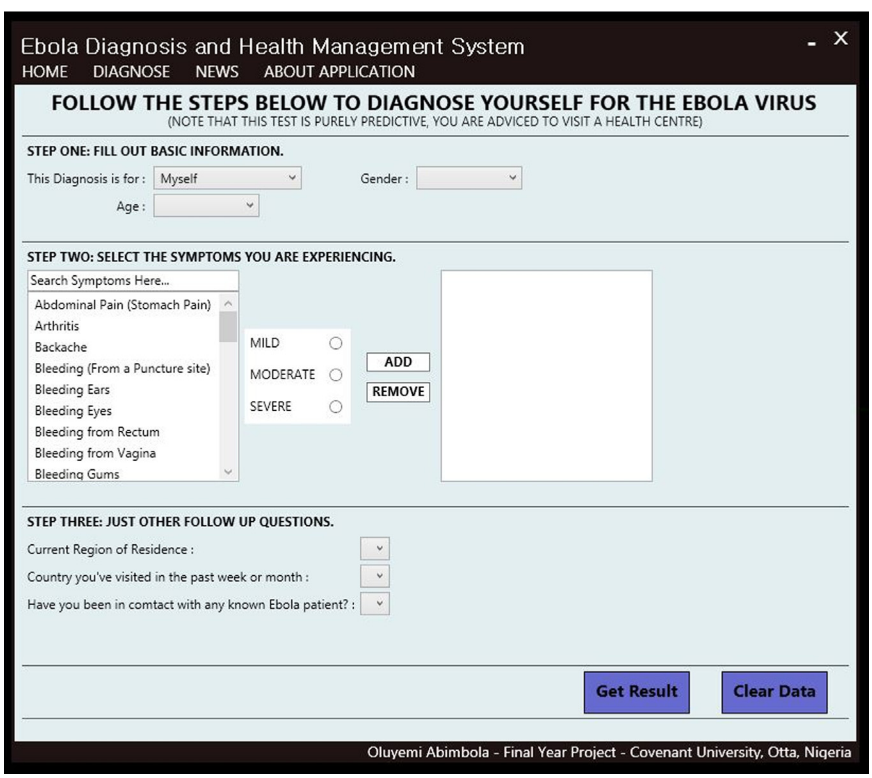


Fig. 8. Diagnosis Section of Ebinformatics Software without symptom selection. legend: This section consists of the symptoms section before symptoms identified on a patient were selected and added to a list.

Sierra Leone collapsed under the heavy weight and shock of Ebola [31]. These West African countries lacked quality health infrastructures. However, in Nigeria, the Ebola cases were brought under control through early reporting and isolation for specialized treatment [32,33]. These nations also lacked sufficient medical personnel. Furthermore, these countries lacked useful informatics

