# Effects of COVID-19 Vaccines on Mortality Rate

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***Abstract*—This study attempts to assess the effectiveness of COVID vaccination to prevent SARS-CoV-2 infection. We conducted a detailed analysis between those vaccinated and unvaccinated population. The end result of our research suggests that the vaccine has been a promising approach for curbing the COVID-19 pandemic. The analysis aims to promote acceptance of vaccinations for prevention and preparedness for next pandemic.**

***Index Terms*—covid-19, vaccinations, pandemic, death, visualization, analysis**

## I. Introduction

The novel beta-coronavirus SARS-CoV-2 is thought to have emerged from bats in Wuhan in 2019. In the last two decades, beta-coronaviruses have jumped between species and caused three zoonotic outbreaks: SARS CoV (2002-03), MERS-CoV (2012), and SARS-CoV-2 (2019-to-date). The presence of a plethora of coronaviruses in bats, including many SARS-related CoV (Severe Acute Respiratory Syndrome related Coronaviruses), as well as the sporadic crossing over of coronavirus species barriers to humans, suggest that future occurrences of zoonotic transmission events may be sustained.

The outbreak spread so quickly around the world that it was termed as a pandemic soon in March 2020. Effective epidemic control necessitated the development of herd immunity, which provides susceptible individuals with indirect protection by surrounding them with immunized individuals. The herd immunity threshold determines the proportion of people who must be vaccinated in order to achieve herd immunity. However, the number of susceptible individuals and the opportunities for infectious and susceptible individuals to come into contact with one another influence the spread of an epidemic.

As the entire world has been concerned with achieving desired herd immunity to overcome the health crisis. Vaccines were developed at an unprecedented speed, with testing in humans starting in March 2020. It's really important to find out that the proposed solution which is vaccinations is actually having the desired effect on the population. The best way to measure this would be to analyse vaccination numbers against the most severe case of the disease, deaths.

It's critical to understand how COVID-19 death rates change with the vaccination status in order to comprehend how the pandemic is progressing. The death rate is an important measure for determining how effective immunizations are against severe kinds of disease. In some of the previous work, [1] Johnson AG, Amin AB, Ali R, validate COVID-19 vaccine effectiveness decreased with the emergence of the Delta variant and waning of vaccine-induced immunity, protection against hospitalization and death has remained high. They provide the initial analysis of the effectiveness of the vaccine and mortality rate for the Omicron variant. [2] Xu S et al. have presented that the mortality rate of vaccinated people was lower than the unvaccinated people for other health problems. Not a lot of work has been done on the Omicron variant and the effect of booster. We wish to analyse the data further to validate our hypothesis that the mortality rate among the unvaccinated people will be high as compared to people that are vaccinated.

In our research, we will be conducting a detailed analysis of the effectiveness of the vaccine and mortality rate for all variants. Also, we will be performing a comprehensive analysis to better understand the relationship between vaccinations and the mortality rate for the novel COVID19 dataset till now. We aim to analyze data and present our results in such a way that we are more prepared for the next disease/epidemic; thus, allowing for accelerated research, R&D for diagnostics, therapeutics and vaccines and their timely access.

## II. Methodology

After gathering and fusing our data (sources - CDC and John Hopkins University), we used visualization techniques of Python and Tableau to showcase results inline with our hypothesis.

### A. Datasets

We used the following datasets from CDC and John Hopkins University:

1) John Hopkins COVID-19 Dataset [3] - US state-wise time series for deaths, cases and hospitalizations.
2) John Hopkins COVID-19 Dataset [4] - US state-wise time series for partially and fully vaccinated people.
3) John Hopkins COVID-19 Dataset [5] - Global country level time series for deaths, cases, and partially & fully vaccinated people.
4) CDC COVID-19 [6] - Data for CDC's COVID Data Tracker site on Rates of COVID-19 Cases and Deaths by Vaccination Status, which also includes booster data.
5) CDC COVID-19 [7] - Data for CDC's COVID Data Tracker site on Rates of COVID-19 Cases and Deaths

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by Vaccination Status, which does not include booster data.
6) CDC COVID-19 [8] - Rates of laboratory-confirmed COVID-19 hospitalizations by vaccination status

### B. Data Wrangling

1) John Hopkins time series data [3] and [4] had running totals for vaccinations, cases and deaths. In order to see daily numbers, we calculated delta difference for each state for consecutive days,
2) Since vaccinations started way after the daily cases and deaths were reported, there were a lot of NA values in that column, which we filled with 0. Also, while calculating this we noticed that for a few dates there were negative delta values, which is not possible. This was assumed to be some data discrepancy, and therefore we made these values to be 0 too.
3) Dataset [3] had daily separate reports, where each date had a separate file containing numbers for all states. We aggregated data by combining all these files into one.
4) We then joined [3] and [4] using State and Date as primary key, to have cases, deaths and vaccinations numbers in the same dataset.
5) We added "Variant" column to this single dataset after defining time periods for each of the variants - Alpha, Delta and Omicron.
6) We added date column to two datasets [6] and [7] manually. The date column originally didn't have the date in the correct format.
7) We also had to replace some values in the Age Group column in [6] and [7]. To cite an example, values like "5-11" were being accounted as a date - "5 November", so we had to replace them to be "5-11" string values so as to make them consistent.

### C. Data Visualization

*1) Python:* Python is a high-level, interpreted, general-purpose programming language. We harness the power of Python as a general-purpose programming language to build a web app to show different type of interactive and dynamic data visualizations. We use Streamlit to facilitate our purpose of data visualization through a web app [14]. Streamlit [9] is an open source app framework in Python language. It helps us create web apps for data science and machine learning in a short time and also let us deploy the web app on cloud.

