Analysis of Herd Immunity Using Vaccination and Recovery Data Sets

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2021 12th International Conference on Computing Communication and Networking Technologies (ICCCNT) | 978-1-7281-8595-8/21/$31.00 ©2021 IEEE | DOI: 10.1109/ICCCNT51525.2021.9580121

***Abstract*— The Covid-19 pandemic that created a situation of public health emergency worldwide called for an urgent requirement of vaccine to prevent further spread of the disease. Successful vaccines started coming into view publicly since December 2020 with Pfizer-BioNTech vaccine being the first with a 95 percent efficacy. The primary purpose of the research is to conduct a statistical analysis of the effect of the covid-19 vaccines on herd immunity. Different countries that have used similar vaccines have been paired and analyzed based on the number of the new cases, recovered cases and the amount of vaccines taken. A comparative study on the herd immunity of the countries before and after the intake of the vaccination is made, to analyze the effect of the vaccines.**

Keywords—COVID-19, Vaccination, Herd Immunity

I. INTRODUCTION

The Covid-19 pandemic has left a deep impact in the functioning of our world economy. The effect is very evident and our living environment has been seriously affected due to the extreme spread of this highly contagious virus. The world organizations are playing a vital role in containing its spread by taking suitable measures against the spread of the virus to the population. In spite of taking anti-spreading measures, the control of mutants has been very difficult due to the inability of attaining herd immunity for the different virus mutants in the population.

As of 2020 Aug 20, the basic reproduction value of the virus ranges between 1.0011 and 2.7936. Since the least value is more than 1, it's an epidemic in almost all countries. It is broadly accepted that the pre-pandemic regularity will not return until a safe and powerful antibody technique opens up and a worldwide immunization program is actualized effectively.

In an emphatically associated and incorporated world, the effects of the virus past mortality and morbidity has gotten evident since the flare-up. The pandemic has prompted an enormous worldwide general wellbeing effort to moderate the spread of the infection. This can be achieved by expanding the behavior of hand washing, lessening face to face contact, wearing face mask out in the open and physically keeping distance between individuals.

The work done in this research had been to study the vaccination used by different countries and to further understand how this has affected the immunity rate of individuals. Furthermore, the immunity obtained by the population who were infected and had recovered were also considered while conducting the analytical study. The focus was more on obtaining an index of the herd immunity, which refers to the indirect protection from a disease that a population obtains when a certain number of people are immune to the disease and It is achieved by the masses in different countries around the world. In focus, the analysis was done on comparing the measured and computed values for Bahrain and UAE.

Based on this initial study it was found out that to immunize a whole population against the Covid 19, achieving herd immunity is the solution. When herd immunity is attained, even the people who are not immune to the disease can be safe from it. Herd immunity differs for various populations depending upon the size of the population and basic reproduction number of the virus.

Rest of the paper is organized as follows. Section II brings out the scope of the problem addressed in the paper. The existing work is explained in Section III. The methodology of the work done is explained clearly in Section IV. The collected data has been analyzed in section V. Application of the formula and observations are detailed in section VI. Finally, Section VII provides a short conclusion for the paper.

II. RELATED WORK

Coronavirus disease 2019 (COVID-19) is an emerging infectious disease caused by the novel severe acute respiratory syndrome coronavirus 2 [1]. A protected and successful antibody could assist with ensuring these citizens in two manners: direct assurance, where high-hazard groups are vaccinated to forestall illness, and aberrant assurance, where those in contact with high-risk people are immunized to diminish transmission.

In the work done by Anderson and May [2], the authors have explained the relationship between the transmission of highly infectious diseases like Covid-19 virus and the attainment of herd immunity. This study helps in the understanding of best practices to be followed to protect the population against the diseases.

In another work done by Rashid et. al., [3] an in-depth analysis and review of the relationship between vaccination and herd immunity have been explained with suitable literature. In the same work a comparison of the different types of vaccines has also been done to understand the efficacy and potency of different vaccines available for the same set of diseases.

