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ANALYSIS

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Fuzzy logic based predictive model for likelihood of water related disease

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ABSTRACT

A fuzzy logic-based system has been applied to a number of cases in medicine especially in the area of the development of diagnostic systems and has been discovered to produce accurate results. In this paper, a fuzzy logic-based system is presented which is used to simulate a predictive model for predicting the likelihood of water related disease (malaria). Knowledge was elicited from an expert at Medical Centre, Osogbo, Osun State, Nigeria and was used in developing the rule-base and simulated the prediction model using the MATLAB software. The results of the fuzzification and defuzzification of variables, inference engine definition and model testing was also presented and showed that the fuzzy logic based model is very useful in the prediction of the likelihood of water related disease (malaria) in South Western Nigerian.

Keywords: fuzzy logic, prediction model, water related disease, likelihood

1. INTRODUCTION

According to Lenntech, (2014) Water borne diseases are diseases that are caused as a result of contaminated water. Water-borne diseases are any illness caused by drinking water contaminated by human or animal faeces, which contain pathogenic microorganisms (Lenntech, 2014). Water borne diseases spread by contamination of drinking water systems with the urine and faeces of infected animal or people.. In Nigeria, contaminations of drinking water with pathogens have also been reported in several towns (Bai *et al*., 2007).

Water-borne outbreaks of enteric diseases have occurred either when public drinking water supplies were not adequately treated after contamination with surface water or when surface waters contaminated with enteric pathogens have been used for recreational purpose (Johnson *et al*., 2003). Today only 58% of Nigerians have access to safe water (UNICEF and WHO, 2012). Thus, most households have to resort to drinking water from wells and streams especially in the rural and sub-urban communities. These water sources are largely untreated and might harbor water-borne and vector-borne diseases such as cholera, typhoid fever, diarrhea, hepatitis and guinea worm (Rahman *et al*., 2001; Adekunle, 2004; Fenwick, 2006).

In developing countries, particularly in Nigeria, the two main water problems man contends with are the quantity and quality of water (Adeniyi, 2004; Olajuyigbe, 2010). In view of its occurrence and distribution pattern, water is not easily available to man in the desirable amount and quality. These factors have led to the growing rate of water borne diseases like typhoid fever and cholera experienced in this part of the world (Edwards, 1993).

Although water-related diseases have largely been eliminated in wealthier nations, they remain a major concern in much of the developing world. The World Health Organization estimated in the 2000 assessment states that there are four billion cases of malaria each year in addition to millions of other cases of illness associated with the lack of access to clean water. Since many illnesses are undiagnosed and unreported, the true extent of these diseases is unknown. Water-related diseases are typically placed in four classes: waterborne, water-washed, water-based, and water-related insect vectors. The first three are most clearly associated with lack of improved domestic water supply.

Fuzzy logic is a means of providing a path for the diagnosis and decision making process due to its ability to deal with uncertainties (fuzziness) and ambiguity which may exist in the knowledge and information relating to a domain of study. Today, medical practitioners have identified possible and promising areas for implementing fuzzy logic systems for medical diagnosis Mishra et al, 2014). The idea of Fuzzy logic was presented by Lofti A Zadehn in 1965 based on the fuzzy set theory. Fuzzy logic systems are implemented by the manipulation of membership functions which simulate variables by the inference engine (rule-base).

Membership functions (MF) are curves that defines how each point in the input and output space is mapped to a membership value (or degree of membership) between 0 and 1.This implies that for every label of each variable; a membership function will be used to define the level of membership of the value entered with respect to the degree of membership to the label. Unlike, classical set; a fuzzy logic may be defined as follows:

If X is a universe of discourse and its elements are denoted by x, then a fuzzy set A in X is defined as a set of ordered pair:

$$A = \{x, \mu_A(x) | \ x \epsilon X \} \qquad (1)$$

$\mu_A(x)$is called a membership function (or MF) of x in A. The membership function maps each element of X to a membership function value between 0 and 1. For the purpose of this study, the following must be noted:

i. The set A is any input (sickle-cell factors) or output (sickle-cell likelihood) variable considered for this study;
ii. The set X is the set of values for which a variable is valid, for example a set A = degree of Anemia will be valid for value x=0 for No and x=1 for Yes. Hence for the set A, the set X is the set containing {0, 1}; and

iii. $\mu_A(x)$ is the map of the membership function that will be used to plot the degree of membership.

Furthermore, there is no widely acceptable and readily available cure for patients with sickle cell anemia at present. Curable methods such as gene therapy and bone marrow transplantation, which may be associated with several complications, are not readily available in developing nations (Omoti, 2005). This disease is a serious threat to human life and it is believed that such tragedy can be reduced by early diagnosis of its existence, hence this study.

This paper is aimed at developing a fuzzy logic based system that predicts the likelihood of sickle cell disease in an individual by requesting for a 3-tuple record consisting of the Level of fetal hemoglobin, Genotype and the degree of Anemia. The study is limited to knowledge elicited from a physician located in western Nigeria based on experience gathered in the diagnosis of the likelihood of sickle cell disease in patients in western Nigeria.

This paper is aimed at developing a fuzzy logic based system that predicts the likelihood of water Related disease in South Western Nigeria. The study is limited to knowledge elicited from a physician located in western Nigeria based on experience gathered in the diagnosis of the likelihood of water Related disease in patients in western Nigeria.

2. RELATED WORKS

Craun *et al*. (2006) worked on waterborne outbreaks reported in the United States and discussed that the epidemic waterborne risks in the paper. Despite the fact that the true incidence of waterborne illness was not reflected in the then reported outbreak statistics, outbreak surveillance has provided information about the important waterborne pathogens, relative degrees of risk associated with water sources and treatment processes, and adequacy of regulations. Pathogens and water system deficiencies that are identified in outbreaks may also be important causes of endemic waterborne illness. In recent years, investigators have identified a large number of pathogens responsible for outbreaks, and research has focused on their sources, resistance to water disinfection, and removal from drinking water. Outbreaks in surface water systems have decreased in the recent decade, most likely due to recent regulations and improved treatment efficacy. Of increased importance, however, are outbreaks caused by the microbial contamination of water distribution systems. A suggestion was made that, in order to better estimate waterborne risks in the United States, additional information is needed about the contribution of distribution system contaminants to endemic waterborne risks and undetected waterborne outbreaks, especially those associated with distribution system contaminants