First of all, we gather and load all the following datasets [3], [4], [6] and [7] in our web app for showing different interactive data visualizations. In order to make the web app render faster, we also cache these datasets so that they will be available faster on the next load of the web app. Then we go on to plot different type of visualizations which can be broadly categorized into following categories:

- Cases and Deaths w.r.t vaccinations across the US (country level)
- Hospitalizations w.r.t vaccinations across the US (country level)
- Cases and Deaths w.r.t vaccinations for all states in the US
- Cases and Deaths w.r.t vaccinations during different variants of COVID-19 for all states in the US

All the data visualizations have been plotted the value of the metric/s vs time. That is, we have used line charts for almost all the visualizations that have been mentioned above. The details about these different visualizations are presented in the Results section and their interpretations are presented in the Discussion section.

*2) Tableau:* Tableau Software [10] is an interactive data visualization tool focused on business intelligence. We make use of Tableau's extraordinary capabilities to show on the geographical map the relationship between the vaccinations and deaths in various countries of the world and the states of Unites States of America. We have used these maps to basically show summarized results visually on the map. The visualizations can be categorised in the following manner:

- Deaths w.r.t vaccinations across the US (state level)
- Deaths w.r.t vaccinations across the world (country level)
- Deaths vs vaccinations for five countries that recorded highest deaths in the world.

The specifics of these various visualizations are presented in the Results section, and their analysis are presented in the Discussion section.

## III. Results

The following visualizations are prepared for the categories mentioned in the Data Visualization sub-section:

- Cases and Deaths w.r.t vaccinations across the US (country level)
  - ✦ Overall rate of COVID-19 cases and deaths based on vaccination status (without booster dose)
    We plot the *age adjusted rate of cases and deaths per 100000 population* from the dataset [7] for the unvaccinated people as well as fully vaccinated people as shown in Figure 1 and Figure 2.
  - ✦ Overall rate of COVID-19 cases and deaths based on vaccination status (with booster dose)
    We plot the *age adjusted rate of cases and deaths per 100000 population* from the dataset [6] for the unvaccinated people, fully vaccinated people as well as fully vaccinated people with booster dose as shown in figure Figure 3 and Figure 4.
  - ✦ Overall rate of COVID-19 cases and deaths for different vaccine types
    We plot the *age adjusted incidence rate of cases and deaths per 100000 population* from the dataset [6] for the unvaccinated people, people who took Janssen [11] vaccine, people who took Moderna [12] vaccine as well as people who took Pfizer [13] vaccine as shown in Figure 5.
  - ✦ Overall rate of COVID-19 cases and deaths for age groups based on vaccination status (with and without booster dose)

