CHAPTER-42

THE USE OF A FUZZY EXPERT SYSTEM FOR SYSTEM-BASED COVID-19 VIRAL LOAD PREDICTION

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ABSTRACT

Shocking the world and still posing a threat to billions of lives is the viral sickness known as COVID-19. Coronavirus (COVID-19) detection has become increasingly important for doctors to do in recent years. COVID-19, unfortunately, spreads rapidly between humans, and within a few months might affect millions of individuals throughout the world. To stop the disease from spreading further, it is crucial to locate those who are afflicted as soon as possible. Despite the use of many medical tests for injury diagnosis, the hoped-for efficiency of detection has not yet been achieved. COVID-19 is a global epidemic that has already affected many countries. COVID-19 disease can cause symptoms ranging from quite minor to life-threatening. These symptoms are also intricate and difficult to predict. Using the severity score helps with suspect treatment that is heavily symptom-based. Fuzzy Expert System, one of the best approaches to modeling complex and uncertain systems, is used in this research to deal with this issue. Due to the recent nature of the pandemic and data around COVID-19. Most of the world's population was infected by COVID-19, and the virus had far-reaching consequences. It highlighted the insufficiency of available funds for medical care. diseases were rendered more nebulous by factors such as the wide variation in symptoms, preexisting diseases, age, diagnostic sophistication, and degree of uncertainty. Medical stakeholders, experts, hospitals, pharmaceutical companies, and others can all benefit from Fuzzy's ability to handle the fuzziness and ambiguity inherent in large amounts of patient data. When dealing with a situation involving ambiguity, incomplete information, or a lack of precision, many turn to Fuzzy Logic. In this research, we use the Fuzzy Inference System (FIS) in MATLAB to create a fuzzy expert system that can determine the severity of an infection from a patient's reported symptoms, which may include high body temperature, difficulty breathing, a dry cough, a diminished sense of smell or taste, and an inability to eat. Numerical and graphical representations of viral load as a function of symptom kind are presented. We have also covered the use of correlation and regression analysis to determine which symptoms are most strongly associated with a given viral load.

Keywords: *Fuzzy expert system, COVID-19, Correlation, Regression, MATLAB*

INTRODUCTION

The use of fuzzy logic is crucial in the field of medicine for making diagnoses. Symptoms and disease are the two cornerstones of a diagnostic thinking in medicine. An innovative method that can be easily assimilated by the required medical skills to provide reliable diagnostic judgments is the application of fuzzy logic to medical diagnosis. In this paper, we present a simple yet powerful methodology for developing fuzzy expert systems for use in medical diagnosis. A fuzzy expert system has proven its value in medical diagnostics by accurately answering questions about COVID19. This system can be used for both quantitative and qualitative assessments of medical data. In this study, we will use patients' reports of their symptom improvement to draw conclusions about the effectiveness of treatment for COVID19.

Fuzzy logic was first proposed by Zadeh et al. (1977) as an artificial intelligence system used for issue resolution when a numerical solver is unable to provide adequate results. It uses a more data-friendly computation method in hostile conditions. Fuzzy logic is a departure from traditional Boolean logic that use a pictorial, incremental calculation method known as "degree of truth." Chowdhury et al. (2020) employed an AI system to assess the role that various environmental factors play in the transmission of COVID-19. A decision support system based on physicians' knowledge and a fuzzy inference system (FIS) was developed by Govindan et al. (2020) to aid in demand management in the healthcare supply chain and reduce the spread of COVID-19. In 2020, Shaban et al. advocated using patient laboratory findings for rapid and accurate diagnosis. The three primary parts of the Hybrid Diagnosis Strategy (HDS) are the pre-processing, feature ranking, and classification phases. In pre-processing, we employ the wrapper strategy, which ranks features according to their contribution to the NB classifier's accuracy at making predictions. An Adaptive Neuro-Fuzzy Inference System (ANFIS) based on texture analysis characteristics was proposed by Al-ali et al. (2021) for automatically detecting COVID-19 in chest X-rays. Mangla et al. (2021), using the Mamdani-based fuzzy expert system, discuss the risk factors, clinical factors, and other features that influence the mortality rate of COVID-19. Ilyas et al. (2021) detailed a real-time, rule-based Fuzzy Logic classifier (FLCD) for detecting COVID-19. With the purpose of differentiating symptomatic from asymptomatic COVID-19 users, the suggested model makes advantage of the IoT infrastructure to collect user-reported symptoms in real-time. For determining the severity of COVID-19 disease in suspects, Jadhav and Nhivekar (2021) created a fuzzy-based expert system. The detection of covid 19 positive cases based on symptoms and risk factors was investigated by Sathyapriya et al. (2021) using MATLAB and the idea of fuzzy logic and decision making. Shatnawi et al. (2021) provided a smart fuzzy inference technique for the preliminary diagnosis of COVID-19. The probability of a COVID-19 infection is determined by the system based on the patient's symptoms. This inference technique can help physicians make accurate diagnoses, and it can also help patients make informed decisions about their health. Using Fuzzy Logic in R, Pawar et al. (2022) developed a fuzzy Inference System for pattern identification and classification to improve performance. In this article, we'll examine how to build a Fuzzy Rule foundation, Model, and Inference in order to examine the COVID 19 dataset. Simşek and Yangin (2022) combined the findings from these separate systems into a single FIS to derive an individual's risk index. Conclusions about population health can be drawn and used by health professionals and epidemiologists. Data can be a useful tool for self-control and a window into the world.

MEMBERSHIP FUNCTIONS AND PLOTS OF INPUT AND OUTPUT VARIABLES

$$X_1 = Fever$$

$$\mu_{VLF}(X_1) = \begin{Bmatrix} 1 & 35 \leq x_1 \leq 35.5 \\ -2x + 72 & 35.5 \leq x_1 \leq 36 \end{Bmatrix}$$

$$\mu_{LF}(X_1) = \begin{Bmatrix} 2x - 71 & 35.5 \leq x_1 \leq 36 \\ -2x + 73 & 36 \leq x_1 \leq 36.5 \end{Bmatrix}$$

$$\mu_{MF}(X_1) = \begin{Bmatrix} 2x - 72 & 36 \leq x_1 \leq 36.5 \\ -2x + 74 & 36.5 \leq x_1 \leq 37 \end{Bmatrix}$$

$$\mu_{HF}(X_1) = \begin{Bmatrix} x - 36.5 & 36.5 \leq x_1 \leq 37.5 \\ -x + 38.5 & 37.5 \leq x_1 \leq 38.5 \end{Bmatrix}$$

$$\mu_{VHF}(X_1) = \begin{Bmatrix} 2x - 76 & 38 \leq x_1 \leq 38.5 \\ 1 & 38.5 \leq x_1 \leq 40 \end{Bmatrix}$$