In Lipsitch, Marc, and Natalie E. Dean. "Understanding COVID-19 vaccine efficacy", [4] it was stated that vaccines are especially appropriate for making group herd immunity in light of the fact that their assignment can be explicitly focused to exceptionally risked populaces, for example, medical care laborers or people with continuous contact with infected clients. Deaths can be forestalled by firstly focusing on exceptionally weak populaces, in spite of the fact that it is normal that immunizations may not be as effective in more elder citizens. In numerous nations, lockdown procedures have been actualized and social distancing is required to lessen individual-to-individual transmission and consequently ensure residents moderate the Covid-19 spread and control the

related effect on medical services frameworks including serious consideration limits, anticipating a critical diminishing of infection spread, populace based invulnerability through normal expose to the infection group invulnerability.

In Determinants of Coronavirus immunization acknowledgment in the US composed by Malik, A. A., McFadden, S. M., Elharake, J., and Omer, S. B. [6] states in their investigation that 67% acknowledgment of a Coronavirus antibody, there were perceptible segment and topographical aberrations in immunization acknowledgment. Before a Coronavirus immunization is acquainted with the U.S., general wellbeing authorities and policymakers should focus on powerful Coronavirus antibody acknowledgment informing for all Americans, particularly the individuals who are generally defenseless. The worldwide requirement for antibody and the wide geographic variety of the pandemic require more than one powerful immunization approach. Joint effort will be fundamental among biotechnology and drug organizations, a large number of which are presenting an assortment of antibody as draws near.

III. Scope of the Paper

Herd immunity is a type of aberrant assurance that is offered to the community when a high percentage of people contained locally are invulnerable to a specific disease like Covid-19 which was not the case at beginning of the pandemic. This invulnerability can be because of immunization or to the recuperation post-sickness. Powerful herd immunity in Covid-19 has a few obstacles upon progress [14]. Getting to know whether and if recuperation from Coronavirus gives invulnerability to the seriousness of, reinfection is probable to educate current endeavors to securely downsize populace based mediations, for example, social distancing [15].

Though people can attain natural immunity after recovering from the disease COVID-19, the rate at which this will help in reaching the required immunity to herd immunity is slow. This necessitates the usage of vaccines which will help in increasing the number of people immune to the disease hence speeding up the attainment of herd immunity. Herd immunity is an important concept for epidemic control and this paper focuses on understanding how vaccines affect herd immunity in different countries.

IV. Methodology

Any study requires a clear set of steps to identify and conduct a result based on the data. It includes a hypothetical analysis of the assortment of strategies and principles related with a part of information.

A. Proposed Model

Data analysis is a technique used to understand the insight embedded inside the data patterns. This will enable us to extract useful knowledge for decision making. The process followed in this research is shown in Fig 1.

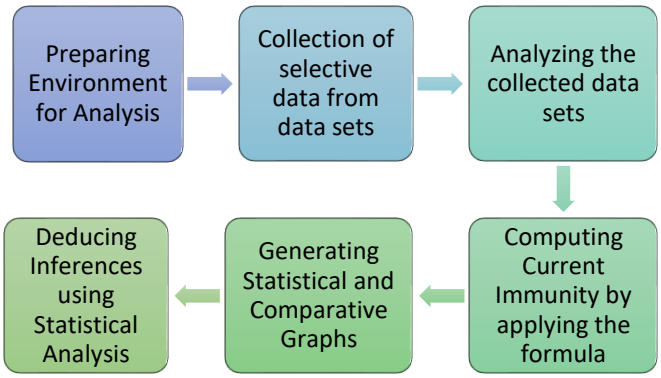

Fig 1. A Typical Process Flow used for Data Analysis

This research was done by collection of sample data from various online data websites like Kaggle.com [7] and OurWorldinData.com [8] for getting the number of people infected, vaccinated and recovered. Then this data was uploaded on *RStudio*, an IDE for statistical learning, which is then used for the statistical analysis of the data thus collected. Statistical graphs are plotted to understand the changes in the Covid-19 situation in different countries.

V. Analysis Of Collected Data

For analyzing the effect of vaccination on herd immunity, comparison of countries that have used the same vaccines is done. The countries that have been taken into consideration in this paper are UAE and Bahrain.