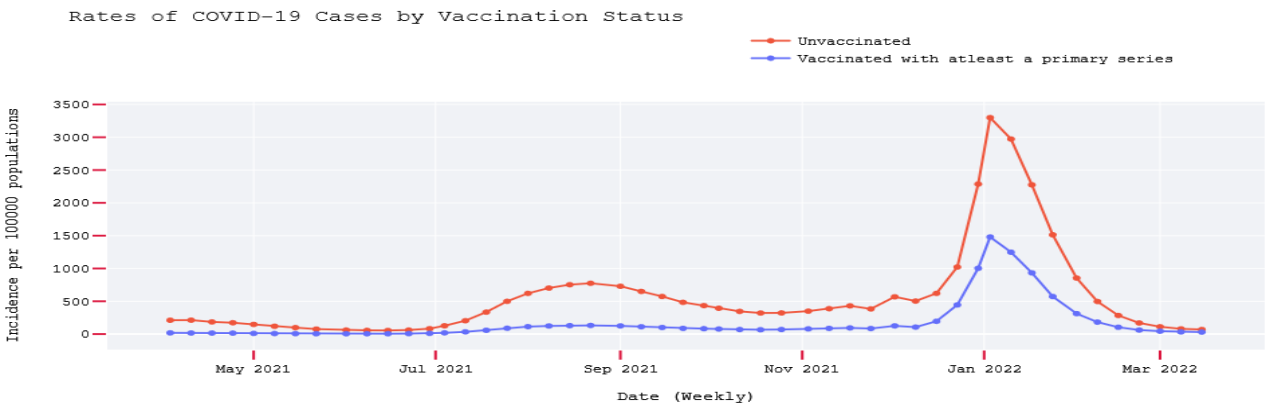


Fig. 1. US - Cases and Vaccines

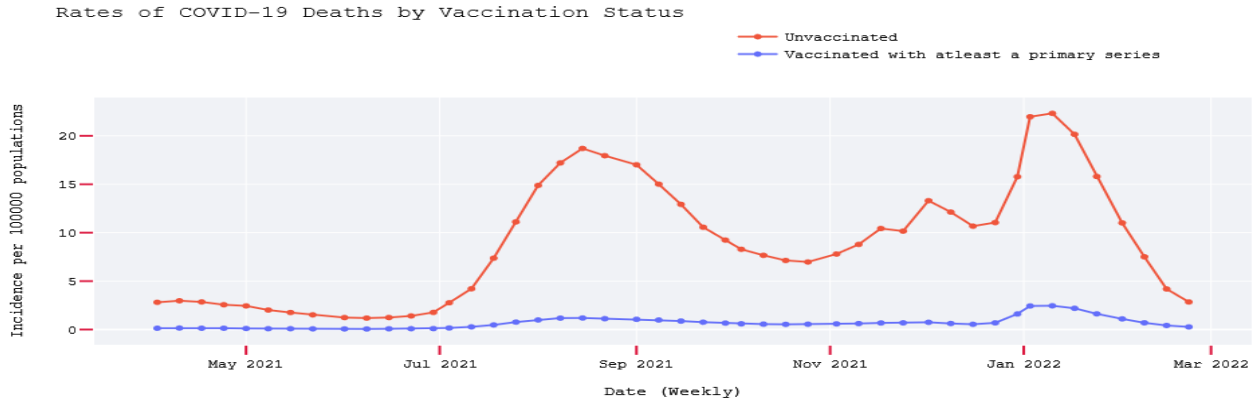


Fig. 2. US - Deaths and Vaccines

We plot the *rate of cases and deaths per 100000 population* from the dataset [6] and [7] for the unvaccinated people as well as fully vaccinated people for different age groups like [ages 5-11, ages 12-17, ages 18-29, ages 30-49, ages 50-64, ages 60-79, ages 80+]. The plots for these visualizations have not been included in the report due to space constraint but they can be easily accessed on the deployed web app [14].

- Hospitalizations w.r.t vaccinations across the US (country level)
  - ✦ Overall rate of COVID-19 hospitalizations based on vaccination status (without booster dose)
    We plot the *age adjusted rate of cases and deaths per 100000 population* from the dataset [8] for the unvaccinated people as well as fully vaccinated people as shown in Figure 6.
  - ✦ Overall rate of COVID-19 hospitalizations based on vaccination status (with booster dose)
    We plot the *age adjusted rate of cases and deaths per 100000 population* from the dataset [8] for the unvaccinated people, fully vaccinated people as well as fully vaccinated people with booster dose as shown in Figure 7.
  - ✦ Overall rate of COVID-19 hospitalizations for age groups based on vaccination status (with and without booster dose)
    We plot the *rate of cases and deaths per 100000 population* from the dataset [8] for the unvaccinated people as well as fully vaccinated people for different age groups like [ages 5-11, ages 12-17, ages 18-49, ages 50-64, ages 65+]. The plots for these visualizations have not been included in the report due to space constraint but they can be easily accessed on the deployed web app.
- Cases and Deaths w.r.t vaccinations for all states in the US
  - ✦ Daily death count due to COVID-19 for multiple states in US
    We plot the *daily death count* field that was calculated as mentioned in the Data Wrangling sub-section from the dataset that was created after joining dataset [3] and [4] as shown in Figure 13. We have included a multi-valued selectbox so that the end user can change the state from that selectbox and visualize the different trends in the visualization for different

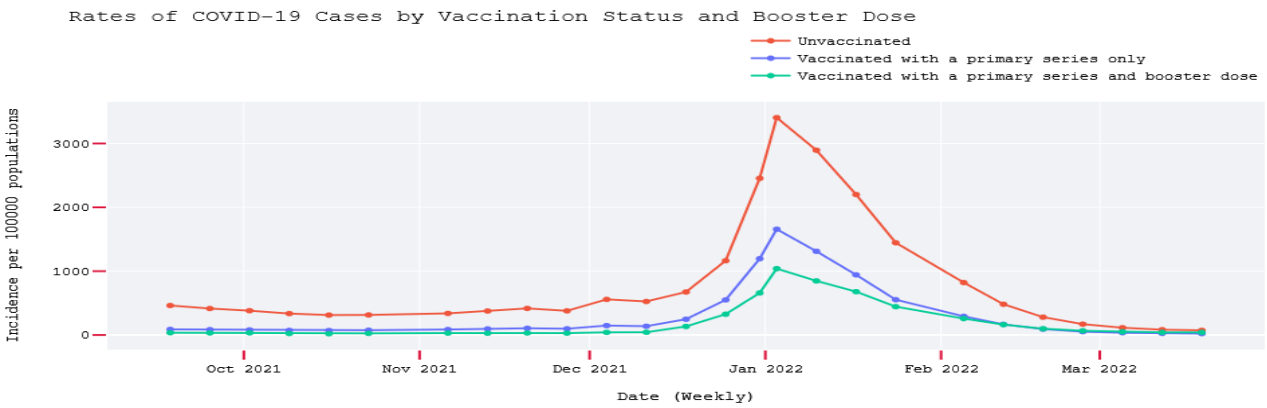


Fig. 3. US - Cases and Vaccines (Booster)

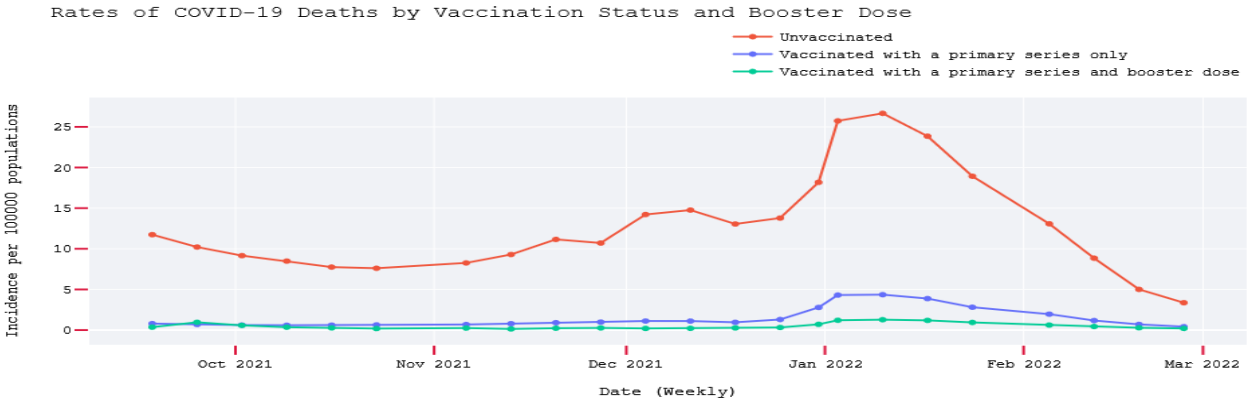


Fig. 4. US - Deaths and Vaccines (Booster)

states in the US.