Idowu (2012) Worked on development of a web based geo-spatial environmental health tracking system for Southwestern Nigeria studied and assessed the problem of environmental health, developed a spatial environmental health data and predictive models to forecast the likelihood of environmental health related diseases. This was with a view to prototyping the models for environmental health tracking. Data were collected from purposively twenty four local government areas within Southwestern Nigeria comprising of four local government areas from each of the six states. Observation and personal interview (both structured and unstructured) were also used to identify and assess environmental health problems within Southwestern Nigeria. The design of a spatial environmental health data model was done using the unified modelling language (UML). The model to predict the likelihood of environmental related diseases based on environmental health problems was formulated using the MATLAB Fuzzy Logic Toolbox. The prototype was developed using MySQL and PhP codes. Data collected from the local government areas was used to validate the performance of the model. The result showed that, when general sanitation, water, toilet facility and refuse disposal facility had probability of 0.000, the probability that environmental related diseases could occur was 0.870. If general sanitation, water, toilet facility and refuse disposal facility had probability of 0.500, then the probability that environmental related diseases could occur was 0.581. Also, if general sanitation, water, toilet facility and refuse disposal facility had probability of 1.00 , then the probability that environmental related diseases could occur was 0.130. In addition, the performance assessment of the environmental health tracking system was done on three occasions and the average value for the three occasions was recorded. The system was accessed for 4 different xv mobile broadband networks at the radius of 100m away from their base stations. It was observed that on the average for the 4 mobile broadband networks, the response time were 2.60, 2.60, 3.00 and 3.00 seconds respectively. On the average, the response time to access the system in any mobile broadband network in Nigeria is 2.80 seconds. In conclusion, the environmental health tracking system allows real time tracking of environmental health problem with the ability to forecast the possibility of environmental health related diseases within the study area.

Hopkins (1984) Worked on waterborne Disease in Colorado: Three Years' Surveillance and 18 Outbreaks observed that there has been a steady increase in the number of reported waterborne disease outbreaks occurring in the United States since the early 1960s. The average annual number reported for 1971-72 was 32; from 1980-82 the average was 41.1.1 The actual number of outbreaks that occur is certainly greater than this. Over a three-year period prior to June 1980, six waterborne outbreaks were reported in Colorado but about 20 additional clusters of gastrointestinal illness was suspected to be waterborne. Energy development, tourism, and population growth combine to place stress on water systems that typically have relied on protected or remote surface sources of supply with marginal treatment. Prior to June 1980, the Colorado Department of Health had a passive waterborne outbreak surveillance system, and responsibility for follow-up of water-related complaints was divided among two Sections of the Water Quality Control Division and the communicable Disease Control Section. From June 1980 through June 1983, a field epidemiologist was made responsible for improving the detection of waterborne illness. The project was housed in the Communicable Disease Control Section, Division of Disease Control and Epidemiology, which receives reports of communicable disease cases from the state's 63 counties. It was discovered that the Colorado Department of Health conducted intensive surveillance for waterborne diseases during the three-year period July 1, 1980-June 30, 1983. Eighteen outbreaks of waterborne illness were investigated. Outbreaks involved from 15 to 1,500 ill persons. Giardia lamblia was confirmed or suspected as the agent in nine outbreaks, rotavirus in one, and no agent could be identified in eight. Seventeen outbreaks occurred on surface-water systems; none of these had adequate chemical pretreatment and filtration.

3. MATERIALS AND METHODS

3.1 Research design

In this paper, a fuzzy logic-based prediction model is proposed with the aim of predicting the likelihood of water related disease in south western Nigerian. The study started with the identification of the problem of predicting water related disease likelihood given a number of symptoms/factors considered as input variables (3 in all). A review of related literature was performed to identify understand water related disease and its symptoms in addition to related works done in the past. Following this, knowledge was elicited from an expert (medical practitioner) located at the primary health Centre, Osogbo, Ondo State in understanding and verifying the information concerning water related disease symptoms.

The elicited knowledge was used to build the inference engine of the proposed system – this is part of the model formulation technique which also includes the fuzzification of the input and output variables. the model formulation is made complete by the identification of the aggregation method chosen for the inference engine alongside the defuzzification method required for producing the output variable which is the likelihood of water related disease (No and Yes).

3.2. Data identification and collection

A number of symptoms/factors are known to be connected to likelihood of malaria disease, among all these factors only 3 were identified as being the most important and relevant symptoms: the level of fetal water borne disease. This information was collected via structured interview with the medical practitioner who identified the factors and emphasized 3 main factors which are most easily used in identifying the likelihood of malaria disease based on his experience in medical practice. The water borne disease likelihood is defined as either: 0%, between 50% and 100%, and greater than 50%; the malaria was classified as either No, Fair and Yes while the degree of likelihood of malaria is classified as either less than 50% and greater than or equal to 50%.

In addition to the identification of the data variables, an understanding of the pattern of distribution was important in identifying the best membership function that could be used in plotting the labels of each variables. The number of rules required by the fuzzy logic inference system was calculated by multiplying the labels of each variable with each other; therefore we have 3*3*2 = 18 different rules. This information was necessary in the development of the fuzzy logic inference system.

3.3. Fuzzy logic model formulation

Fuzzy logic systems have the ability to decide and control a system using the knowledge of an expert. Fuzzy logic systems are mostly profitable in systems with sophisticated environments where a clear and obvious model of the system is not achievable. In order to develop the fuzzy logic system required for the prediction of likelihood of malaria disease, a number of activities are needed to be accomplished. The Fuzzy Logic System available in the Fuzzy Logic Toolbox of the MATLAB R2012a software has three parts:

- A set of Inputs represented by their respective membership functions;
- An Inference Engine which contains the IF-THEN rules (domain knowledge); and
- An Output represented by its membership functions.

The membership functions will be used to map the values of each input and output variables into a [0, 1] interval with the use of triangular and trapezoidal membership functions (where appropriate); this process is referred to as a Fuzzification process. After Fuzzification; the fuzzified inputs must be mapped to the fuzzified output via the use of operators (AND, OR and NOT) to develop IF-THEN rules that describe the relationship between every input (water related likelihood factors) and output (likelihood of the disease) variable. The different rules are used to generate different results which are then aggregated to just one fuzzified output. This fuzzified output will then be defuzzified using the centroid method which selects the centre of the polygon to determine the label of the output variable as Yes, Fair or No.