$$X_2 = Shortness\ of\ breath\ (\%)$$

$$\mu_{VLSOB}(X_2) = \begin{Bmatrix} 1 & 0 \leq x_2 \leq 15 \\ -0.1x + 2.5 & 15 \leq x_2 \leq 25 \end{Bmatrix}$$

$$\mu_{LSOB}(X_2) = \begin{Bmatrix} 0.1x - 1.5 & 15 \leq x_2 \leq 25 \\ -0.1x + 3.5 & 25 \leq x_2 \leq 35 \end{Bmatrix}$$

$$\mu_{MSOB}(X_2) = \begin{Bmatrix} 0.1x - 2.5 & 25 \leq x_2 \leq 35 \\ -0.1x + 4.5 & 35 \leq x_2 \leq 45 \end{Bmatrix}$$

$$\mu_{HSOB}(X_2) = \begin{Bmatrix} 0.1x - 3.5 & 35 \leq x_2 \leq 45 \\ -0.1x + 5.5 & 45 \leq x_2 \leq 55 \end{Bmatrix}$$

$$\mu_{VHSOB}(X_2) = \begin{Bmatrix} 0.03x - 1.5 & 45 \leq x_2 \leq 75 \\ 1 & 75 \leq x_2 \leq 100 \end{Bmatrix}$$

$$X_3 = Dry\ cough\ (\%)$$

$$\mu_{VLDC}(X_3) = \begin{Bmatrix} 1 & 0 \leq x_3 \leq 15 \\ -0.1x + 2.5 & 15 \leq x_3 \leq 25 \end{Bmatrix}$$

$$\mu_{LDC}(X_3) = \begin{Bmatrix} 0.1x - 1.5 & 15 \leq x_3 \leq 25 \\ -0.1x + 3.5 & 25 \leq x_3 \leq 35 \end{Bmatrix}$$

$$\mu_{MDC}(X_3) = \begin{Bmatrix} 0.1x - 2.5 & 25 \leq x_3 \leq 35 \\ -0.1x + 4.5 & 35 \leq x_3 \leq 45 \end{Bmatrix}$$

$$\mu_{HDC}(X_3) = \begin{Bmatrix} 0.1x - 3.5 & 35 \leq x_3 \leq 45 \\ -0.1x + 5.5 & 45 \leq x_3 \leq 55 \end{Bmatrix}$$

$$\mu_{VHDC}(X_3) = \begin{Bmatrix} 0.03x - 1.5 & 45 \leq x_3 \leq 75 \\ 1 & 75 \leq x_3 \leq 100 \end{Bmatrix}$$

$$X_4 = Smell\ and\ taste\ loss\ (\%)$$

$$\mu_{VLSTL}(X_4) = \begin{Bmatrix} 1 & 0 \leq x_4 \leq 15 \\ -0.1x + 2.5 & 15 \leq x_4 \leq 25 \end{Bmatrix}$$

$$\mu_{LSTL}(X_4) = \begin{Bmatrix} 0.1x - 2.5 & 15 \leq x_4 \leq 25 \\ -0.1x + 4.5 & 25 \leq x_4 \leq 35 \end{Bmatrix}$$

$$\mu_{MSTL}(X_4) = \begin{Bmatrix} 0.1x - 2.5 & 25 \leq x_4 \leq 35 \\ -0.1x + 4.5 & 35 \leq x_4 \leq 45 \end{Bmatrix}$$

$$\mu_{HSTL}(X_4) = \begin{Bmatrix} 0.1x - 3.5 & 35 \leq x_4 \leq 45 \\ -0.1x + 5.5 & 45 \leq x_4 \leq 55 \end{Bmatrix}$$

$$\mu_{VHSTL}(X_4) = \begin{cases} 0.03x - 1.5 & 45 \le x_4 \le 75 \\ 1 & 75 \le x_4 \le 100 \end{cases}$$

$$X_5 = Lack\ of\ appetite\ (\%)$$

$$\mu_{VLLOA}(X_5) = \begin{cases} 1 & 0 \le x_5 \le 15 \\ -0.1x + 2.5 & 15 \le x_5 \le 25 \end{cases}$$

$$\mu_{LLOA}(X_5) = \begin{cases} 0.1x - 2.5 & 15 \le x_5 \le 25 \\ -0.1x + 4.5 & 25 \le x_5 \le 35 \end{cases}$$

$$\mu_{MLOA}(X_5) = \begin{cases} 0.1x - 2.5 & 25 \le x_5 \le 35 \\ -0.1x + 4.5 & 35 \le x_5 \le 45 \end{cases}$$

$$\mu_{HLOA}(X_5) = \begin{cases} 0.1x - 3.5 & 35 \le x_5 \le 45 \\ -0.1x + 5.5 & 45 \le x_5 \le 55 \end{cases}$$

$$\mu_{VHLOA}(X_5) = \begin{cases} 0.03x - 1.5 & 45 \le x_5 \le 75 \\ 1 & 75 \le x_5 \le 100 \end{cases}$$

$$Y = Covid - 19\ virus\ load\ (\%)$$

$$\mu_{VLVL}(Y) = \begin{cases} 1 & 0 \le y \le 15 \\ -0.1x + 2.5 & 15 \le x_4 \le 25 \end{cases}$$

$$\mu_{LVL}(Y) = \begin{cases} 0.1x - 1.5 & 15 \le y \le 25 \\ -0.1x + 3.5 & 25 \le y \le 35 \end{cases}$$

$$\mu_{MVL}(Y) = \begin{cases} 0.1x - 2.5 & 25 \le y \le 35 \\ -0.1x + 4.5 & 35 \le y \le 45 \end{cases}$$

$$\mu_{HVL}(Y) = \begin{cases} -0.1x + 5.5 & 35 \le y \le 45 \\ -0.1x + 5.5 & 45 \le y \le 55 \end{cases}$$

$$\mu_{VHVL}(Y) = \begin{cases} 0.03x - 1.5 & 45 \le y \le 75 \\ 1 & 65 \le y \le 100 \end{cases}$$

Figure 1: Membership plot of input variable 1 (Fever)