A. Overview

The data on number of people infected, vaccinated and recovered has been obtained from online resources like Kaggle.com and OurWorldinData.com. The basic reproduction number of the virus has been obtained from the preliminary estimation conducted by Rahman, B., Aziz, I.A., Khdhr, F.W. and Mahmood, D.F., 2020. in the Middle East [9].

TABLE I. COMPARISON BETWEEN UAE AND BAHRAIN

Characteristics/Country		**UAE**	**Bahrain**
Population		9,980,000	1,700,000
Type of vaccine		Oxford/AstraZeneca, Pfizer/BioNTech, Sinopharm/Beijing, Sinopharm/Wuhan, Sputnik V	Pfizer/BioNTech, Sinopharm/Beijing
Cumulative vaccination doses administered per 100 people		35.45	8.18
Cumulative test per 100 people		52.148	22.294
Cumulative confirmed case per 100 people	After	1.0697	0.936
	Before	0.289	0.372

Recovery rate (percentage difference)	2.90%	1.60%
Basic Reproduction number of Covid-19	2.75	3.39
Number of total recovered cases	3.67	6.5

1) Observations:

- UAE has approximately 6 times the population of Bahrain and has administered 4 times the vaccination doses as that of Bahrain.
- Both countries show an increase in the number of confirmed cases of about 2.5 to 3.5 times the cases after vaccination
- It was observed that UAE has administered higher number of doses than Bahrain (population proportion considered) as can be seen in the graph shown in Fig.3.
- United Arab Emirates and Bahrain are both gulf countries that take the vaccines Pfizer/BioNtech and Sinopharm. (As the vaccines Oxford/AstraZeneca and Sputnik V are used lesser in number, it can be assumed that both countries have used Pfizer and Sinopharm in a bigger number comparatively)

VI. Computation of Base Prevelance and Herd Immunity

Base prevalence (current immunity), the proportion of the population that has acquired immunity against the disease either by recovering from the disease or by getting vaccinated, can be calculated as shown in equation 1.

$$BP = \frac{(VC * VE + PR)}{P} * 100\% \quad (1)$$

where,

BP is the Base Prevalence metric value

VC is the Number of people vaccinated in the respective geography,

VE is the Vaccine efficacy specifying the percentage efficacy of the vaccine,

PR is the number of people who recovered from the *COVID-19* infection in a geographic area, and

P is the total size of the population in the respective geographic area.

Using the base prevalence formula, the current immunity of the population against Covid-19 is plotted over a period of two months for Bahrain and United Arab Emirates.

The first period taken into consideration in the graph shown in Fig. 2 is the pre-vaccination period from 22nd of November 2020 to 22nd of December 2020 represented by a red plot line (Before). The second period is during the vaccination period from 14th January 2021 to 14th February 2021 represented by a blue plot line (After).

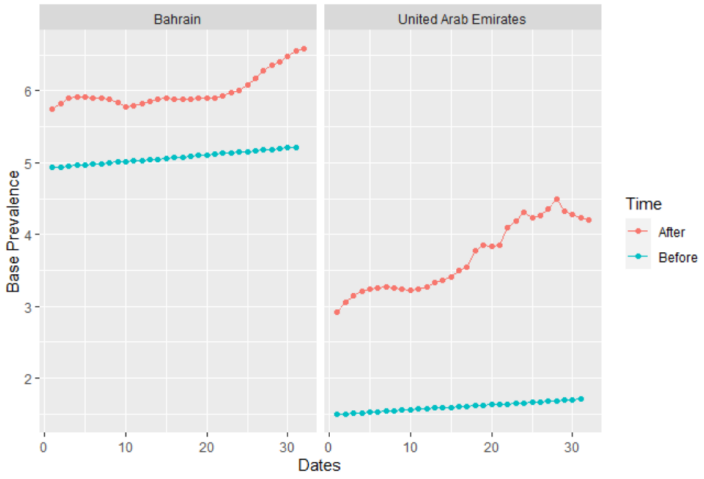

Fig 2. Comparison of Base Prevalence in Bahrain and UAE

By analyzing the graph in Fig 2, it can be observed that in the initial period without vaccination, the base prevalence of the population sees a small positive slope. In the second period after vaccination starts, the increase is high especially multifold in the United Arab Emirates.

