2022 IEEE International Conference on Distributed Computing and Electrical Circuits and Electronics (ICDCECE)

2022 IEEE International Conference on Distributed Computing and Electrical Circuits and Electronics (ICDCECE) | 978-1-6654-8316-2/22/$31.00 ©2022 IEEE | DOI: 10.1109/ICDCECE53908.2022.9793024

A Proposed Quantitative Model for the Computation and Analysis of Waning Immunity for COVID-19 Virus among Human Population

Senthil Velan. S
Information Science and Engineering
CMR Institute of Technology
Bengaluru, India
svsugana@gmail.com

Rubini. P
Computer Science and Engineering
SOET, CMR University
Bengaluru, India
prubini.cs@gmail.com

Surbhi Choudhary
Computer Science and Engineering
SOET, CMR University
Bengaluru, India
sur.choudhary17@gmail.com

***Abstract*—Waning Immunity is an important and relevant concept during these days as the COVID-19 pandemic is expected to become endemic in the coming months. By definition, Waning Immunity is the loss of protective antibodies over time and hence necessitates booster shots at regular intervals of time. This quantitative study is on proposition of a model for computing a newly defined metric called Waning Immunity Index (WII). The model takes into account the three group of people namely, susceptible, infected and recovered individuals from the COVID-19 infections. The required data can be collected from the Kaggle repository that contains information on infections, recovery, vaccination and booster doses given on the human population while considering a geographical location. The proposed model and its implementation have thrown light on the spread, control and effect of COVID-19 virus. Results of the proposed model and the measurement can help health officials to seamlessly plan the duration of booster doses administered on vaccinated population. A sample data has been prepared for testing the model and the application of the proposed metrics. Based on the results, it is found that vulnerability of the Waning Immunity increases steeply at some duration and gradually steadies in time.**

Keywords—Waning Immunity, COVID-19, Data Analytics.

I. INTRODUCTION

Immunity is the ability to fight pathogens, such as bacteria and viruses, which causes different types of infections in the human body. The process is a very complex biological system that can identify and accept the belongings of self and reject other foreign bodies. It can be empirically measured using medical tests and can be directly related to the spread of a disease.

In today's scenario, with the advent of fast spreading viruses, like COVID-19, increasing the immunity of people residing in a specific geographic location [1] [2] is highly relevant for health officials around the world. Immunity can be acquired by two ways, either by getting affected by the pathogen and recovering thereby obtaining immunity, or by through proven vaccines. But, the immune system also loses the knowledge of fighting the disease over a period of time. This concept of losing the immunity over a period of time is called as waning immunity.

Waning Immunity [3] is the decline in anti-bodies which has been acquired through immunization over a period of [time. This happens when the immune acquired individual is not able be in an environment of infection for an extended period of time. Some quantitative studies on COVID-19 infections have seen reduction of immunity to a very low level after 6 to 8 months of getting the second vaccine dose. And these studies are still under further research requiring more investigations and quantitative analysis.

Considering the important problem of waning immunity, the research work explained through this paper focuses on quantitative analysis. A new set of metrics have been defined accounting all the different factors of acquiring immunity and its waning over a period of time. The model can be applied using data retrieved through the COVID-19 daily infection details available in the Kaggle [4] repository. The paper proposes a simple and comprehensive model that can be considered for application across different geographical locations. Based on the sample data for testing the initial application of the model, inferences have been generated for its efficacy and applicability. The results could help the respective health officials in planning for the frequency of booster doses that need to be administered for the vaccine. This model can be extended further by using machine learning techniques for future predictions of Waning Immunity for a specific pathogen.

The rest of the paper is organized as follows: Section II explains the research work done by other authors on Acquired and Waning Immunity. A clear statement of the research problem that has been addressed in this paper have been narrated in Section III. Section IV describes the proposed method for measuring the Waning Immunity for the data collected from the repository. In Section V the proposed metrics are explained with suitable formulae, all of which result in the computation of Waning Immunity Index (WII). Section VI discusses on the inferences that can be deduced based on this measurements. Finally, Section VII provides conclusions and extensions that can be carried out on the proposed model and metrics developed in this research.