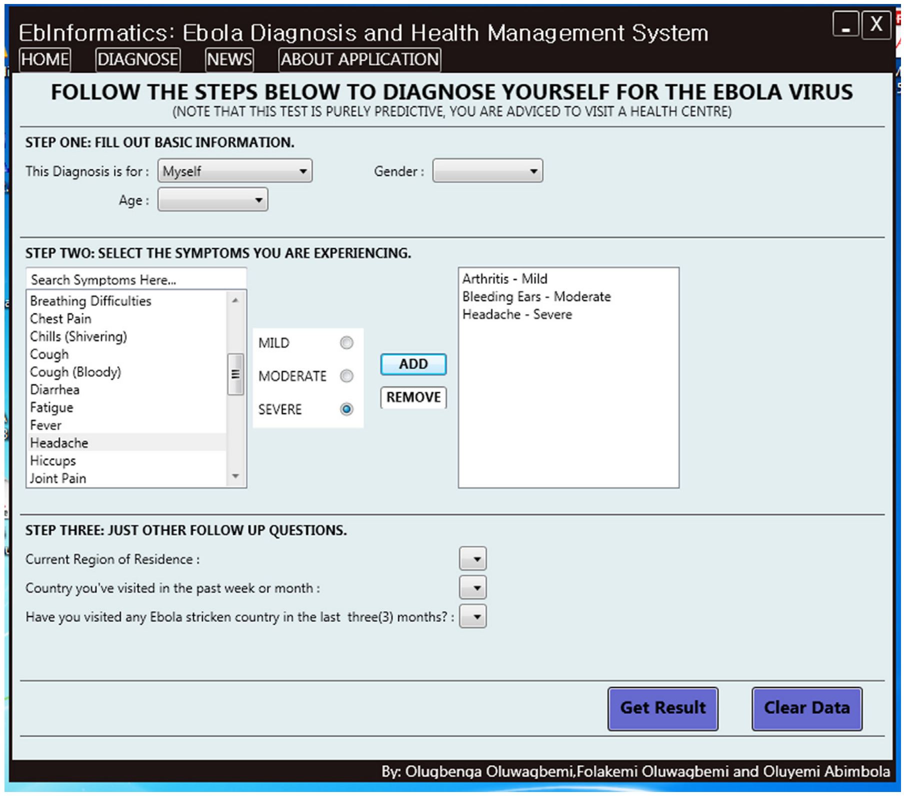


Fig. 9. Diagnosis Section of Ebinformatics Software with symptom selection. legend: This section consists of the symptoms section after symptoms identified on a patient have been added to a list within the Ebinformatics software.

software to conduct a preliminary self-diagnosis or checkup on the Ebola status of rural community, urban and city dwellers in these countries. These problems, coupled with others, led to the escalatory trend of Ebola in these Ebola-hit West African countries [34–37].

Quality health infrastructures are essential in curbing the menace of Ebola. These infrastructures are numerous and they include: high-quality health laboratories, Standard hospitals and health centers, High number of qualified medical doctors, pharmacists, nurses, good work conditions for health workers, manpower and capacity for effective operations in public health institutions, good transportation and communication infrastructures, private–public collaborations by jointly investing in Ebola-affected developing countries, setting aside strange traditions and culture, adequate remunerations for health workers, success by Government to provide adequate financial resources to implement result-oriented health goals, good electricity, good sanitation and hygiene, Ebola health facilities for isolating and treating Ebola patients [34,35,38–46].

However, these infrastructures cannot individually function in isolation. In essence, they cannot function independently. Each infrastructure has to depend on two or more other infrastructures to yield an excellent result. Our Ebinformatics software acts as a feasible solution to complement the efforts of existing health infrastructures. The software creates awareness in people about the possible existence of Ebola and prompts people to go for medical tests and checkups.

In situations that symptoms highlighted share similarities with other infectious diseases, a more comprehensive clinical check-up is very essential to actually ascertain the authenticity that it is not EVD. This is the reason for incorporating the recommender module of the Ebinformatics software. However, if Ebola Virus Disease (EVD) was confirmed after a detailed and comprehensive medical examination and checkups, it helps medical doctors and health practitioners to urgently isolate such Ebola patient for intensive treatment and management. Thus, Ebinformatics software acts as a complementary platform for facilitating rapid containment of EVD.

6.3. *Recommendations*

For future work the *Ebinformatics* system is open for further reviews and improvements, therefore the following recommendations are made concerning the improvements of the system.

(1) Multi-Lingua facilities can be incorporated into future versions of the *Ebinformatics* software especially for countries that do not have English as their official language.
(2) Web-Based and Mobile features can be integrated into *Ebinformatics* in order to make it more accessible and more available to users.
(3) Ebinformatics with interactive voice-enabled explanatory facility can also be incorporated into future versions of *Ebinformatics* software.

7. Conclusion

This paper reports the development of *Ebinformatics* software and its application to facilitate the diagnosis and early containment of Ebola-related medical conditions. Based on the user evaluation result, it has proven to be a valuable addition to the operational and research enterprise in the fight against Ebola. For institutions, communities, hospitals interested in adopting our *Ebinformatics* software, the software is freely available at no cost for use.

Contributorship statement

Olugbenga Oluwagbemi conceived the project. Olugbenga also contributed to the design and development of the Ebinformatics software as well as the experimental aspect of implementing the software through some codes, the mathematical aspects of detailing the internal components of the software, the acquisition, analysis and interpretation of the data, and drafting of the manuscript. He also conceived the Ebinformatics algorithm and provided guidance to the implementation of the algorithm in the *Ebinformatics* software.