- ✦ Daily vaccinated count due to COVID-19 for multiple states in US
  We plot the *daily fully vaccinated count* field that was calculated as mentioned in the Data Wrangling sub-section from the dataset that was created after joining [3] and [4] as shown in Figure 14. We have included a multi-valued selectbox so that the end user can change the state from that selectbox and visualize the different trends in the visualization for different states in the US.
- ✦ Daily death and vaccinated count due to COVID-19 for a single state in US
  We plot the *daily fully vaccinated count* and *daily death count* fields that were calculated as mentioned in the Data Wrangling sub-section from the dataset that was created after joining [3] and [4] as shown in Figure 8. We use dual Y-axis as the range of the values for the two fields are very different and so it makes sense to use secondary Y-axis to make a clear distinction between the two values. One can hover/zoom in the data points to see the exact values in the visualization. We have included a selectbox so that the end user can change the state from that selectbox and visualize the different trends in the visualization for different states in the US.
- ✦ Overall death and vaccinated count due to COVID-19 for a single state in US
  We plot the *total fully vaccinated count* and *total death count* fields which denotes the cumulative sum of those values till a time from the dataset that was created after joining [3] and [4] as shown in Figure 9. We use dual Y-axis as the range of the values for the two fields are very different and so it makes sense to use secondary Y-axis to make a clear distinction between the two values. One can hover/zoom in the data points to see the exact values in the visualization. We have included a selectbox so that the end user can change the state from that selectbox and visualize the different trends in the visualization for different states in the US.

- Cases and Deaths w.r.t vaccinations during different variants of COVID-19 for all states in the US
  We plot the *daily fully vaccinated count* and *daily death count* fields that were calculated as mentioned in the Data Wrangling sub-section for the COVID-19 variant and for

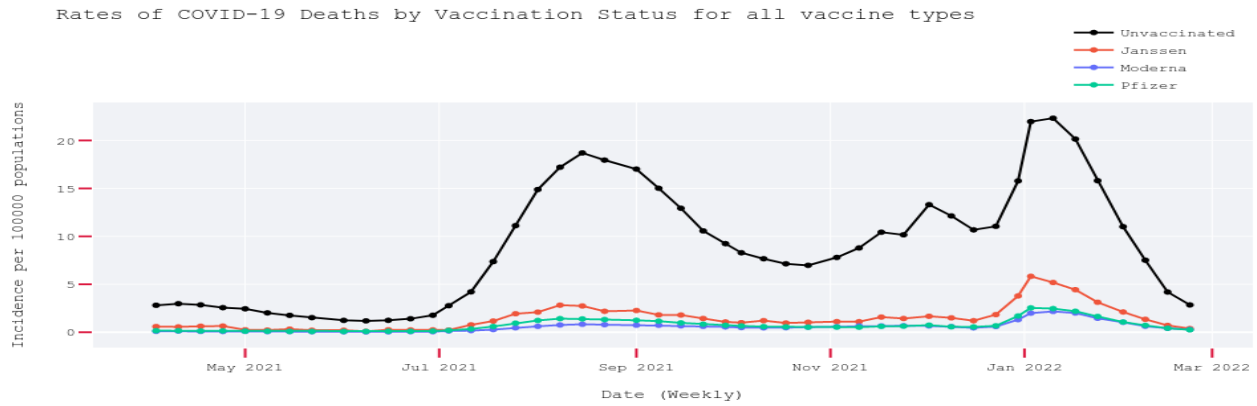


Fig. 5. US - Deaths and Vaccine types

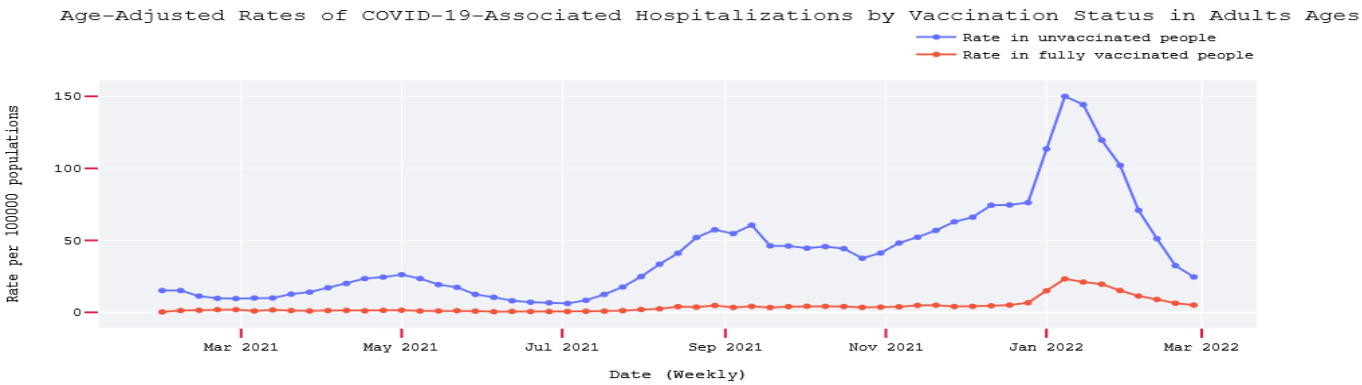


Fig. 6. US - Hospitalizations and Vaccines

the state that were selected by the user from the dataset that was created after joining [3] and [4] as shown in Figure 10. We use dual Y-axis as the range of the values for the two fields are very different and so it makes sense to use secondary Y-axis to make a clear distinction between the two values. One can hover/zoom in the data points to see the exact values in the visualization. We have included a selectbox so that the end user can change the state as well as the COVID-19 variant from that selectbox and visualize the different trends in the visualization for different states in the US for different variants of COVID-19.