The most prominent reasons that justify the use of fuzzy logic systems today are:

- The sophistication of the natural world which leads to an approximate description or a fuzzy system for modeling; and
- The necessity of providing a pattern to formulate mankind knowledge and applying it to actual systems.

The process of development of the fuzzy inference system needed for the prediction of water related disease may be summarized as follows:

- Fuzzification of inputs and outputs;
- Construction of the inference engine;
- Rule aggregation; and
- Defuzzification of output variables.

3.4. Defining membership functions

Before the process of Fuzzification, it is very important to properly describe the crisp values that was used in mapping the values of the membership function which was needed by the fuzzy logic system. For the discrete variables with nominal values or Boolean (yes/no) – the values: 0, 1, 2…… n-1 was assigned to each value for n labels; this is the case for malaria as NO=0, Fair=0.5 and Yes=1. For the continuous variables which are measured; a value of the percentage expressed as a proportion of 0, 0.5 and 1 was used, i.e. 0%, 50% and 100% respectively into the appropriate membership functions.

3.5. Fuzzification of the variables

For the purpose of this study, the triangular and trapezoidal membership functions were used to map the degree of membership of the labels of each variable used both input and output variable. Following is a description of each variable and the type of membership function used for the labels alongside the ordered pair that was used in mapping the degree of membership for each variable's label.

a. The malaria outbreak prediction model

Presence of Bush in the environment = (No [-0.4 0 0.4], Fair [0.1 0.5 0.9], Yes [0.6 1 1.4])

$$PresenceOfBush(No; -0.4\ 0\ 0.4) = \begin{Bmatrix} 0,\ x \leq -0.4 \\ \frac{x+0.4}{0.4}, -0.4 \leq x \leq 0 \\ \frac{0.4-x}{0.4},\ 0 \leq x \leq 0.4 \\ 0,\ 0.4 \leq x \end{Bmatrix} \quad (2)$$

$$PresenceOfBush(Fair; 0.1\ 0.5\ 0.9) = \begin{Bmatrix} 0,\ x \leq 0.1 \\ \frac{x-0.1}{0.4}, 0.1 \leq x \leq 0.5 \\ \frac{0.9-x}{0.4},\ 0.5 \leq x \leq 0.9 \\ 0,\ 0.9 \leq x \end{Bmatrix} \quad (3)$$

$$PresenceOfBush(Yes; 0.6\ 1\ 1.4) = \begin{Bmatrix} 0,\ x \leq 0.6 \\ \frac{x-0.6}{0.4}, 0.6 \leq x \leq 1 \\ \frac{1.4-x}{0.4},\ 0.6 \leq x \leq 1.4 \\ 0,\ 1.4 \leq x \end{Bmatrix} \quad (4)$$

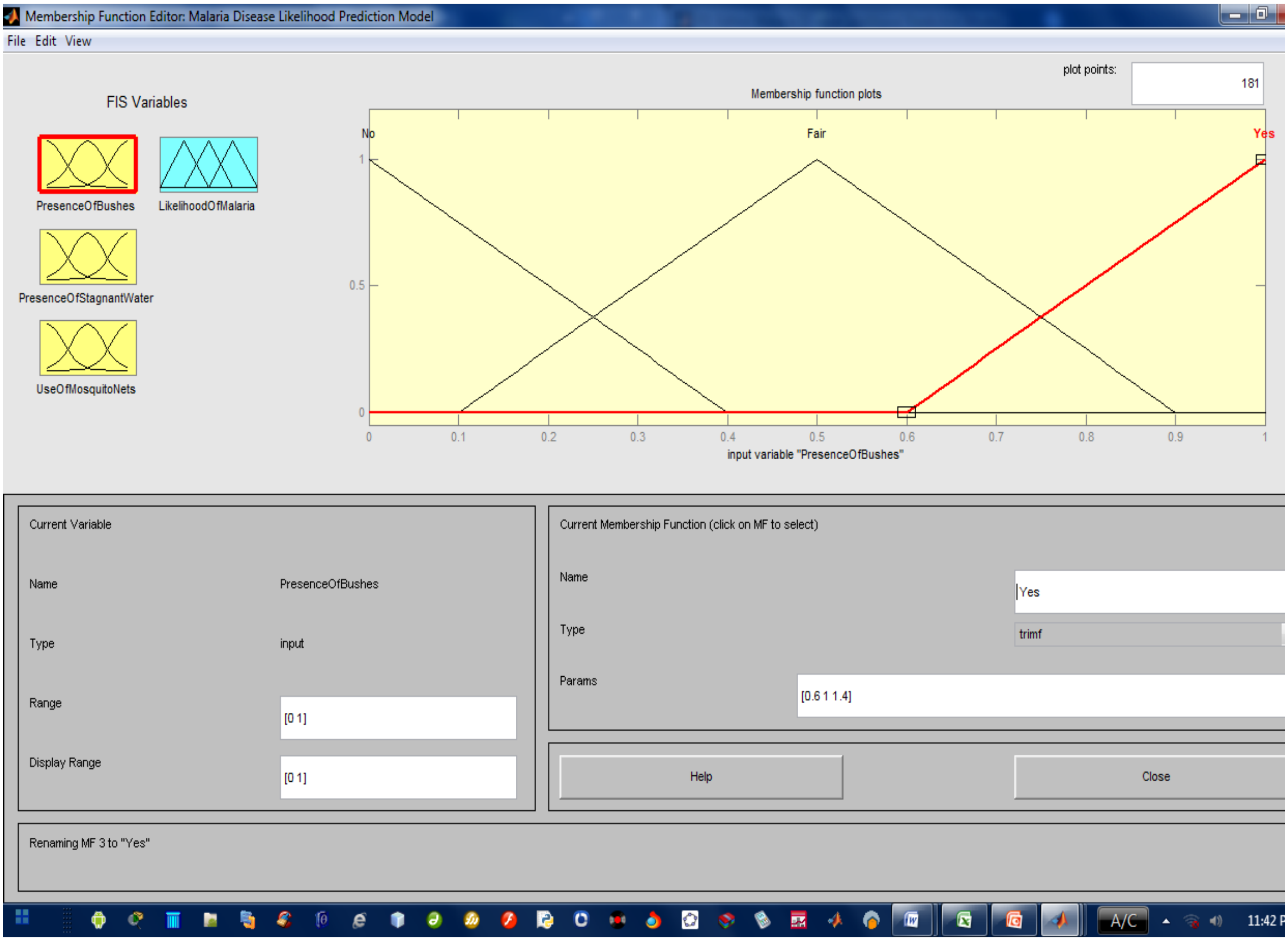

Figure 1 Membership function for the presence of bushes in the environment

Presence of stagnant water = (No [-0.4 0 0.5], Yes [0.5 1 1.5])