II. EXISTING WORK

In modern times and after the unexpected advent of COVID-19 pandemic, a number of researchers have been working on analyzing its different facets [5] [6]. A lot of interesting results have been reported while analyzing the dietary habits, regional behavior, social connections and others using statistical tools and techniques. In this context, the following subsections briefly list the work done on Acquired Immunity and Waning Immunity in the context of COVID-19 infections and recoveries.

A. Acquired Immunity

Several authors have been analyzing the immunity acquired through vaccination for the COVID-19 virus. In a work done by Madhi et. al., [7] a sero-epidemiological survey was conducted from October 22 for a period of two weeks to determine the sero-prevalence of SARS-CoV-2 virus. The

overall sero-prevalence level was 73.1% and it was also found that female participants were more likely to be sero-positive than the male participants.

In another work done by Francis et. al., [8] based on the scientific and statistical evidence it is found that T-cells play a significant role in acquiring immunity for COVID-19 virus considering both natural infection and vaccination. The authors also describe that more work need to be done on the study of waning immunity.

MacIntyre et. al, [9] have done statistical analysis on the availability of multiple vaccines in Australia in the year 2021 and their impact on further stopping the spread COVID-19 virus. The authors have forecast that slower rate of vaccination will increase the time span of human population living with COVID-19 much longer. Hence, a healthy rate of vaccination is mandatory to bring further spread of virus under control.

Ahmed et. al., [10] have used the vaccinated and recovery datasets from a particular geographical location to compute the attainment of Herd Immunity. Based on the study they have reported that there is a marginal increase in the Herd Immunity among the population under consideration. Also, Ramachandran et. al., [11] have analyzed the effect of food habits on COVID-19 infections and recovery.

B. *Waning Immunity*

Rabiu and Iyaniwura [12] have developed an endemic model for COVID-19 in-order to study the impact of vaccination and waning of immunity on the dynamics of COVID-19 disease. Based on the model, authors have suggested that waning of vaccine-related immunity has more effect on the disease compared to the post-recovery based immunity which has a direct impact on the eradication of COVID-19.

A study has been done by Goldberg et. al., [13] on the development of natural immunity that results from the COVID-19 infections by estimating the rates of further infection. The study also covers protection afforded by the natural immunity or vaccine induced immunity called as hybrid immunity. Based on the study a single vaccine done administered on the recovered patient improved the restoration of protection from reinfection.

Based on another the study by Goldberg et. al., [14] it was found that immunity against the delta variant of COVID-19 virus waned in all age groups after the administration of second dose of the vaccine in Israel. Hence, more empirical study is required in-order to understand the duration of administering booster vaccine doses for the COVID-19 disease.

In an unique model, proposed by Ehrhardt et. al., [15] a finite differentiation scheme together with qualitative results for immunization and waning immunity have been developed by the authors. In the study, only existing metrics of basic and effective reproduction numbers of the virus have been considered for statistical analysis. Similarly, an ARIMA based model has been developed by Joshua et. al, [16] in their research findings on the effects of COVID-19.

III. Research Problem

Measurement of Waning Immunity Index required a clear methodology and well defined set of metrics. In this introductory research a new set of inclusive metrics have been defined and applied to measure Waning Immunity Index for COVID-19 virus among human population.

A structured methodology has also been proposed and used for the measurement of the WII metric along with inferences. The proposed model considers three important classes of people, namely, the susceptible, immunized and infected/recovered individuals in the human population measured in a specific geographical area.

IV. Methodology

Computing the change in Immunity for a specific pathogen measured in the human population requires a structured methodology. This needs to include all the factors that positively or negatively contribute to the antibodies present in an inoculated individual. Vaccines are common form of providing the necessary knowledge for the human immune system. Hence, a clear understanding of the duration in reduction of antibodies beyond an acceptable level will help the health workers plan for the administration of booster doses.