- Deaths w.r.t vaccinations across the US (state level)
  - ✦ We use Dual-Axis to overlay ”symbol map” over ”maps” in each state of US where ”symbol map” contains the number of deaths per state in the form of density circles and ”map” contains the number of vaccinations per state as we can see in Figure 15.
  - ✦ The darker a shaded region in the map, the higher the number of vaccinations in that state, similarly the larger and darker the spot on each state, the higher the death numbers.
- Deaths w.r.t vaccinations across the world (country level)
  - ✦ In the same way as above visualization, as shown in Figure 16 we use Dual-Axis to overlay ”symbol maps” over ”maps” in every country around the world, where ”symbol maps” contain the number of deaths per country in the form of a circle and ”maps” contain the number of vaccinations per country.
  - ✦ The darker the shaded region on the map, the greater the number of vaccinations in that country; similarly, the larger and darker the spot on each country, the greater the number of deaths.
- Deaths vs vaccinations for five countries that recorded highest deaths in the world
  We show bar graphs (Figure 17) for five countries with highest deaths throughout COVID period: European Union, United States, Brazil, India and Russia, showing comparison of deaths and vaccinations in these countries, We also show the data for China, as we can see a very big relationship between vaccinations and deaths.

## IV. Discussion

In this sections, we present our findings from the data visualizations discussed in the Results section along with its significance to our presented hypothesis. We also point out some of the limitations of our data visualizations and suggest

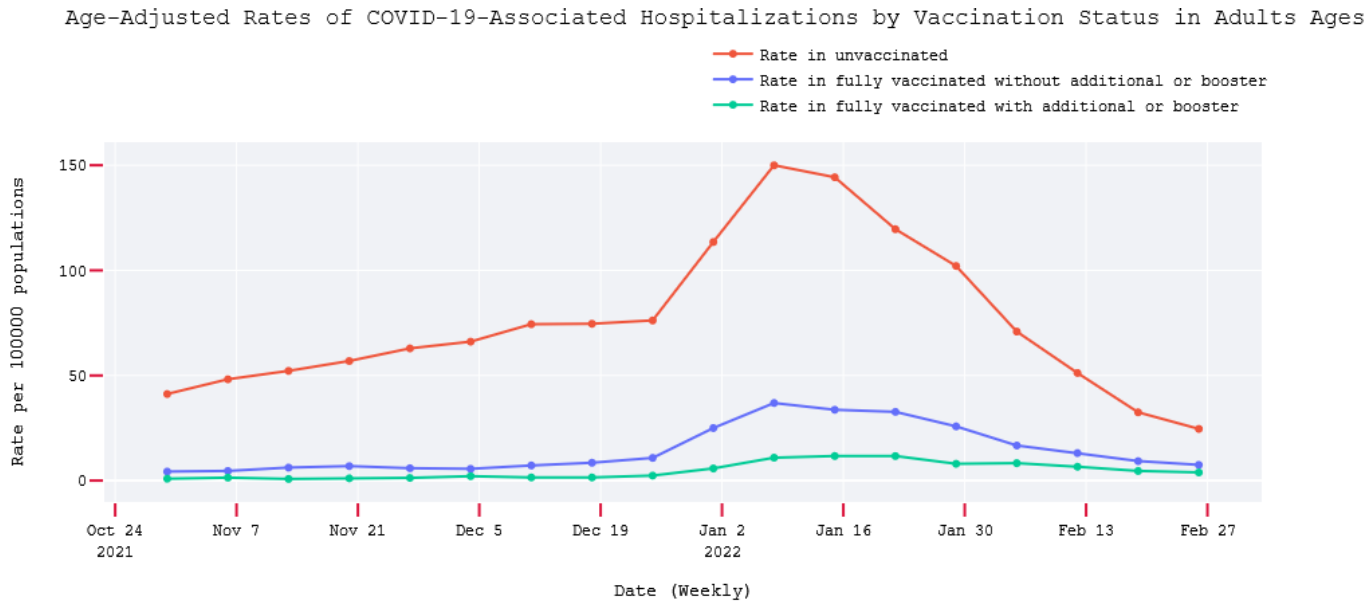


Fig. 7. US - Hospitalizations and Vaccines (Booster)