$$PresenceOfStagnantWater(No; -0.5\ 0\ 0.5) = \begin{Bmatrix} 0,\ x \le -0.4 \\ \frac{x+0.4}{0.5}, -0.4 \le x \le 0 \\ \frac{0.5-x}{0.5},\ 0 \le x \le 0.5 \\ 0,\ 0.5 \le x \end{Bmatrix} \quad (5)$$

$$PresenceOfStagnantWater(Yes; 0.5\ 1\ 1.5) = \begin{Bmatrix} 0,\ x \le 0.5 \\ \frac{x-0.5}{0.5}, 0.5 \le x \le 1 \\ \frac{1.5-x}{0.5},\ 1 \le x \le 1.5 \\ 0,\ 1.5 \le x \end{Bmatrix} \quad (6)$$

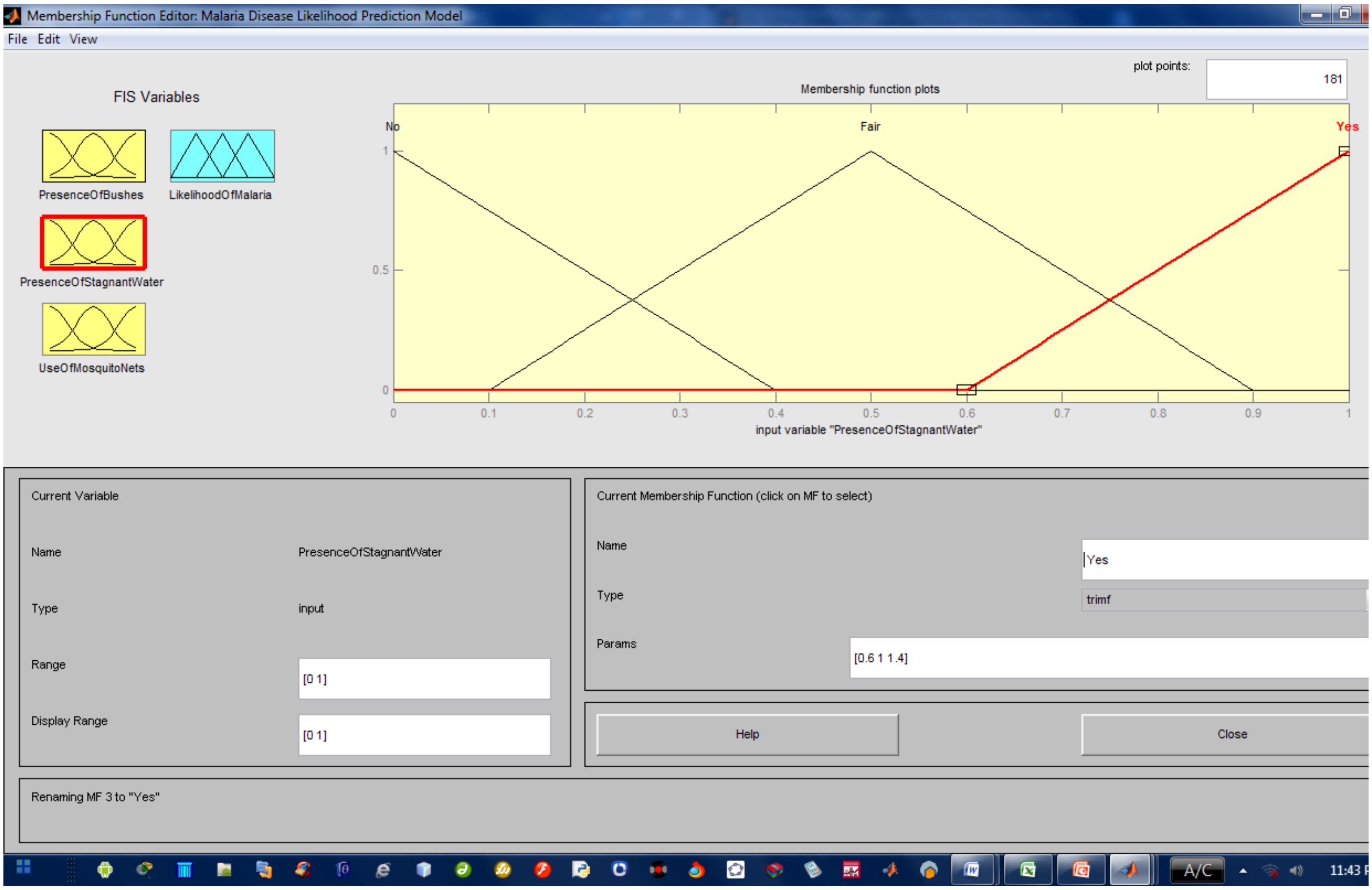

Figure 2 Membership function for presence of stagnant water

Use of mosquito nets = (Yes [-0.4, 0, 0.4], Fair [0.1 0.5 0.9], No [0.6 1 1.4])

$$UseOfMosquitoNets(Yes; -0.4\ 0\ 0.4) = \begin{Bmatrix} 0, \ x \leq -0.4 \\ \frac{x+0.4}{0.4}, -0.4 \leq x \leq 0 \\ \frac{0.4-x}{0.4}, \ 0 \leq x \leq 0.4 \\ 0, \ 0.4 \leq x \end{Bmatrix} \quad (7)$$

$$UseOfMosquitoNets(Fair; 0.1\ 0.5\ 0.9) = \begin{Bmatrix} 0, \ x \leq 0.1 \\ \frac{x-0.5}{0.4}, 0.1 \leq x \leq 0.5 \\ \frac{0.9-x}{0.4}, \ 0.5 \leq x \leq 0.9 \\ 0, \ 0.9 \leq x \end{Bmatrix} \quad (8)$$

$$UseOfMosquitoNets(Yes; 0.6\ 1\ 1.4) = \begin{Bmatrix} 0, \ x \leq 0.6 \\ \frac{x-0.6}{0.4}, 0.6 \leq x \leq 1 \\ \frac{1.4-x}{0.4}, \ 0.6 \leq x \leq 1.4 \\ 0, \ 1.4 \leq x \end{Bmatrix} \quad (9)$$