In this research, a comprehensive and quantitative model shown in Fig. 1 has been proposed that defines a new metric called Waning Immunity Index (WII) Measurement Model. The measurement takes into consideration all the possible factors that can directly affect the change in Immunity levels of the vaccinated individuals. All the three factors contributing to the ability of developing immunity, namely, Susceptible class, Immunized class and Recovered class have been included in the model for a comprehensive measurement. Inclusion of all the contributing factors can help in improving the comprehensiveness of the proposed model.

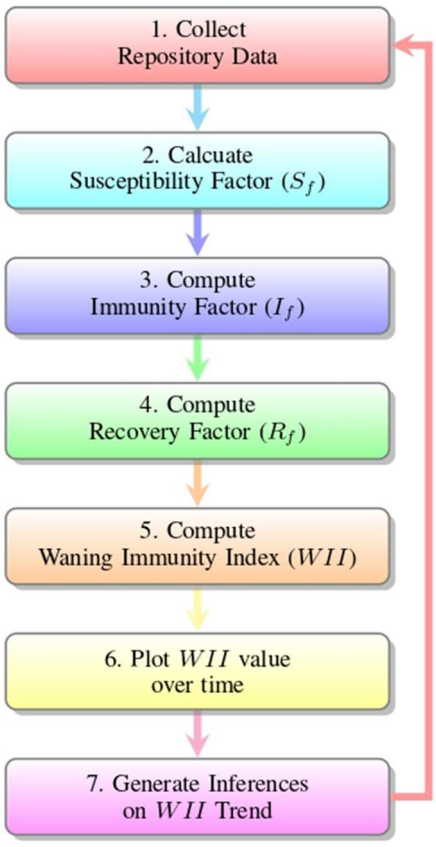

Fig. 1. Process Flow of Waning Immunity Index (WII) Measurement Model

V. Theory and Calculation

The computation of Waning Immunity requires the knowledge of basic reproduction number of the COVID-19 variant virus, percentage of population immunized to the virus and the effective reproduction number of the virus. Hence, the proposed model includes three important factors namely Susceptibility of the population getting infected by COVID-19, Immunity acquired either thorough infection or immunization and Recovery from COVID-19, thereby immune to the disease.

In to perform a quantitative assessment and to measure level of Waning Immunity, three new metrics have been defined in the model. They are: 1) the Susceptibility Factor of COVID-19 infection, 2) the Immunity Factor of COVID-19 infection, 3) the Recovery Factor of COVID-19 infection. The three metrics are explained with necessary formulae and notations in subsections A, B and C.

A. Susceptibility Factor

When the COVID-19 pandemic started in the last quarter of 2019, none of the human population around the world had immunity to the virus. Hence, the whole population was susceptible to the virus that lead to quite a numbers of deaths due to the infection. But, this changed over a period of time due to the acquiring of immunity either through infection and recovery or from vaccination. If immunity of the disease wanes over a period of time, then the number of susceptible people increases leading to the continuation of the epidemic.

Hence, the metric to capture the susceptible class of people need to factor all these possibilities into account. Considering this, a new metric called the Susceptibility Factor (Sf) is defined as given in Equation 1.

$$S_f = \frac{R_1}{R_0} \tag{1}$$

where,

S_f is the Susceptibility Factor of COVID-19 infection,

R_0 is the basic reproduction number of the virus,

R_1 is the effective reproduction number of the virus considering the geographical area.

B. Immunity Factor

Vaccination is one of the best ways to acquire Immunity against COVID-19 virus for the general population. Statistically, more number of people has been vaccinated every day thereby reducing the risk of further infection spread in the community. But knowledge of virus for the immune system can wane over time if booster doses are administered at regular intervals of time.

To take into account the Immunity acquired through vaccination, a new metric has been defined called the Immunity Factor (I_f) given in Equation 2.

$$I_f = \frac{V}{P} \tag{2}$$

where,

I_f is the Immunity Factor of COVID-19 infection,

V is the total number of vaccinated people,

P is the total population of the geographical area.