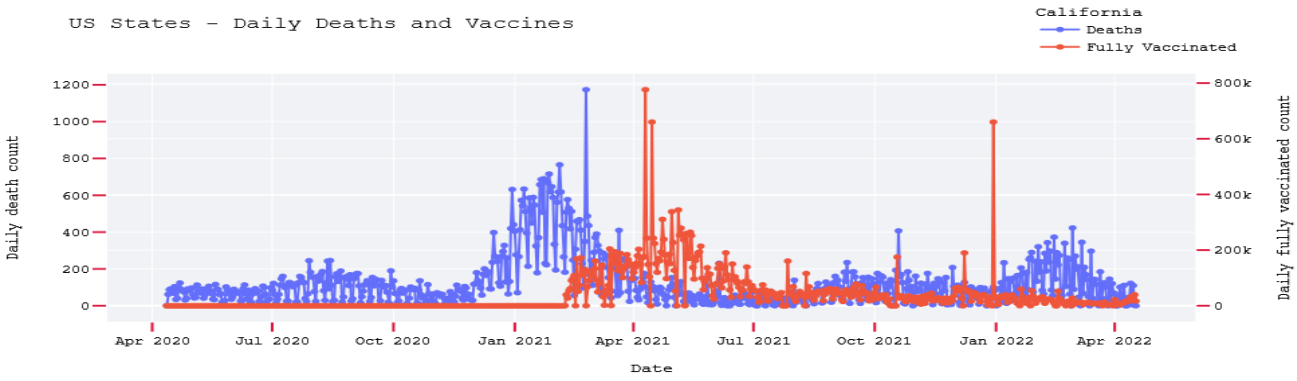


Fig. 8. US State (California) - Daily Deaths and Vaccines

some future work that can be carried out to make the research on this topic more comprehensive.

### A. Findings

The following are some of our findings as well as interpretations from the data visualizations that were discussed in the Results section:

- Cases and Deaths w.r.t vaccinations across the US (country level)
  - ✦ How does the death rate vary with vaccination across the US?
    We can clearly see from the Figure 2 that the *death rate for unvaccinated people is quite high as compared to the fully vaccinated people*. It can also be clearly seen in the Figure 4 that **the death rate for the unvaccinated people is very high as compared to the fully vaccinated people and people who are fully vaccinated along with a booster dose**. Moreover, we see that the people who have taken the booster dose have a lower death rate as compared to the fully vaccinated people who are yet to take a booster dose. All these findings correlates with our hypothesis that the mortality/death rate will be lower for the vaccinated people.
  - ✦ How effective are the vaccines against getting a COVID-19 case across the US?
    In the Figure 1, we can observe that the *rate of cases for unvaccinated people is relatively higher as compared to the fully vaccinated people*. It can also be clearly seen in the Figure 3 that **the rate of COVID-19 cases for the unvaccinated people is very high as compared to the fully vaccinated people and people who are fully vaccinated along with a booster dose**. Moreover, we see that the people who have taken the booster dose have a lower

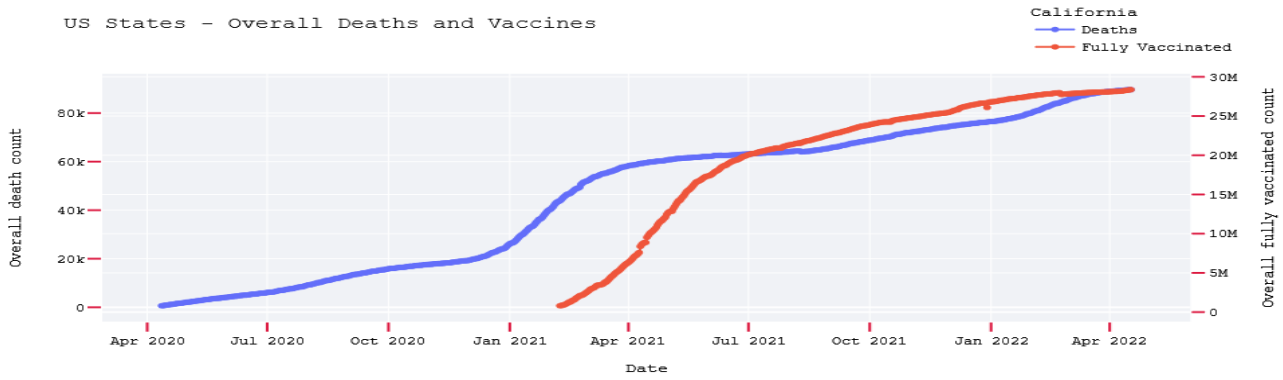


Fig. 9. US State (California) - Overall Deaths and Vaccines

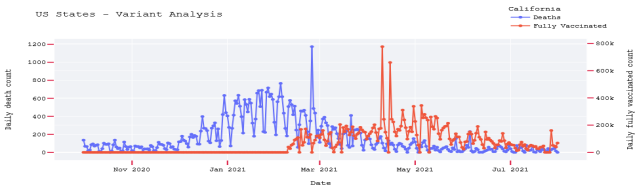


Fig. 10. US State (California) - Delta Variant

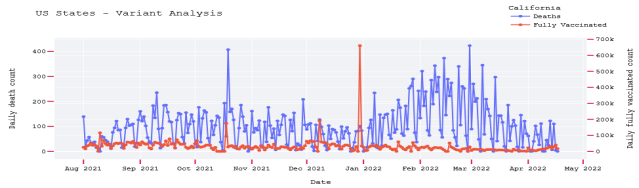


Fig. 11. US State (California) - Omicron Variant

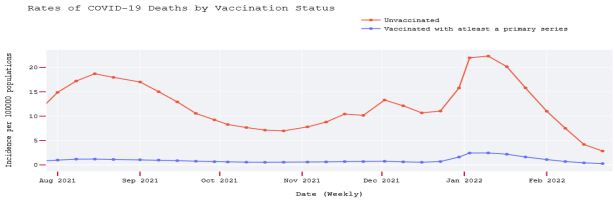


Fig. 12. US - Daily Deaths and Vaccines: Omicron Variant

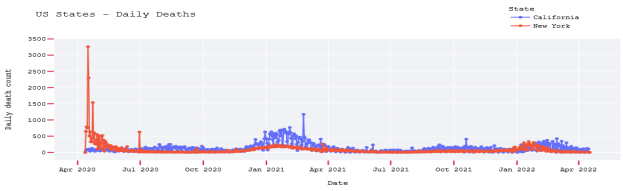


Fig. 13. US State (California and New York) - Daily Deaths

rate of cases as compared to the fully vaccinated people who haven't.