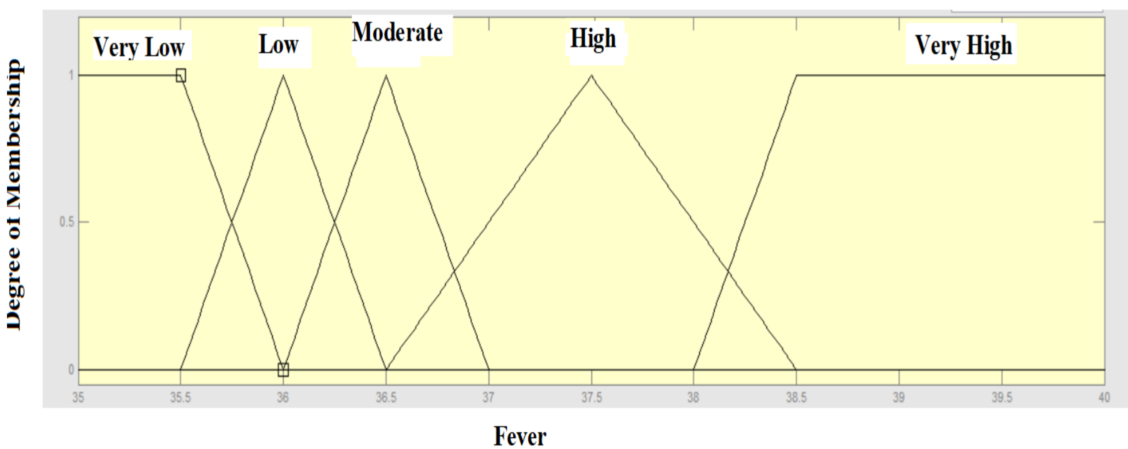


Figure 2: Membership plot of input variable 2 (Shortness of breath)

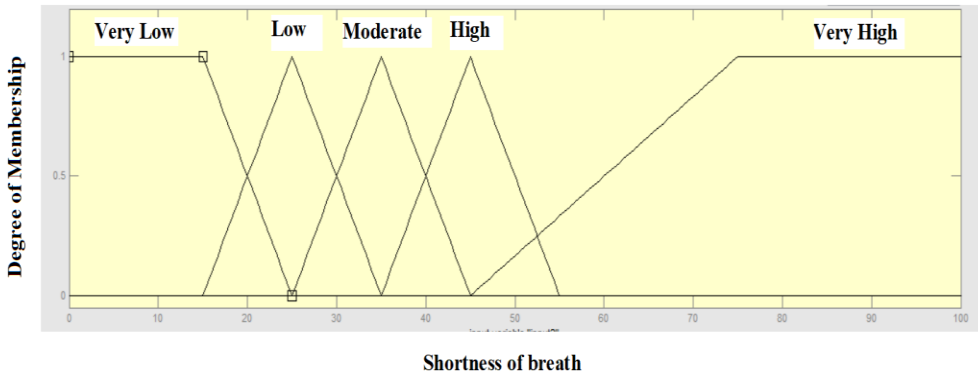


Figure 3: Membership plot of input variable 3 (Dry Cough)

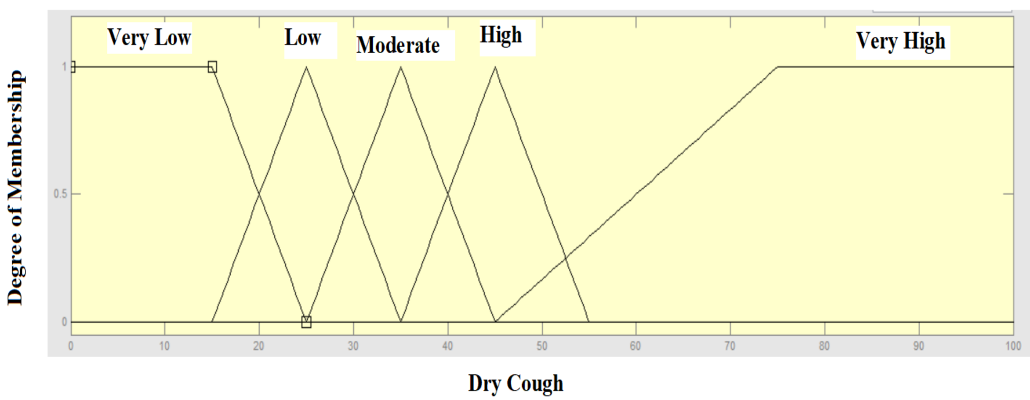


Figure 4: Membership plot of input variable 4 (Smell and Taste Loss)

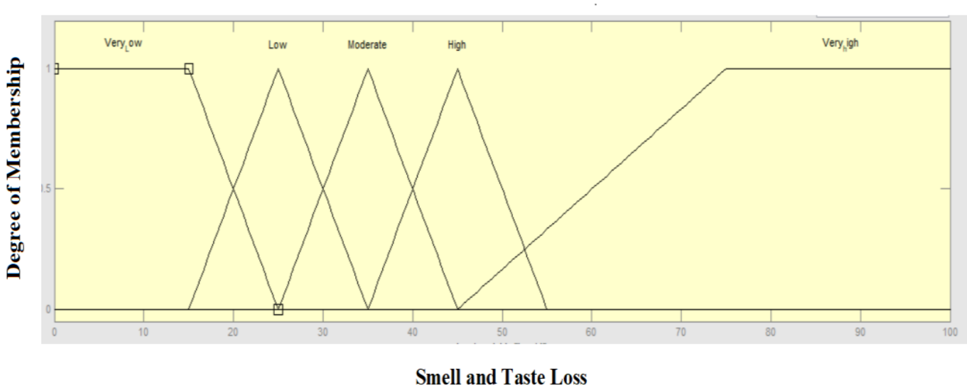


Figure 5: Membership plot of input variable 5 (Lack of appetite)