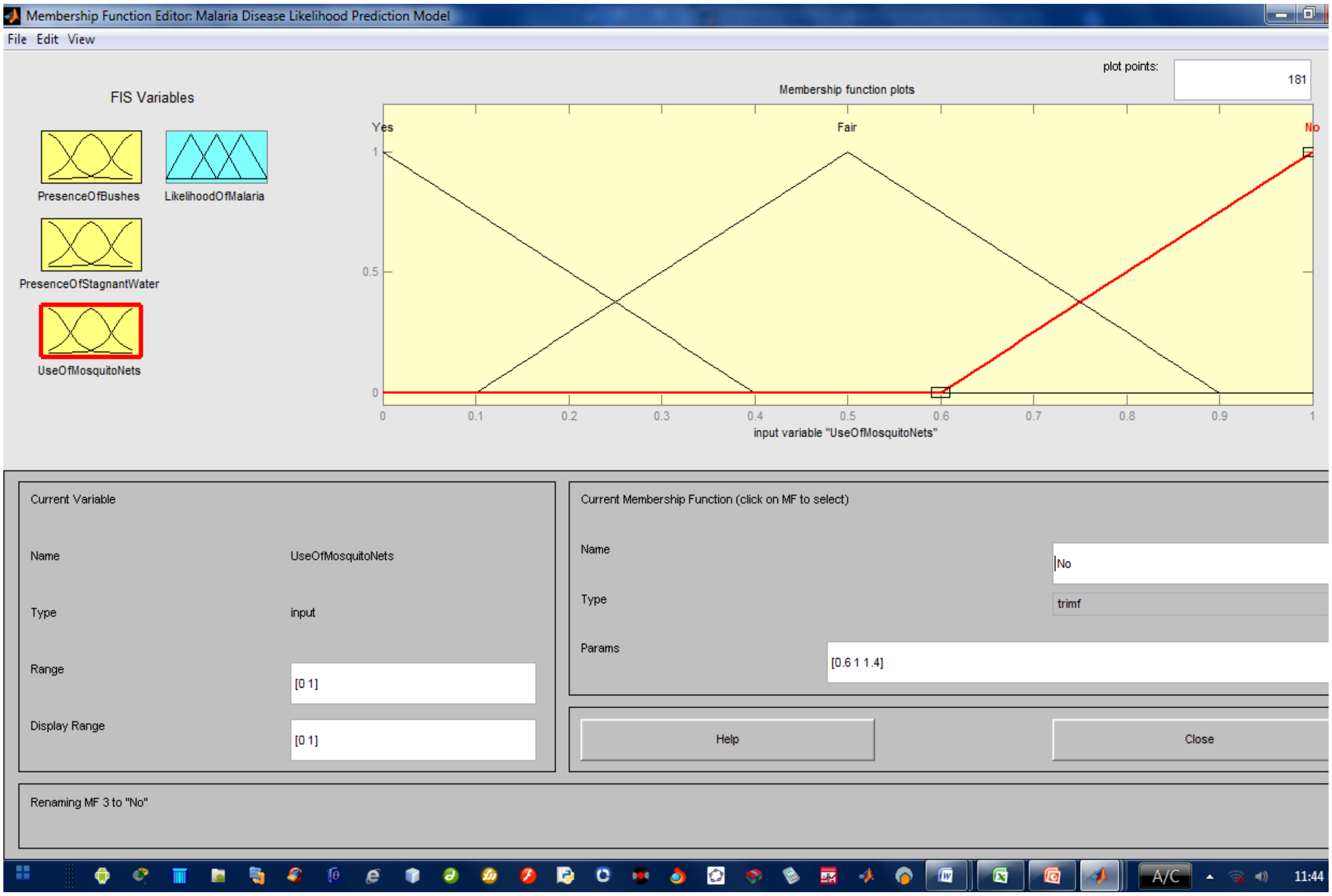

Figure 3 Membership function for use of mosquito nets

Likelihood of malaria outbreak = (No [-0.4 0 0.3], Probably [0.3 0.5 0.6], High [0.6 1 1.4])

$$LikelihoodOfMalariaOutbreak(No; -0.4\ 0\ 0.3) = \begin{Bmatrix} 0, \ x \leq -0.4 \\ \frac{x+0.4}{0.4}, -0.4 \leq x \leq 0 \\ \frac{0.3-x}{0.3}, \ 0 \leq x \leq 0.3 \\ 0, \ 0.3 \leq x \end{Bmatrix} \quad (10)$$

$$LikelihoodOfMalariaOutbreak(Probably; 0.3\ 0.5\ 0.6) = \begin{Bmatrix} 0, \ x \leq 0.3 \\ \frac{x+0.4}{0.4}, 0.3 \leq x \leq 0.5 \\ \frac{0.6-x}{0.1}, \ 0.5 \leq x \leq 0.6 \\ 0, \ 0.6 \leq x \end{Bmatrix} \quad (11)$$

$$LikelihoodOfMalariaOutbreak(High; 0.6\ 1\ 1.4) = \begin{Bmatrix} 0, \ x \leq -0.6 \\ \frac{x+0.4}{0.4}, 0.6 \leq x \leq 1 \\ \frac{0.4-x}{0.4}, \ 1 \leq x \leq 1.4 \\ 0, \ 1.4 \leq x \end{Bmatrix} \quad (12)$$