C. Recovery Factor

Starting from the end of 2019, the number of people infected by COVID-19 virus has been steadily increasing and decreasing over time. Infected people were fighting with their immune system that started learning from the virus. Due to this percentage of population has been increasing, but even this immunity might wane over time.

Considering the recovery of infected people a new metric has been defined namely, Recovery Factor (R_f) as given in Equation 3.

$$R_f = \frac{R}{I} \tag{3}$$

where,

R_f is the Recovery Factor of COVID-19 infection,

R is the total number people recovered from the virus infection,

I is the total number people infected by the virus.

D. Waning Immunity Index (WII)

Waning of Immunity is related to the decrease in knowledge of human immune system to understand and fight against COVID-19 virus. In order to measure the waning of immunity a new metric has been defined and called as Waning Immunity Index (WII). The formula to calculate WII is shown in Equation 4. The metric includes all the three components of Susceptibility, Immunity and Recovery factors of the human population towards COVID-19 infections.

$$WII = \frac{S_f + I_f + R_f}{3} \tag{4}$$

where,

WII is the computed value of Waning Immunity Index.

Since the definition of Waning Immunity as an Index ranging from 0 to 1, is comprehensive, it will be very helpful for the health care officials to plan for the duration of booster doses.

VI. Measurement and Discussions

Application and validation of any new model requires a sample datasets. Since the proposed model can be applied on any geographic region for testing and validation, a sample datasets is taken for illustration and explanation. This datasets consists of simulated values for basic reproduction number of COVID-19 virus and the effective reproduction number considering both vaccinated and infected. Table I shows the calculated values of Susceptibility Factor for the respective values of effective reproduction numbers.

TABLE I. CALCULATION OF SUSCEPTIBILITY FACTOR

Frequency in time (t)	Basic Reproduction Number (R_0)	Effective Reproduction Number (R_1)	Susceptibility Factor ($S_f = \frac{R_1}{R_0}$)
1	2.25	2.25	1
2		2.21	0.982
3		2.15	0.955
4		2.17	0.964
5		2.16	0.96
6		2.4	1.06
7		2.7	1.2
8		1.9	0.844
9		1.5	0.666
10		1.2	0.533

Similarly, the second metric namely the Immunity Factor calculation is shown in Table II.

TABLE II. CALCULATION OF IMMUNITY FACTOR

Frequency in time (t)	Total Population (P)	Total Vaccinated People (V)	Immunity Factor ($I_f = \frac{V}{P}$)
1	25,45,000	8,600	0.0337
2		45,000	0.0176
3		90,000	0.0353
4		1,50,000	0.0589
5		2,85,000	0.1119
6		3,70,000	0.1453
7		4,25,000	0.1669
8		7,48,000	0.2939
9		10,43,000	0.4098
10		14,45,000	0.5677

Sample values have been taken to illustrate the calculation of Immunity Factor after Immunization for people living in a particular geographical area.

The third proposed metric namely, Recovery Factor is calculated using sample values and have been illustrated in Table III.

TABLE III. CALCULATION OF RECOVERY FACTOR

Frequency in time (t)	Total Infected People (I)	Total Recovered People (R)	Recovery Factor ($R_f = \frac{R}{I}$)
1	28,000	2,300	0.0821
2	91,000	15,400	0.1692
3	2,95,750	60,000	0.2028
4	8,87,250	1,02,000	0.1149
5	10,64,700	1,60,000	0.1502
6	12,51,760	3,20,000	0.2556
7	14,45,650	6,25,000	0.4323
8	14,99,200	10,48,000	0.6990
9	16,60,000	14,24,000	0.8578
10	19,10,200	18,45,000	0.9958

Finally based on the three metrics Susceptibility, Immunity and Recovery Factors the Waning Immunity Index has been calculated and tabulated in Table IV.