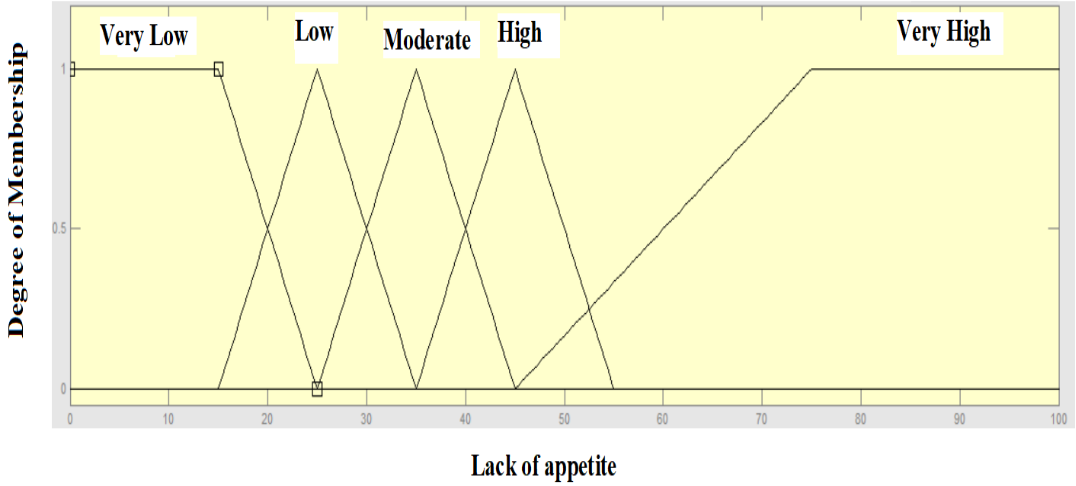
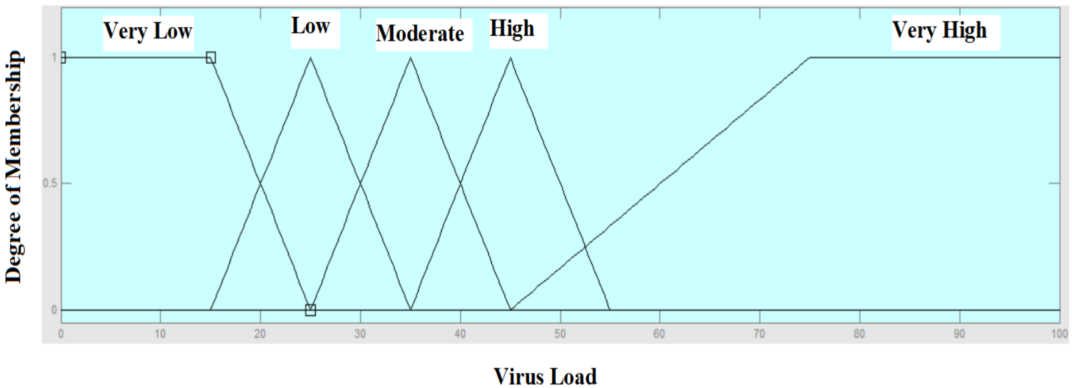


Figure 6: Membership plot of output variable (Virus Load)



RULE BASE

Table-1: Rules for calculating viral load from a variety of input variables

	1	2	3	4	5	
Rules	Fever	Shortness of breath	Dry Cough	Smell and Taste Loss	Lack of appetite	Virus Load
1	Very Low	Very Low	Very Low	Very Low	Very Low	Very Low
2	Very Low	Very Low	Very Low	Low	Very Low	Very Low
3	Very Low	Very Low	Very Low	Moderate	Very Low	Low
4	Very Low	Very Low	Very Low	High	Very Low	Moderate
5	Very Low	Very Low	Very Low	Very High	Very Low	High
6	Very Low	Very Low	Very Low	Very Low	Low	Very Low
7	Very Low	Very Low	Very Low	Very Low	Moderate	Low
8	Very Low	Very Low	Very Low	Very Low	High	Moderate
9	Very Low	Very Low	Very Low	Very Low	Very High	High
10	Very Low	Low	Very Low	Very Low	Very Low	Very Low
11	Very Low	Moderate	Very Low	Very Low	Very Low	Very Low
12	Very Low	High	Very Low	Very Low	Very Low	Low
13	Very Low	Very High	Very Low	Very Low	Very Low	Moderate
14	Very Low	Very Low	Low	Very Low	Very Low	Very Low
15	Very Low	Very Low	Moderate	Very Low	Very Low	Very Low
16	Very Low	Very Low	High	Very Low	Very Low	Low
17	Very Low	Very Low	Very High	Very Low	Very Low	Low
18	Low	Very Low	Very Low	Very Low	Very Low	Very Low
19	Moderate	Very Low	Very Low	Very Low	Very Low	Low
20	High	Very Low	Very Low	Very Low	Very Low	Moderate
21	Very High	Very Low	Very Low	Very Low	Very Low	High
22	Very Low	Very Low	Very Low	Low	Low	Very Low
23	Very Low	Very Low	Very Low	Low	Moderate	Very Low
24	Very Low	Very Low	Very Low	Low	High	Low
25	Very Low	Very Low	Very Low	Low	Very High	High
26	Very Low	Low	Very Low	Low	Very Low	Very Low
27	Very Low	Moderate	Very Low	Low	Very Low	Very Low
28	Very Low	High	Very Low	Low	Very Low	Very Low
29	Very Low	Very High	Very Low	Low	Very Low	High
30	Very Low	Very Low	Low	Low	Very Low	Very Low
31	Very Low	Very Low	Moderate	Low	Very Low	Very Low
32	Very Low	Very Low	High	Low	Very Low	Very Low
33	Very Low	Very Low	Very High	Low	Very Low	High
34	Low	Very Low	Very Low	Low	Very Low	Very Low
35	Moderate	Very Low	Very Low	Low	Very Low	Low
36	High	Very Low	Very Low	Low	Very Low	Moderate
37	Very High	Very Low	Very Low	Low	Very Low	High
38	Very High	Very low	Very High	High	Very High	Very High
39	Very High	low	Very High	High	Very High	Very High
40	Very High	Moderate	Very High	High	Very High	Very High

41	Very High	High	Very High	High	Very High	Very High
42	Very High	Very High	Very High	High	Very Low	Very High
43	Very High	Very High	Very High	High	Low	Very High
44	Very High	Very High	Very High	High	Moderate	Very High
45	Very High	Very High	Very High	High	High	Very High
46	Very High	Very High	Very High	Moderate	Very High	Very High
47	Very High	Very High	Very High	Low	Very High	Very High
48	Very High	Very High	Very High	Very Low	Very High	Very High
49	Very High	Very High	Very High	Very High	High	Very High
50	Very High	Very High	Very High	Very High	Moderate	Very High
51	Very High	Very High	Very High	Very High	Low	Very High
52	Very High	Very High	Very High	Very High	Very Low	Very High
53	Very High	High	Very High	Very High	Very High	Very High
54	Very High	Moderate	Very High	Very High	Very High	Very High
55	Very High	Low	Very High	Very High	Very High	Very High
56	Very High	Very Low	Very High	Very High	Very High	Very High
57	Very High	Very High	High	Very High	Very High	Very High
58	Very High	Very High	Moderate	Very High	Very High	Very High
59	Very High	Very High	Low	Very High	Very High	Very High
60	Very High	Very High	Very Low	Very High	Very High	Very High
61	High	Very High	Very High	Very High	Very High	Very High
62	Moderate	Very High	Very High	Very High	Very High	Very High
63	Low	Very High	Very High	Very High	Very High	Very High
64	Very Low	Very High	Very High	Very High	Very High	Very High