Further, we can see that the people who are vaccinated also have been reported to be COVID-19 positive but the number of such instances are less as compared to the cases reported for the unvaccinated people. This fact can be attributed to the newer variants of COVID-19 which proved the vaccines to be less effective (which is discussed later on) but it reduced the severity of the symptoms. Thus, we can say the vaccinations help against reducing the chances of cases and death if you get a case which is in line with our hypothesis.

- ✦ Which vaccine product is effective to prevent the death against COVID-19?

  We can see from the Figure 5 that *the death rate for people who have opted for Pfizer and Moderna vaccines is similar whereas the death rate for people who opted for Jannsen vaccine is comparatively higher as compared to the other two vaccine products*. Moreover, if we just compare the death rate for the people with all the vaccine product against the death rate of unvaccinated people, we see a huge rise in the death rate for unvaccinated people as compared to the vaccinated people. This finding concurs with our hypothesis presented earlier.
- ✦ How does a vaccine help a particular age group against the death due to COVID-19?

  We observed the death rates as well as rate of cases for different age groups for unvaccinated people along with the vaccinated people and found that *the unvaccinated people in age group 65+ had the highest death and case rate*. We can say that taking vaccinations in general help in surviving against COVID-19 but if the elderly people who are less resistant and considered to be more prone to health problems should definitely take vaccines as it would help them a lot in surviving COVID-19.

- Hospitalizations w.r.t vaccinations across the US (country level)

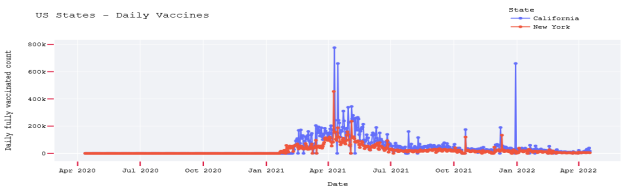


Fig. 14. US State (California and New York) - Daily Vaccines

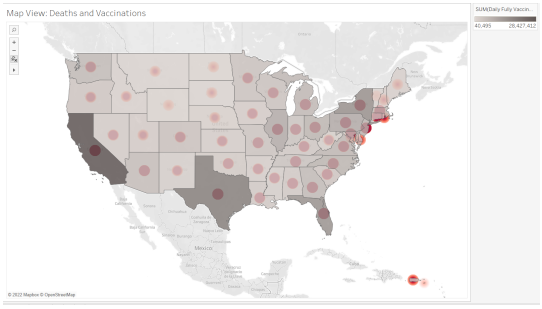


Fig. 15. US Map View - Deaths vs Vaccinations

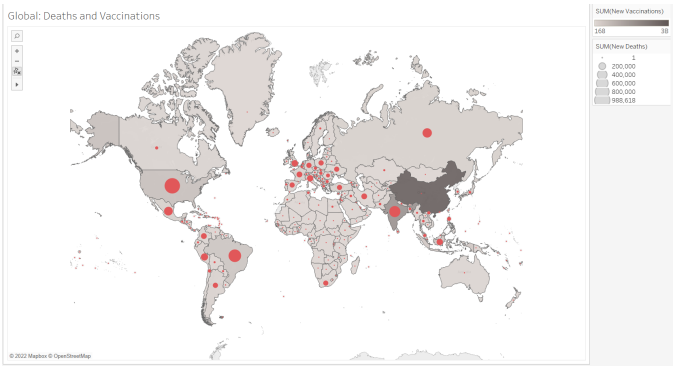


Fig. 16. Global Map View - Deaths vs Vaccinations

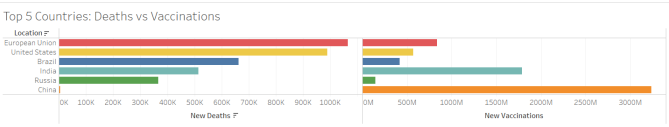


Fig. 17. Top 5 Countries - Deaths vs Vaccinations

- ✦ How does the hospitalization rate vary with vaccination across the US?
  We can clearly see from the Figure 6 that the *hospitalization rate for unvaccinated people is quite high as compared to the fully vaccinated people*. It can also be clearly seen in the Figure 7 that **the hospitalization rate for the unvaccinated people is very high as compared to the fully vaccinated people and people who are fully vaccinated along with a booster dose**. Moreover, we see that the people who have taken the booster dose have a lower death rate as compared to the fully vaccinated people who are yet to take a booster dose.
  Further, we can see that the people who are vaccinated also have been reported to be COVID-19 positive and hospitalized but the number of such instances are less as compared to the cases reported for the unvaccinated people. This fact can be attributed to the newer variants of COVID-19 which proved the vaccines to be less effective (which is discussed later on) but it reduced the severity of the symptoms. Thus, we can say the vaccinations help against reducing the chances of cases and hospitalization if you get a case which is in line with our hypothesis.
- ✦ How does a vaccine help a particular age group against the hospitalization due to COVID-19?
  We observed the hospitalization rates for different age groups for unvaccinated people along with the vaccinated people and found that *the unvaccinated people in age group 65+ had the highest hospitalization rate*. We can say that taking vaccinations in general help in surviving against COVID-19 but if the elderly people who are less resistant and considered to be more prone to health problems should definitely take vaccines as it would help them a lot in surviving COVID-19.