Folakemi Oluwagbemi contributed to the design, analysis of the Ebinformatics software, interpretation of the data, and drafting of the manuscript.

Oluyemi Abimbola contributed to the coding of the Ebinformatics software, analysis and interpretation of the data.

Conflict of interest

None.

Acknowledgments

This research was partly supported in kind (through the provision of computers, software and internet support for the research) by The Oluwagbemi Research, Development and Philanthropic Foundation (TORDPF). We wish to acknowledge and thank all the anonymous individuals who participated in the knowledge of transmission factors regional survey and the user-test evaluation of the *Ebinformatics* software.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.imu.2015.12.001.

References

[1] Gatherer Derek. The 2014 Ebola Virus Disease outbreak in West Africa. J Gen Virol 2014;95(8):1619–24.

[2] WHO Ebola Response Team. Ebola Virus Disease in West Africa—the first 9 months of the epidemic and forward projections. N Engl J Med 2014;371:1481–95.

[3] Dixon Meredith G, Schafer Ilana J. Ebola Viral disease outbreak — West Africa, 2014. Morb Mortal Wkly Rep 2014;63(25):548–51.

[4] Eslami V, Rouhani-Esfahani S, Hafezi-Nejad N, Refaeian F, Abdi S, Togha M. A computerized expert system for diagnosing primary headache based on International Classification of Headache Disorder (ICHD-II). SpringerPlus 2013;2(199) Retrieved from:〈Welcome@123http://www.springerplus.com/content/2/1/199〉.

[5] Yasnoff WA, Miller PL. Decision support and expert systems in public health. In: Magnuson J, editor. Public health informatics and information systems, health informatics. London: Springer-Verlag; 2014. p. 449–67.

[6] Woolery LK, Grzymala-Busse J. Machine learning for an expert system to predict preterm birth risk. J Am Med Inf Assoc 1994;1(6):439–46.

[7] Klausner S, Entacher k, Kranzer S, Sonnichsen A, Flamm M, Fitsch G. ProPath – A Guidel Based Softw Implement into Med Environ 2014.

[8] Azim T, Jaffar AM, Mizra AM. Fully automated real time fatigue detection of drivers through fuzzy expert systems. Appl Soft Comput 2014;18:25–38.

[9] Alder H, Micheal BA, Marx C, Tamborrini G, Langenegger T, Bruehlamann P, Steuer J, Wildi LM. Computer-Based Diagnostic Expert Systems in Rheumatology: Where Do We Stand in 2014? Int Journal Rheumatol 2014.

[10] Duan L, Street WN, Xu E. Healthcare information systems: data mining methods in the creation of a clinical recommender system. Enterp Inf Syst 2011 20:169–81. http://dx.doi.org/10.1080/17517575.2010.3341287.

[11] Ati M, Hussein A, Omar W. Implemenation of a hybrid approach for chronic disease risk assessment and recommendation system. International conference on innovative technologies. Leiria; 2014.

[12] Shortliffe EH. Medical expert systems-knowledge tools for physicians. Med Inform 1986;145:830–9.

[13] Amindito, Pardamean B, Christian R, Abbas BS. Expert-system based medical stroke prevention. J Comput Sci 2013;9(9):1099–105.

[14] Koutsojannis C, Hatzilygeroudis I. FESMI: a fuzzy expert system for diagnosis and treatment of male impotence. KES 2004;2004:1106–13.

[15] Mailafiya I, Isiaka F. Expert system for diagnosis of hepatitis B. Keffi: Nassarawa State University, Department of Computer Science; 2015 [Retrieved 2015].

[16] Brasil LM, Mendes de Azevedo F, Barreto JM. A Hybrid expert system for the diagnosis of epileptic crisis. Artif Intell Med 2000;585:1–7.

[17] Saritas I, Allahverdi N, Sert IU. A fuzzy expert system design for diagnosis of prostate cancer. International conference on computer systems and technologies—CompSysTech'2003; 2003.

[18] Tunmibi S, Adeniji O, Aregbesola A, Dasylva A. A rule based expert system for diagnosis of fever. Int J Adv Res 2013;1(7):343–8.