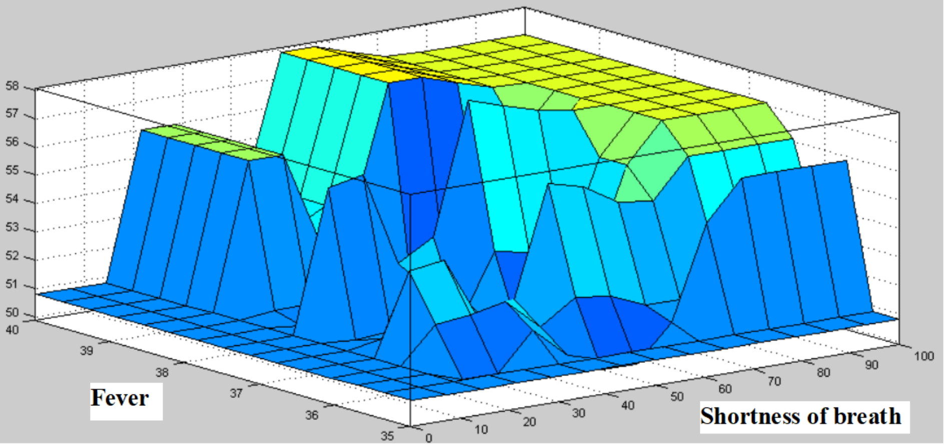
ESTIMATION OF COVID-19 VIRUS LOAD FOR DIFFERENT INPUT VARIABLES (SYMPTOMS)

	X_1	X_2	X_3	X_4	X_5	Y
Rules	**Fever**	**Shortness of breath**	**Dry Cough**	**Smell and Taste Loss**	**Lack of appetite**	**Virus Load**
1	35.9	15.6	9.67	11.6	10.3	50.8
2	38	58.6	54.3	33.4	68.3	60.1
3	35.8	42.7	43.7	85.1	42.3	52.2
4	39.1	94.4	49.7	75.8	47.7	55.9
5	38	45	55	75	50	51.3
6	40	90	95	98	99	62.6
7	39.5	26.2	43.7	53.3	51	52.6
8	38.1	28.1	65	79.1	55	55.1
9	38.6	53.3	52.3	56	55	63.8
10	36.9	40.7	60.3	69.2	64.3	54.4
11	37.4	33.4	50.3	49.3	61	52.4
12	39.5	61.3	73	59.9	25.7	51.8
13	38	42.7	49	31.5	77.7	53.7
14	38.5	59.3	29	72.5	67.7	57.8
15	39.1	56.6	53	68.5	63	64.4

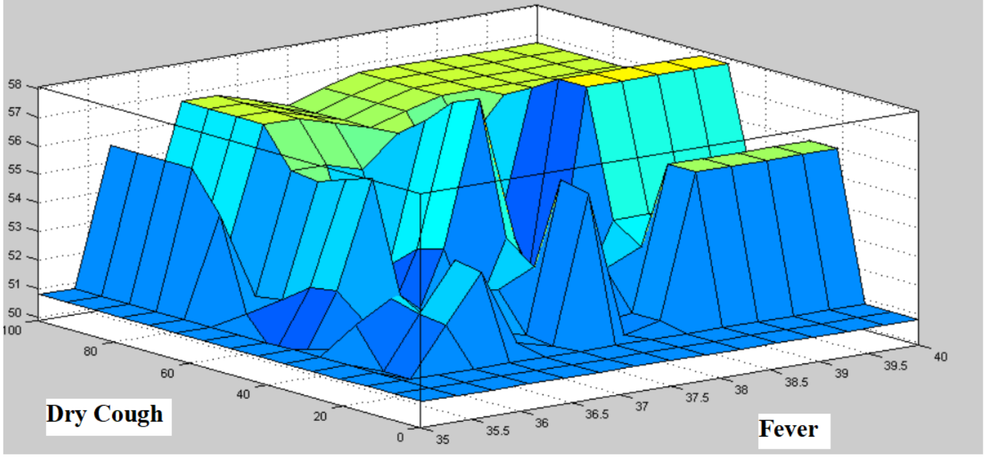
16	36.7	67.2	89.7	88.4	88.3	62.9
17	38.4	19.5	41	56.6	92.3	56
18	37	20.2	63	48.7	76.3	56.8
19	37.5	50	50	50	50	58.1
20	37.6	16.2	23	59.9	89	52

3D SURFACE PLOT OF VIRUS LOAD FOR DIFFERENT SYMPTOMS

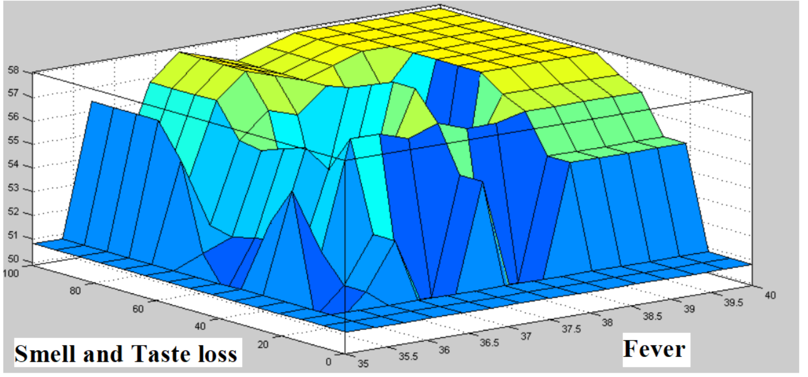
Graph 1: 3D plot of virus load for different values of fever and shortness of breath



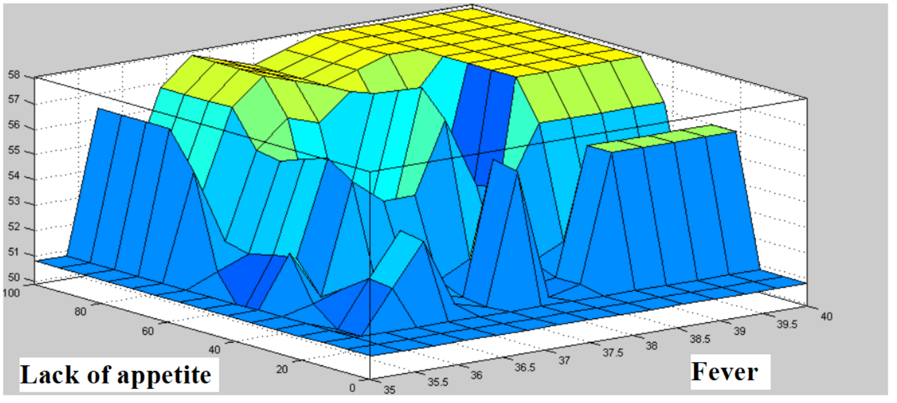
Graph 2: 3D plot of virus load for different values of fever and dry cough