- Cases and Deaths w.r.t vaccinations for all states in the US
  - ✦ From the graph in Figure 13, we observed that *state of California had the highest number of deaths* in the overall period of COVID-19.
  - ✦ In Figure 9, we can observe that as the number of fully vaccinated people starts increasing, the curve showing the number of deaths starts losing its steepness which indicates that *the number of deaths started decreasing as number of fully vaccinated people started increasing*.
  - ✦ Similar trends can be observed in different graphs such as Figure 13 and Figure 14 by plotting multiple states in the same graph.
  - ✦ We also observe almost *identical results for all 50 states* of the US, which indeed validates the findings in our visualizations for overall cases and deaths mentioned in the above sub sections and concurs with our proposed hypothesis.
- Cases and Deaths w.r.t vaccinations during different variants of COVID-19 for US
  - ✦ We show deaths vs vaccinations in the Delta variant phase in Figure 10 state-level. Here we can very clearly see that as the number of vaccinations started increasing (red line), the number of deaths see a sharp decrease (blue line) for California. This clearly indicates that the *vaccinations were highly effective for Delta*.
  - ✦ Whereas, if we observe the same for Omicron vari-

ant in Figure 11 for California and Figure 12 for US, we don't see such effective decline in deaths curve. However, the scale of deaths comparatively is so small, that it proves that **COVID-19 vaccines reduced risks for SARS-CoV-2 infection and COVID-19–associated death** during periods of Delta variant predominance and infection risk during Omicron variant emergence.

- ✦ We can find this out for all states, by zooming in on graphs shown in Figure 1, Figure 2, Figure 3, and Figure 4. Thus, we can say that even though the vaccines have been less effective to newer variant of COVID-19, they have been effective in reducing the severity of the virus and have also helped people to recover early. Hence, we can say that the *vaccines are effective against surviving the COVID-19 to prove our hypothesis again*.

- Deaths w.r.t vaccinations across the US (state level)
  - ✦ From Figure 15, we can observe the states with highest number of vaccinations (the darker the shaded region of the state, the higher are the number of vaccinations) and the highest number of deaths (the larger and darker the circle on the state, the higher the death numbers).
  - ✦ We observe that California has the highest number of deaths and highest number of vaccinations as well.
  - ✦ One thing to notice here is that states, which had high number of deaths, have had higher number of vaccinations as well. One of the reasons for that could be that the number of people residing in the state is high so vaccines must have been distributed in stages and many of people would not have gotten a chance to get vaccinations on time. Also few states had much higher number of deaths in the first phase of COVID i.e., the alpha variant phase.
- Deaths w.r.t vaccinations across the world (country level)
  - ✦ As we can see in Figure 16, we can observe the countries with highest number of vaccinations (the darker the shaded region of the country, the higher are the number of vaccinations) and the highest number of deaths (the larger and darker the circle on the country, the higher the death numbers).
  - ✦ We can clearly spot that China has the highest number of vaccinations and Europe has the highest number of deaths.
  - ✦ We have to keep in mind that population of each country is different, and the death vaccination numbers are with subject to the that.
  - ✦ Looking at the top five countries reporting highest number of deaths all time in Figure 17, we can see that vaccination numbers are higher in countries reporting lesser deaths.
  - ✦ We should also keep in mind here that countries like US and Europe were amongst the first to be hit with COVID waves, when resources were lesser than the patients. Those numbers in itself were very high, compared to the vaccinations administered later on.

### B. Significance

One of the significance of our work is that we have conducted our analysis on the effect of vaccines for the Omicron variant of COVID-19, which have been done by very few studies until now. The other important thing to notice is we have conducted our analysis using the latest data available for COVID-19 cases, deaths and vaccines until 17$^{th}$ April 2022. Lastly, we have developed and hosted a web application [14] that provides a comprehensive data analysis and visualizations of how vaccines play an important role against combating COVID-19 at one place. Through this application, an end user would be able to easily observe and identify the trends for cases, hospitalizations and deaths with regards to vaccinations at different granularity (global, US, states in US).

### C. Limitations

The findings of this work are subject to some limitations. First, the dataset, created by joining dataset [3] and [4], the numbers for cases and deaths used to make certain figures like Figure 8, Figure 9, Figure 15, Figure 16 was used for plotting without considering the actual population of the region. This may make the numbers in the plot look a bit off, however, they can be overcome in the future by considering the population density to make these visualizations. The other visualizations do consider the population and so they can be considered to be correct in the analysis work. Second, we have manually annotated the data to perform the variant analysis based on the timelines (considered 2 weeks of extra data on both sides of the reported timeline) of the COVID-19 virus which might inaccurately classify COVID-19 variants. Third, we are using data from multiple data sources and so variable data linkage may lead to inconsistencies in some of the visualizations. Finally, the dataset used may not contain the data of the overall US population and so it may be difficult to generalize. However, as it covers almost a significant amount of US population, the analysis can be deemed to be true and can be extrapolated as well with certain exceptions.

## V. Conclusion

We have conducted our analysis to see the effect of vaccines at different granularity - Global, US, across different states in the US. In our research, we have compared the death rates for unvaccinated people with the fully-vaccinated and also fully vaccinated people with boosters. Also, we check how the vaccines play an important role in unvaccinated people as well as vaccinated people with regards to COVID-19 cases and hospitalizations. Moreover, we tried to include how effective the vaccine is for different age groups across the US and have prepared data visualizations with different vaccine types. Further, we have tried to perform a study as to how vaccines helped combat the different COVID-19 variants. Thus, we have developed a web application [14] where we deliver the comprehensive analysis of vaccines effectiveness which helped

us validate our hypothesis, i.e., the mortality rate among the unvaccinated people is high as compared to people that are vaccinated.

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