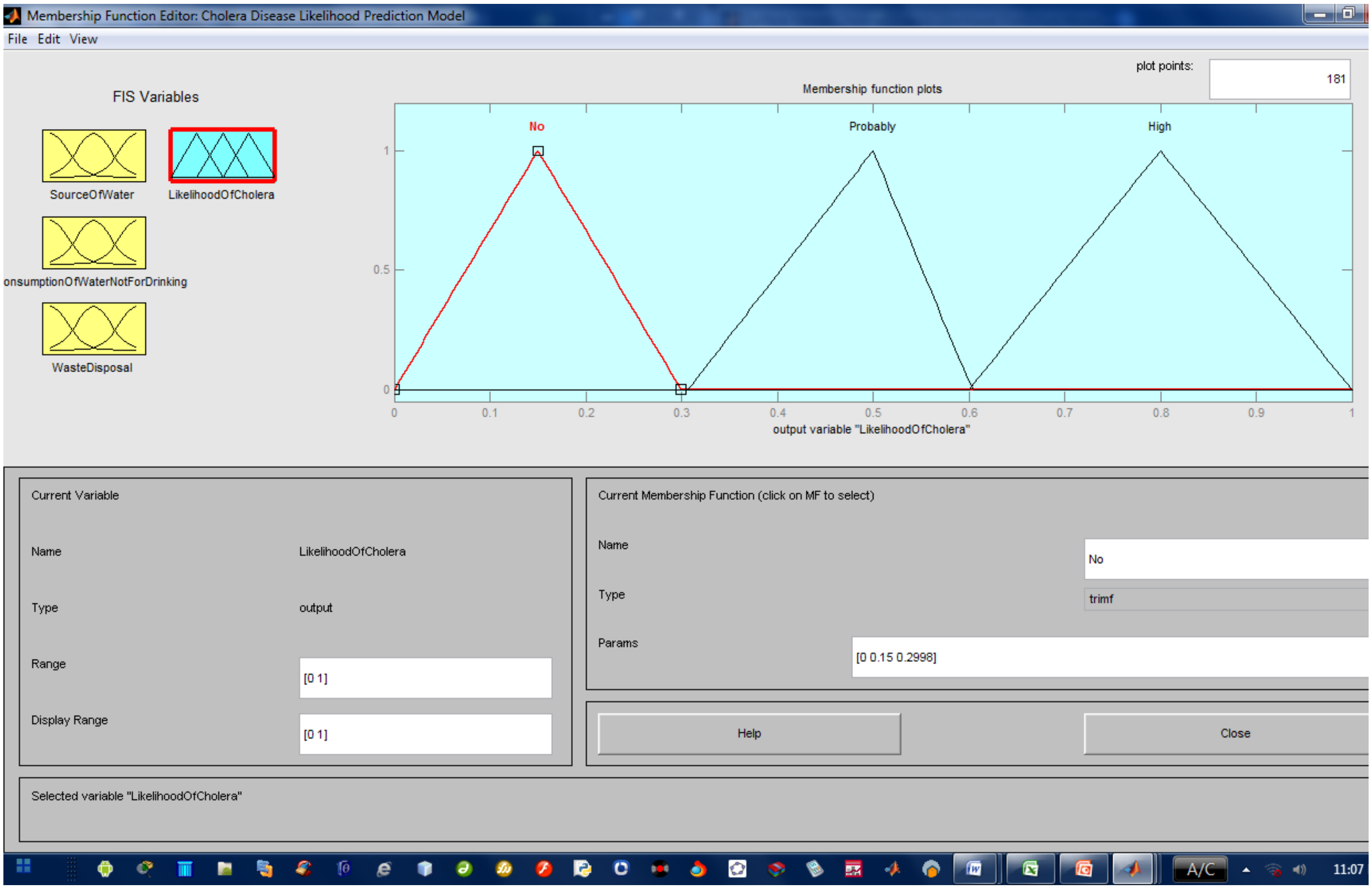

Figure 4 Membership function for likelihood of malaria outbreak

3.6. Inference engine development, aggregation and defuzzification

After developing the membership function, the process of developing the fuzzy inference engine which makes use of the 27 different rules shown in Table 2 below is necessary. It is with the information about the membership functions i.e. the labels that have been used to map each interval of membership functions e.g. malaria had labels: yes, fair and No that the rules were been formed.

Hence, each rules that was provided is a result of a case-based reasoning approach which involves the experience that the expert had had in the years have shown such pattern except otherwise cases where there were misdiagnosis (false positives) or undiagnosed (cases not yet understood).

For the purpose of this study and the variables that are considered – the And Method used in evaluating each degree of membership is Minimum (it selects the smallest value of many), the Or Method used is the Maximum (it selects the largest value out of many); which although is not used in this study and the Implication Method used is the Minimum. These fuzzy operators were used to calculate the output for each rules which now require aggregation to be applied in order to get a single output.

The Aggregation method used in determining the optimum output membership function for the output is chosen to be Maximum (it selects the largest value for every region of the output variable's membership function). This method was chosen since it is the most commonly used method of aggregating linear-wise membership functions like trapezoidal and triangular membership functions.

The defuzzification of the output membership function resulting from the process of aggregation shows the crisp result that gives the likelihood of water related disease as a real number value (a value within the range of the output variable's membership functions). In the case of this study the values 0 0.5 and 1 were used to identify No, probably and Yes respectively.