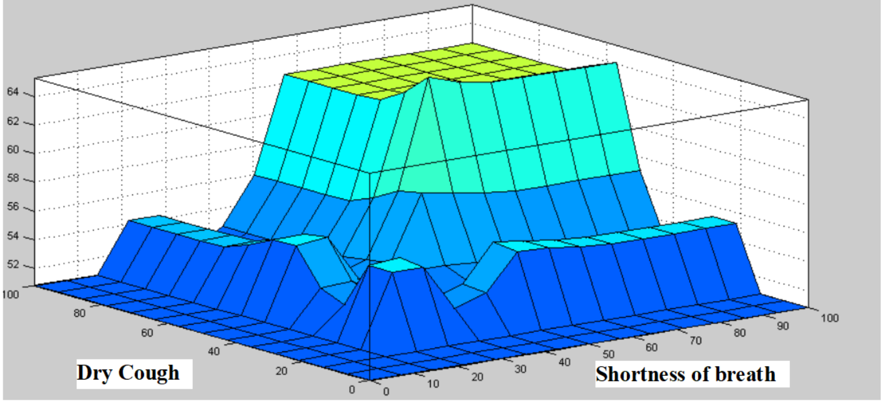
Graph 3: 3D plot of virus load for different values of fever and smell and taste loss



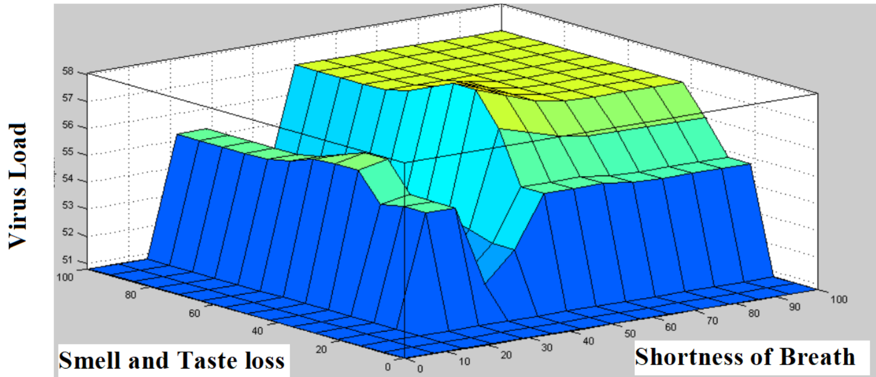
Graph 4: 3D plot of virus load for different values of fever and lack of appetite



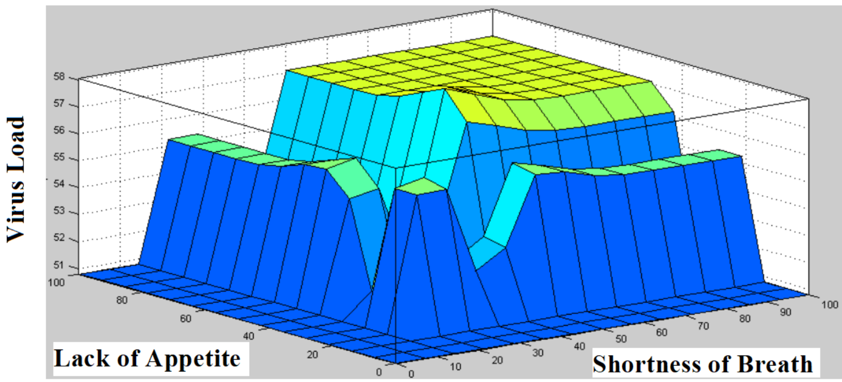
Graph 5: 3D plot of virus load for different values of shortness of breath and dry cough



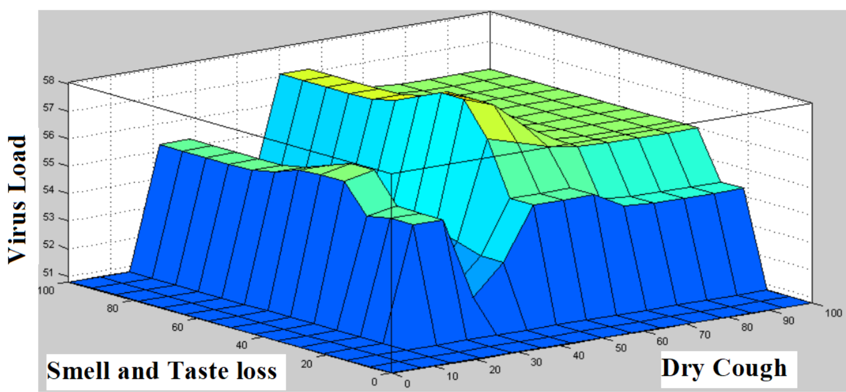
Graph 6: 3D plot of virus load for different values of shortness of breath and smell and taste loss



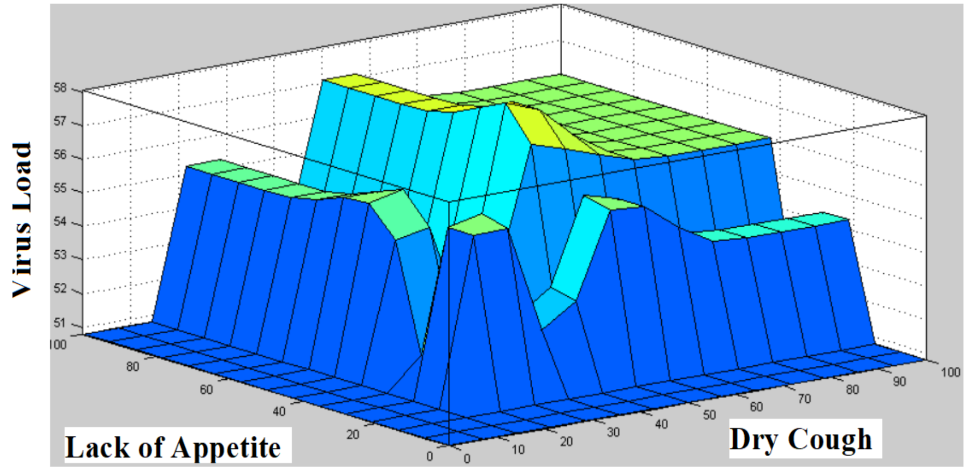
Graph 7: 3D plot of virus load for different values of shortness of breath and lack of appetite