[19] Oluwagbemi OO, Adeoye TE, Fatumo S. Building a computer-based expert system for malaria environmental diagnosis: an alternative malaria control strategy. Egypt Comput Sci J 2009;33(1):55–69.

[20] Oluwagbemi OO, Ofoezie U, Nwinyi O. A knowledge-based data mining system for diagnosing malaria related cases in healthcare management. Egypt Comput Sci J 2010;34(4):1–10.

[21] Oluwagbemi OO, Ojutalayo T, Obinna N. Development of a secured information system to manage malaria related cases in South Western region of Nigeria. Egypt Comput Sci Jl 2010;34(5):23–34.

[22] Ngah UK, Aziz SA, Aziz ME, Murad M, Mahdi NM, Shakaff AY, Arshad MR. A BI-RADS Based expert systems for the diagnoses of breast diseases. Am J Appl Sci 2007;4(11):865–73.

[23] Neshat M, Yaghobi MB, Esmaelzadeh A. Fuzzy Expert System Design for Diagnosis of Liver Disorders. In: International Symposium on Knowledge Acquisition and Modeling, 2008, KAM'08. Wuhan: IEEE; 2008, p. 252–6. http://dx.doi.org/10.1109/KAM.2008.43.

[24] Adlassnig K-P. Fuzzy set theory in medical diagnosis. Syst, Man Cybern 1986;16(2):260–5. http://dx.doi.org/10.1109/TSMC.1986.4308946.

[25] Tripathi KP. A review on knowledge-based expert system: concept and architecture. Artif Intell Tech—Nov Approaches Pr Appl 2011:19–23.

[26] Djam XY, Wajiga GM, Kimbi YH, Blamah NV. A fuzzy expert system for the management of malaria. Int J Pure Appl Sci Technol 2011;5(2):84–108.

[27] Makhubele Kulani. A knowledge based expert system for medical advice provision. Department of Computer Science, University of Cape Town; 2012.

[28] Douah Remi, Kacker Anuj. Developing integrated mobile applications to provide culturally responsive support for minnesota african diaspora and west african families impacted by Ebola virus disease. Sci J Public Health 2015;3(3–1):10–7.

[29] Darrell M, West. Using mobile technology to improve maternal health and fight Ebola: a case study of mobile innovation in Nigeria. Center for Technology Innovation at Brookings; 2015.

[30] Alqahtani AS, Wiley KE, Willaby HW, BinDhim NF, Tashani M, Heywood AE, Booy R, Rashid H. Australian Hajj pilgrims' knowledge, attitude and perception about Ebola, November 2014 to February 2015. Euro Surveill 2015;20(12) [pii=21072].

[31] WHO. 〈http://www.who.int/csr/disease/ebola/one-year-report/response-in-2015/en/〉; 2015 [accessed 21.10.15].

[32] Gomes MFC, Pastore y Piontti A, Rossi L, Chao D, Longini I, Halloran ME, Vespignani A. Assessing the international spreading risk associated with the 2014 West African Ebola outbreak. PLoS Curr 2014. http://dx.doi.org/10.1371/currents.outbreaks.cd818f63d40e24aef769dda7df9e0da5.

[33] Anthony S, Fauci. Ebola — underscoring the global disparities in health care resources. N Engl J Med 2014;371(12):1084–6.

[34] Fowler RA, Fletcher T, Fischer II WA, Lamontagne F, Jacob S, Brett-Major D, Lawler JV, Jacquerioz FA, Houlihan C, O'Dempsey T, Ferri M, Adachi T, Lamah M, Bah EI, Mayet T, Schieffelin J, McLellan SL, Senga M, Kato Y, Clement C, Mardel S, De Villar Rosa Constanza Vallenas Bejar, Shindo N, Bausch D. Caring for critically Ill patients with Ebola virus disease. Perspectives from West Africa. Am J Respir Crit Care Med 2014;190(7):733–7. http://dx.doi.org/10.1164/rccm.201408 – 1514CP.

[35] Gostin Lawrence O, Lucey Daniel, Phelan Alexandra. The Ebola epidemic a global health emergency. J Am Med Asso 2014;312(11):1095–6. http://dx.doi.org/10.1001/jama.2014.11176.