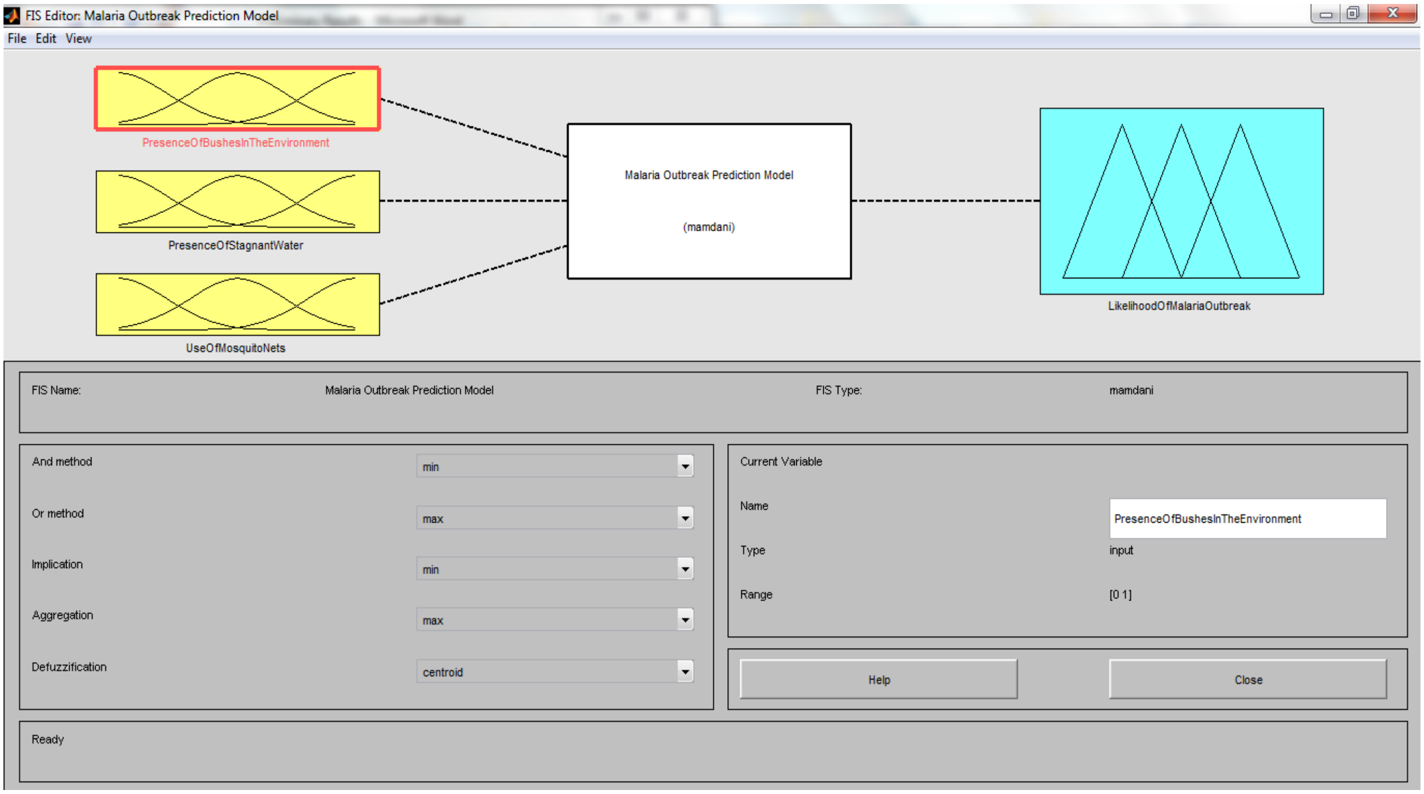

Figure 5 Proposed fuzzy inference system

Table 1 Rule base for likelihood of malaria outbreak

Rule No	*Presence of bushes in the environment*	*Presence of stagnant water*	*Use of mosquito nets*	*Likelihood of malaria outbreak*
1	No	No	No	No
2	No	No	Fair	No
3	No	No	Yes	No
4	No	Fair	No	Probably
5	No	Fair	Fair	Probably
6	No	Fair	Yes	No
7	No	Yes	No	Probably
8	No	Yes	Fair	Probably
9	No	Yes	Yes	No
10	Fair	No	No	Probably
11	Fair	No	Fair	No
12	Fair	No	Yes	No
13	Fair	Fair	No	Probably
14	Fair	Fair	Fair	Probably
15	Fair	Fair	Yes	Probably
16	Fair	Yes	No	High
17	Fair	Yes	Fair	Probably
18	Fair	Yes	Yes	High
19	Yes	No	No	No

20	Yes	No	Fair	Probably
21	Yes	No	Yes	High
22	Yes	Fair	No	Probably
23	Yes	Fair	Fair	Probably
24	Yes	Fair	Yes	No
25	Yes	Yes	No	High
26	Yes	Yes	Fair	High
27	Yes	Yes	Yes	Probably

The method of defuzzification chosen for this study is the centroid method – it simply calculates the centre-of-gravity of the final polygon that results from the process of aggregation. It is also chosen for its compatibility with linear-wise membership functions. Figure 5 shows the diagram of the simulated fuzzy logic system for the prediction of the likelihood of Sickle-cell disease in an individual given the values for three (3) input variables, namely: ***Presence of stagnant water***, ***Use of mosquito nets*** and ***Presence of bushes in the environment***. This is the view of the fuzzy inference system using the fuzzy logic toolbox available in the MATLAB R2012a software used as the simulation environment.