TABLE IV. CALCULATION OF WANING IMMUNITY INDEX

Frequency in time (t)	Susceptibility Factor (Sf)	Immunity Factor (If)	Recovery Factor (Rf)	Waning Immunity Index ($\frac{S_f + I_f + R_f}{3}$)
1	1	0.0337	0.0821	0.3719
2	0.982	0.0176	0.1692	0.3896
3	0.955	0.0353	0.2028	0.3977
4	0.964	0.0589	0.1149	0.3792
5	0.96	0.1119	0.1502	0.4073
6	1.06	0.1453	0.2556	0.4869
7	1.2	0.1669	0.4323	0.5997
8	0.844	0.2939	0.6990	0.6123
9	0.666	0.4098	0.8578	0.6445
10	0.533	0.5677	0.9958	0.6988

A graphical depiction of the trend of WII is shown in Fig 2 The graph is drawn by taking the sequence of calculated values of WII over time.

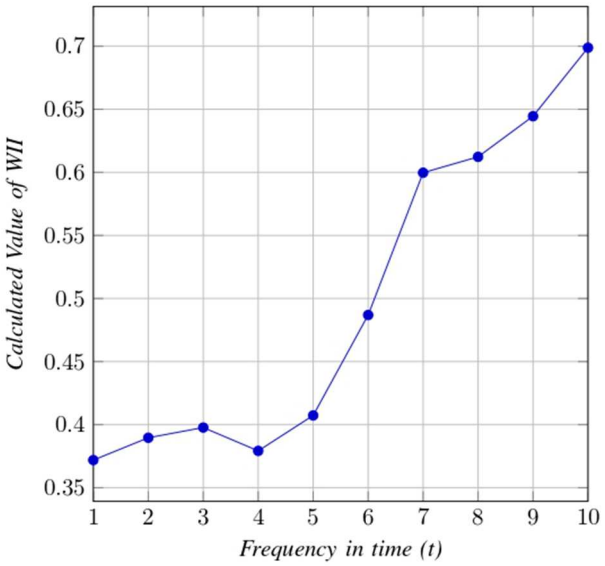

Fig. 2. Trend line of Waning Immunity Index

Based on the results obtained on the sample data, a lot of interesting facts begins to emerge that can aid in the understanding of Waning Immunity in human population. In the initial part of the measurement, Waning immunity mildly increase and decreases with the same magnitude. But after that, there is a huge increase in the Waning Immunity Index and later slows down again at the later part of the measurement. This has happened because of the increase in infections and vaccinations during the intermediate duration. These steep increases and decreases are marking signs for the health officials to plan for the duration of booster doses.

If the WII value suddenly shows sign of sudden increase, then the number of booster doses administered. This is due to the increase in the number of infections caused in the general population and because of the loss of immunity among the people living in the geographical area. The number of intervals taken for testing the proposed model is very limited. In extension, if the same model is applied to the data collected with more number of intervals, then further information can be deduced using computation and analysis.

VII. Conclusions and Future Directions

Immunity in a human system provides the best line defense against the pathogens found in the environment. But, if this immunity is not able to come across known pathogens for an extended period of time, then we have a possibility of waning of immunity. In this quantitative research based study, a model for the comprehensive evaluation and a new set of easily measurable metrics have been defined and explained in clear set of terms.

The proposed model can be applied to analyze waning of immunity to any geographical area by downloading necessary data available in the web portal Kaggle.com. The measurement can help the health officials for planning the duration of booster doses to avoid further spread of COVID-19 virus in the community.

The model has been applied to a sample set of data and the proposed set of metrics have been computed and tabulated. Based on the different factors of Susceptibility, Immunization and Infection/Recovery suitable metrics contributing to Waning of Immunity has been calculated. Finally, the important metric of Waning Immunity Index have been computed and analyzed using graphical representation. Initial inferences have been generated based on the trend of computed values of WII.

This work is planned to be extended by applying the proposed model for specific geographic location and generating inferences out of the measured values. Further, more number factors can also be identified and included in the Waning Immunity Index measurement. Also, the WII metric and its contributing factors will be analyzed using Neural Networks based models for in-depth analysis and knowledge extraction.