[36] Abdullah1 S, Karunamoorthi. K. Ebola and blood transfusion: existing challenges and emerging opportunities. Eur Rev Med Pharmacol Sci 2015;19:2983–96.

[37] Bausch DG, Schwarz L. Outbreak of Ebola virus disease in guinea: where ecology meets economy. Plos Negl Trop Dis 2014;8(7):e3056. http://dx.doi.org/10.1371/journal.pntd.0003056.

[38] David L, Heymann Lincoln, Chen Keizo, Takemi David P, Fidler Jordan W, Tappero Mathew J, Thomas Thomas A, Kenyon Thomas R, Frieden Derek, Yach Sania, Nishtar Alex, Kalachem Piero L, Olliaro Peter, Horby Els, Torreele Lawrence O, Gostin Margareth, Ndomondo-Sigonda Daniel, Carpenter Simon, Rushton Louis, Lillywhite, Bhimsen Devkota Khalid, Koser Rob, Yates Ranu S, Dhillon Ravi P, Rannan-Eliya. Global health security: the wider lessons from

the west African Ebola virus disease epidemic. Lancet 2015;385(9980):1884–901.
[39] Gostin Lawrence O. Ebola: towards an International Health Systems Fund. Lancet 2014 [published online first (September 4)]⟨http://download.thelancet.com/flatcontentassets/pdfs/S0140673614613453.pdf⟩.
[40] Ayenigbara GO. The facts, the fears, and the prevention of Ebola haemorrhagic fever: a focus on Nigeria. Int Res J Public Environ Health 2014;1(9):192–6.
[41] Upchurch D, McCrary DG. Healthcare infrastructure: deciphering the spread of Ebola in West Africa. Journal Gend, Inf Dev Afr (JGIDA) 2013;2(1 & 2):63–75.
[42] Fan Hao-Jun, Gao Hong-Wei, Ding Hui, Zhang Bi-Ke, Hou Shi-Ke. The Ebola Threat: China's Response to the West African Epidemic and National Development of Prevention and Control Policies and Infrastructure. Disaster Med Public Health Prep 2015;9(01):64–5.
[43] Roca Anna, Afolabi Muhammed O, Saidu Yauba, Kampmann Beate. Ebola: A holistic approach is required to achieve effective management and control. J Allergy Clin Immunol 2015;135(4):856–67.
[44] Buseh Aaron G, Stevens Patricia E, Bromberg Mel, Kelber Sheryl T. The Ebola epidemic in West Africa: Challenges, opportunities, and policy priority areas. Nurs Outlook 2015;63(1):30–40.
[45] Barbiero VK. It's not Ebola… it's the systems. Glob Health: Sci Pract 2014;2(4):374–5. http://dx.doi.org/10.9745/GHSP-D – 14 – 00186.
[46] Lamunu M, Lutwama JJ, Kamugisha J, Opio A, Nambooze J, Ndayimirije N, Okware S. Containing a haemorrhagic fever epidemic: the Ebola experience in Uganda (October 2000–January 2001). Int J Infect Dis 2004;8(1):27–37.
[47] Tsoukalas LH, Uhrig. RE. Fuzzy and neural approaches in engineering. John Wiley & Son, Inc.; 1993.
[48] Novák V, Perfilieva I, Močkoř J. Mathematical principles of fuzzy logic Dodrecht. Kluwer Academic; 1999 ISBN: 0-7923-8595-0.
[49] Ahlawat Nishant, Gautam Ashu, Sharma Nidhi. International Research Publications House 2014) "Use of logic gates to make edge avoider robot. Int Journal Inf Comput Technol 2014;Volume 4(Issue 6):630 [ISSN 09742239 (Retrieved 27 April].
[50] Fuzzy Logic. Stanford encyclopedia of philosophy. Stanford University; 2006 – 07 – 23. [Retrieved 30.09.08].
[51] Zadeh LA. Fuzzy sets. Inf Control 1965;8(3):338–53. http://dx.doi.org/10.1016/s0019 – 9958(65)90241-x.
[52] Novák V. Are fuzzy sets a reasonable tool for modeling vague phenomena? Fuzzy Sets Syst 2005;156:341–8. http://dx.doi.org/10.1016/j.fss.2005.05.029.