A sample calculation of base prevalence and the related metrics for UAE and Bahrain is shown in Table II.

Table I.Sample of Base Prevalence Calculation in United Arab Emirates (Before and During Vaccination)

Country	***UAE***					***Bahrain***				
Date	***VC***	***VE***	**PR**	***P***	***BP***	***VC***	***VE***	**PR**	***P***	***BP***
22/11/20	0	0.83	149578	9,980,000	1.49169	0	0.83	84017	1,700,000	4.93111
23/11/20	0		150261		1.49877	0		84166		4.94217
24/11/20	0		151044		1.50562	0		84335		4.95094
25/11/20	0		151870		1.51346	0		84510		4.96088
26/11/20	0		152708		1.52174	0		84653		4.97117
14/1/21	91448		215820		2.92306	5852		93329		5.75026
15/1/21	103490		218988		3.05495	6089		93726		5.82386
16/1/21	111082		222106		3.14933	6353		94039		5.90139
17/1/21	113744		225374		3.20422	6727		94297		5.91174
18/1/21	114896		228364		3.24376	7350		94646		5.91776

Herd immunity is calculated based on the reproduction number of the virus. It can be calculated by using the formula given in equation 2.

$$Herd\ Immunity = \left(1 - \frac{1}{R_o}\right) \times 100 \qquad (2)$$

where,

R_0 is the basic reproduction number of the virus COVID-19

Calculation of Herd Immunity for two countries namely the UAE and Bahrain is given below:

UAE:

$$\text{Herd Immunity} = \left(1 - \frac{1}{R_o}\right) \times 100$$
$$= \left(1 - \frac{1}{2.75}\right) \times 100$$
$$= 63.63\%$$

Bahrain:

$$\text{Herd Immunity} = \left(1 - \frac{1}{R_o}\right) \times 100$$
$$= \left(1 - \frac{1}{3.39}\right) \times 100$$
$$= 70.5\%$$

Herd Immunity of the countries above represents the minimum amount of people that should be immune to the disease so as to not make the disease an epidemic. United Arab Emirates needs to immunize a minimum of 63.63% of its population whereas Bahrain needs to immunize 70.5% of its population.

VII. Observations

- By observing the graphs in Fig. 2, Fig. 4, it can be seen that in the period before vaccination, recovery from the disease was the only form to attain immunity.
- In the period after vaccination, from Fig.3 and Fig.4, we can note that the immunity has a high positive impact due to the vaccination. United Arab Emirates shows a high peak in the immunity contributed by the vaccination.