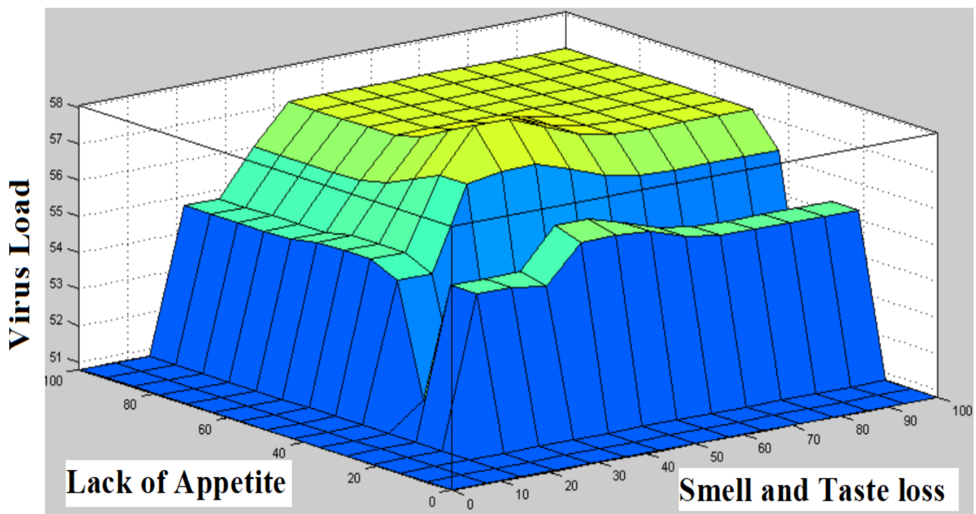
Graph 8: 3D plot of virus load for different values of dry cough and smell and taste loss



Graph 9: 3D plot of virus load for different values of dry cough and lack of appetite

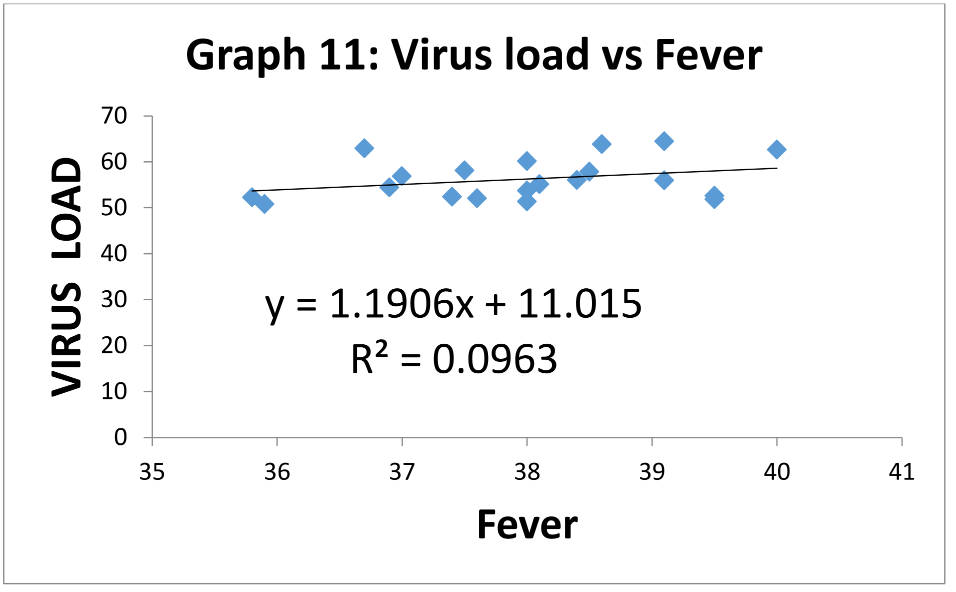


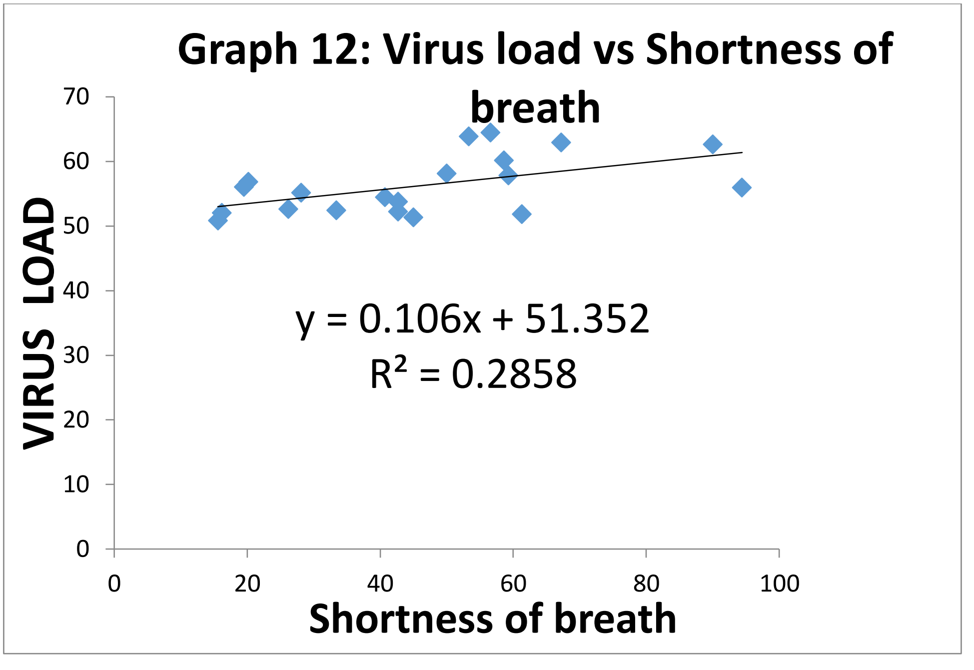
Graph 10: 3D plot of virus load for different values of smell and taste loss and lack of appetite