References

[1] Haley E. Randolph, Luis B. Barreiro, “Herd Immunity: Understanding COVID-19,” Immunity, Volume 52, Issue 5, 2020, pp. 737-741.

[2] Rachel Thomas and Marianne Freiberger, “Understanding Numbers: Statistically Speaking,” 2020, pp. 32-38.

[3] URL: https://plus.maths.org/content/so-whats-waning

[4] URL: http://www.kaggle.com

[5] J. DSouza and S. Velan S., “Using Exploratory Data Analysis for Generating Inferences on the Correlation of COVID-19 cases,” 2020 11th International Conference on Computing, Communication and Networking Technologies (ICCCNT), 2020, pp. 1-6.

[6] J. Vadlapati, S. Senthil Velan and E. Varghese, “Facial Recognition using the OpenCV Libraries of Python for the Pictures of Human Faces Wearing Face Masks during the COVID-19 Pandemic,” 2021 12th International Conference on Computing Communication and Networking Technologies (ICCCNT), 2021, pp. 1-5.

[7] Madhi, S.A., Kwatra, G., Myers, J.E., Jassat, W., Dhar, N., Mukendi, C.K., Nana, A.J., Blumberg, L., Welch, R., Ngorima-Mabhena, N. and Mutevedzi, P.C., “Population Immunity and COVID-19 Severity with Omicron Variant in South Africa,” New England Journal of Medicine, Feb 23, 2022.

[8] Stieber, F., Allen, N., Carpenter, K., Howard, J., Alagna, R., Manissero, D., and Nikolayevskyy, V., “Accuracy of Interferon Gamma Release Assays for the COVID-19 Immunity Assessment,” Journal of Virological Methods, 2022, pp. 114472.

[9] MacIntyre CR, Costantino V, Trent M, “Modelling of COVID-19 vaccination strategies and herd immunity, in scenarios of limited and full vaccine supply in NSW, Australia,” Vaccine, 24 April, 2021.

[10] M. Ahamed, S. Velan S and D. I. Wadekar, "Analysis of Herd Immunity Using Vaccination and Recovery Data Sets," 2021 12th International Conference on Computing Communication and Networking Technologies (ICCCNT), 2021, pp. 1--5.

[11] R. Ramachandran, S. Velan S and D. Imtiyaz Wadekar, "Statistical Comparison of COVID-19 Infections Based Upon the Food Habits/Diets in Countries Using RStudio," 2021 11th International Conference on Cloud Computing, Data Science & Engineering (Confluence), 2021, pp. 1095-1101.

[12] Rabiu M, Iyaniwura SA., “Assessing the Potential Impact of Immunity Waning on the Dynamics of COVID-19 in South Africa: An Endemic Model of COVID-19,” Nonlinear Dynamics, Jan 25, 2022, pp. 1-21.

[13] Goldberg Y, Mandel M, Bar-On YM, Bodenheimer O, Freedman L, Ash N, Alroy-Preis S, Huppert A, Milo R, “Protection and waning of natural and hybrid COVID-19 immunity,” MedRxiv, Jan 1, 2021.

[14] Goldberg, Yair, Micha Mandel, Yinon M. Bar-On, Omri Bodenheimer, Laurence Freedman, Eric J. Haas, Ron Milo, Sharon Alroy-Preis, Nachman Ash, and Amit Huppert, “Waning immunity after the BNT162b2 vaccine in Israel,” New England Journal of Medicine, Vol 385, No. 24, 2021, pp. e85.

[15] Ehrhardt, M., Gašper, J. and Kilianová, S., “SIR-based mathematical modeling of infectious diseases with vaccination and waning immunity,” Journal of Computational Science, 37, 2019, p.101027.

[16] J. S. R. R, S. A. Babu, J. W. James and R. Vedaiyan, “ARIMA based Time Series Analysis: Forecast COVID-19 Most Vaccinated Process and Active Cases classify using Probability Distribution Curve Rates (ARIMAPDC),” 2021 2nd International Conference on Smart Electronics and Communication (ICOSEC), 2021, pp. 546-551.