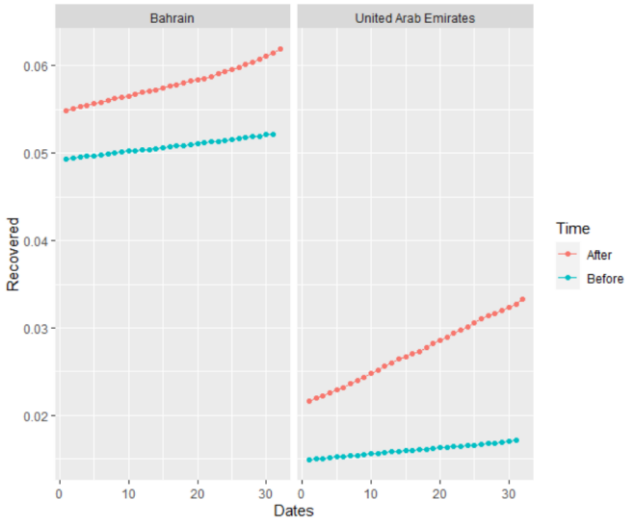

Fig 3: Number of recovered cases in Bahrain and United Arab Emirates

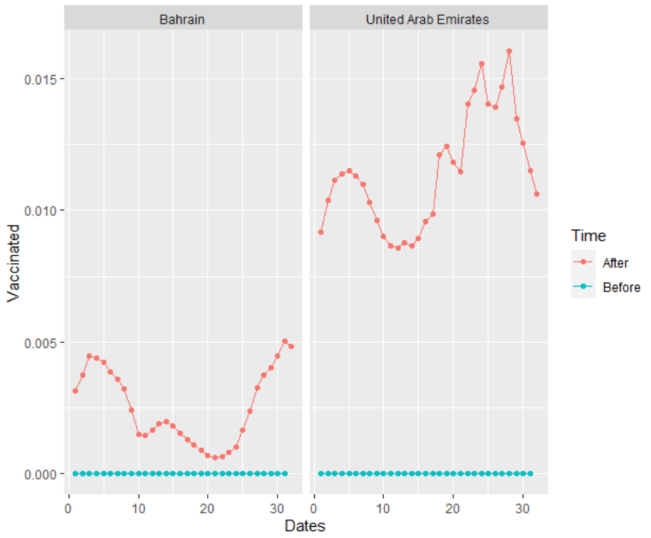

Fig 4: Number of people vaccinated in Bahrain and United Arab Emirates

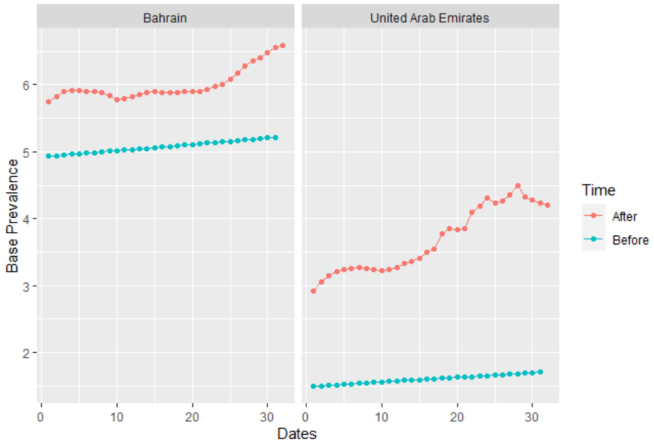

Figure 5: Immunity in Bahrain and United Arab Emirates

- The calculations of herd immunity in the end of section VI point that United Arab Emirates need to achieve an immunity of 63.63% whereas Bahrain needs to achieve an immunity of 70.5% of their corresponding populations to end the epidemic.

VIII. Conclusion

Immunization forestalls infection to a degree and further it limits forward transmission of infection to the masses. The vaccines that are currently being used are of high efficacy and provides successful immunization against the COVID-19. The analysis done from the calculated immunity of the compared populations has shown that, there is a sharp increase in the immunity of the population after a proportion of the population got vaccinated as compared to immunity before vaccination which resulted solely from recovery from the disease. Therefore, the study has led to the indication that vaccines can help in fastening the rate at which the required immunity in the population i.e. herd immunity against the Covid 19 is reached and hence vaccinations should be widely taken.

Every nation ought to assess various methodologies and designation plans depending on the study of disease transmission, hidden populace wellbeing, projections of accessible immunization dosages, and inclination for

inoculation systems that favor immediate or circuitous advantages [16].

Supporting high immunization inclusion rates may turn out to be more difficult as individuals question the limit of antibodies. Later on, keeping up public support for immunization will be basic for forestalling flare-ups of antibody preventable illnesses. As Rabinovich, N. R., McInnes, P., Klein, D. L., & Hall, B. F. [13], said that recent advances in the essential sciences are currently fueling the improvement of new generation of antibodies that will be founded on reasonable perspectives. Two components that are making this conceivable will be an improved comprehension of the microbial elements needed for infection and the working of the immune system when encountered by it[18].

The limitations of the paper is that it doesn't consider factors like lockdown, travelling restrictions, health issues etc. while calculating the herd immunity. The paper could be improved by studying relations between more countries to arrive at a more concrete conclusion. As there will be variation based on diet and satiety of people in the attempt to achieve immunity and countries under lockdown have shown food supply at lower rate than minor lockdown[17].

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