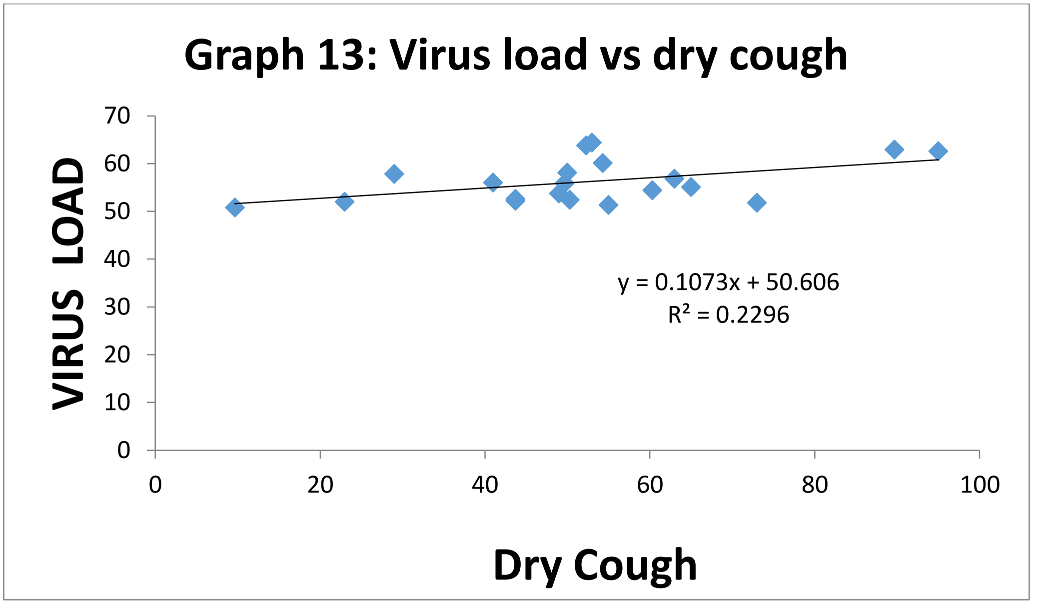


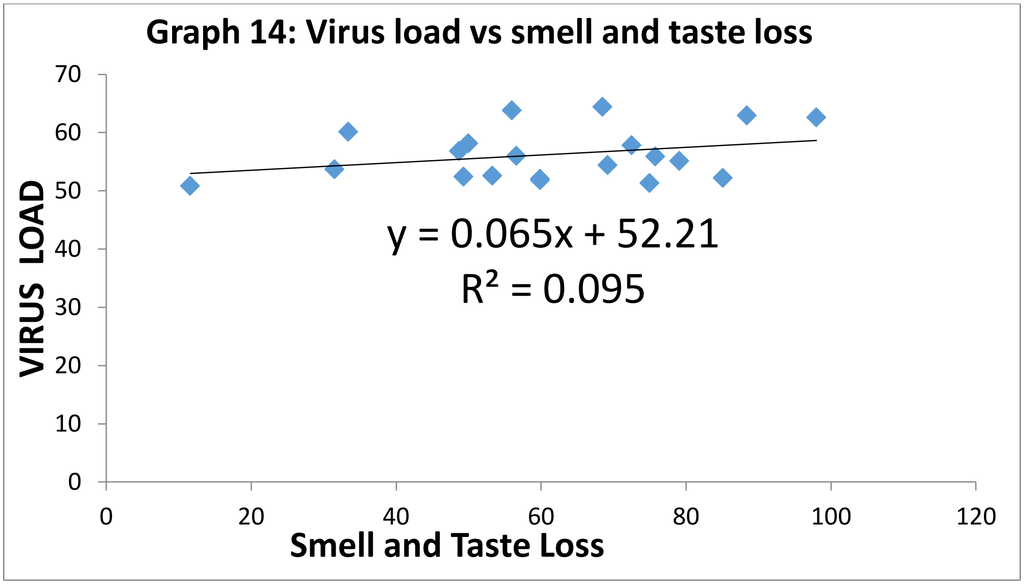
3D surface plot of virus load with different symptoms has been shown in graph (1-10).

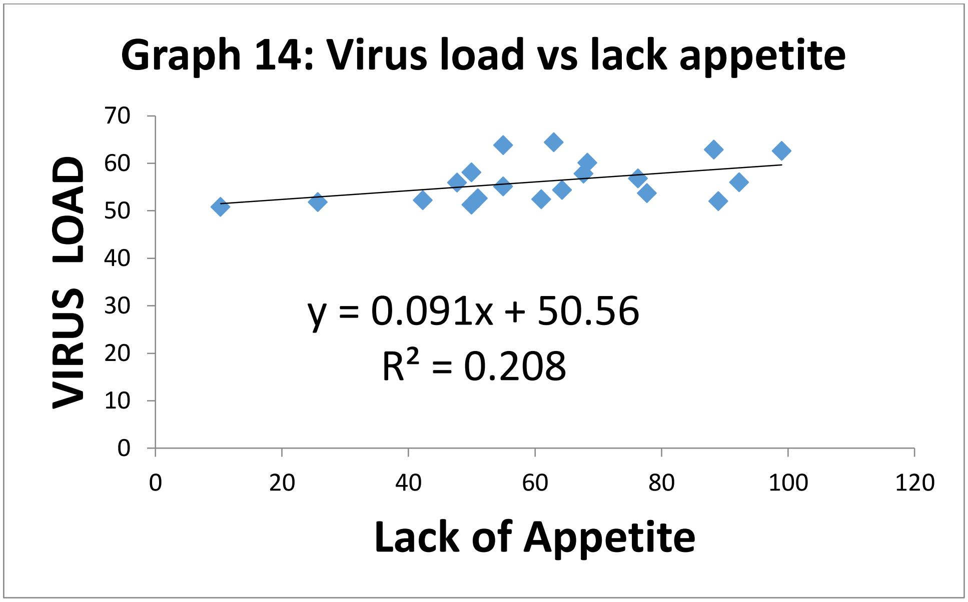
CORRELATION AND REGRESSION ANALYSIS






Graph 13: Virus load vs dry cough
VIRUS LOAD
70
60
50
40
30
20
10
0
0
20
40
60
80
100
y = 0.1073x + 50.606
R² = 0.2296
Dry Cough


Graph 14: Virus load vs smell and taste loss
VIRUS LOAD
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
y = 0.065x + 52.21
R² = 0.095
Smell and Taste Loss



From graph (11), it is observed that

$R^2 = 0.096, R = 0.309839$

Results of the linear regression indicated that there is low significant effect between virus load and fever.

From graph (12), it is seen that

$R^2 = 0.285, R = 0.533854$

Results of the linear regression indicated that there is moderate significant effect between virus load and shortness of breath.

From graph (11), it is noted that

$R^2 = 0.229, R = 0.478539$

Results of the linear regression indicated that there is moderate significant effect between virus load and dry cough.

From graph (11), it is examined that

$R^2 = 0.095, R = 0.308221$

Results of the linear regression indicated that there is low significant effect between virus load and smell and taste loss.

From graph (11), it is viewed that

$R^2 = 0.208, R = 0.45607$

Results of the linear regression indicated that there is moderate significant effect between virus load and smell and taste loss.

CONCLUDING REMARKS

Without the intervention of doctors, the Fuzzy Expert System (FES) can predict the likelihood that someone may contract the Covide-19 virus. FES relies on data that may be collected using a simple instrument that doesn't call for any special training to use. The newly developed Fuzzy Expert system can aid in delivering early assessments of people's health state in regards to COVID-19. Here, we dissect the rule that is based on fuzzy systems and explain how input and output variables function. In addition to its usefulness as a teaching tool, MATLAB is used to actualize research into the decision-making process. Enormous populace nations like India and China face a test in giving clinical medicines and offices, as well as bringing issues to light among various kinds of society; If these automated solutions were implemented at micro level units, hospitals, clinics, or individual practitioners' service points or clinics, this would lessen the burden placed on government and specialty hospitals.

In further revisions, the system will be connected to the internet of things, allowing the user to access it from afar.

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