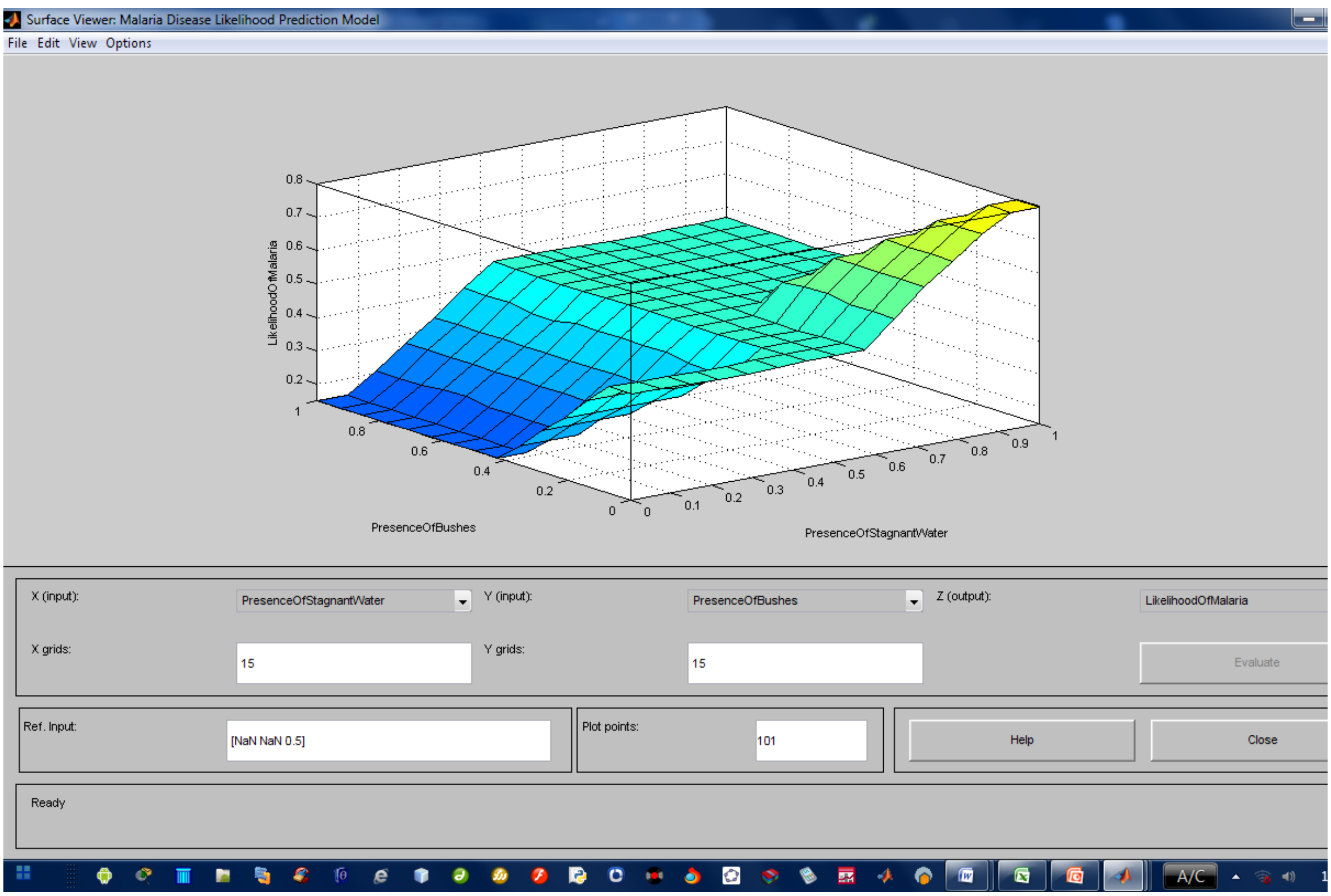

Figure 6 Surface diagram showing use of mosquito nets and presence of bushes

4. RESULTS AND DISCUSSIONS

After formulating the model necessary for simulating the fuzzy logic inference system – the model was implemented using the MATLAB Versions 7 software developed as Release 2012. The fuzzy logic toolbox which is among the many toolboxes available in the MATLAB software was used in simulating the predictive model using triangular and trapezoidal membership functions for the fuzzification of the input and output variables. The fuzzy logic system was used to perform a view of the surface diagram which shows the distribution of the many possible values and the relationship between any two variables. Figures 6-7 gives a plot of the surface diagram showing the relationship between level of stagnant water and mosquito nets; it can be observed that the diagram clearly shows that there is more likelihood of cases of malaria.

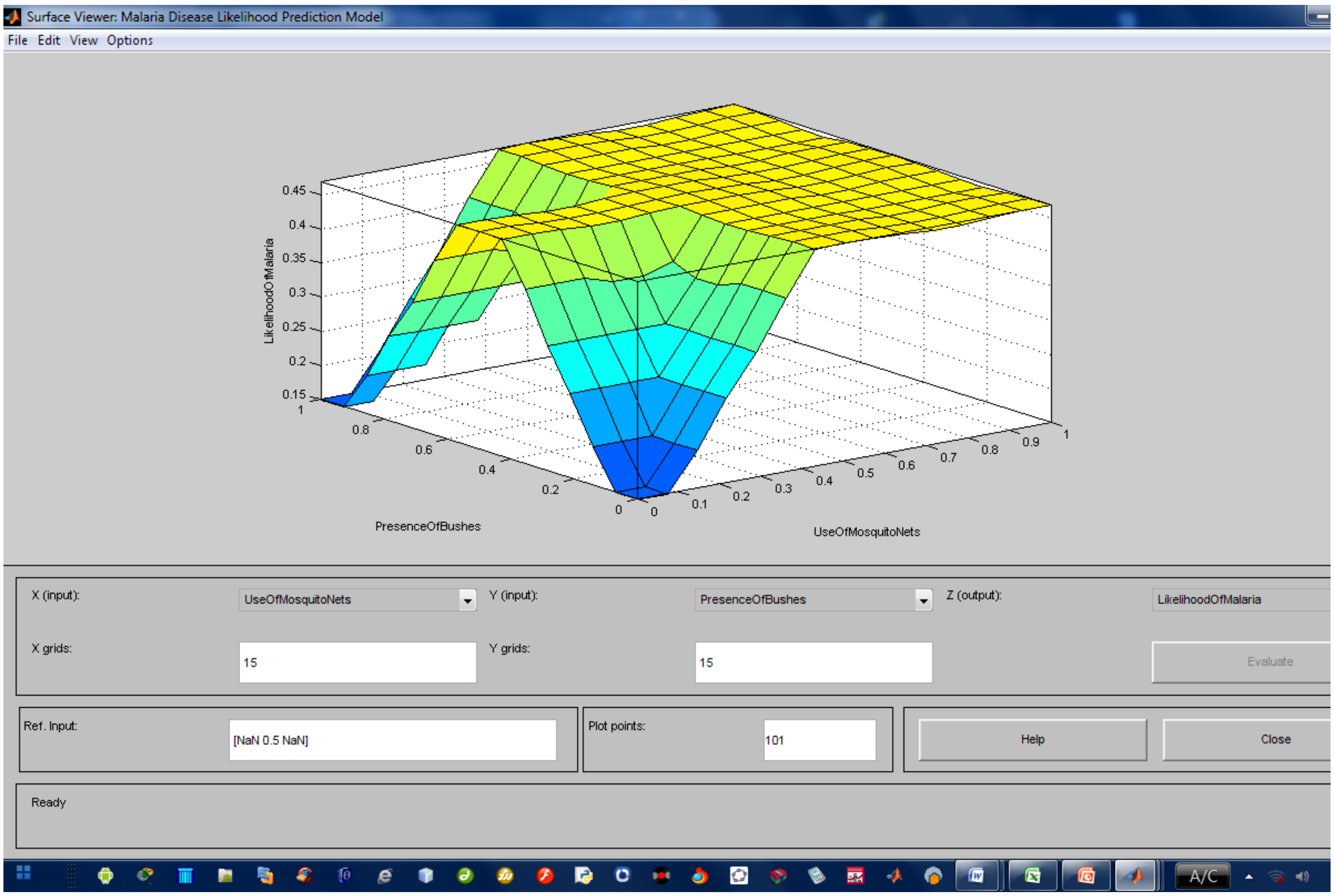

Figure 7 Surface diagram showing use of mosquito nets and presence of stagnant water

5. CONCLUSION

The proposed model for the prediction of the likelihood of water related disease presented using 3 input variables namely: the presence of bushes, presence of stagnant water and use of mosquito nets. The variables were identified and knowledge defining the relationship between variables was used in developing the inference system of the fuzzy inference system. The variables were all fuzzified and the fuzzified input variables were fed to the inference engine. The 27 output that were produced after the inference engine are aggregated to a single output which was defuzzified to get the crisp output i.e. No or Yes.

The model was simulated using the fuzzy logic toolbox available in the MATLAB software and the results of the behavior of the proposed model presented via the surface diagram. It is believed that this model will help diagnose the likelihood of water related disease having provided a record containing the inputs as a 3-tuple. This model should help reduce the number of untimely deaths which occur as a result of spread of the disease.

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