ORIGINAL ARTICLE

A Tale of Two Scenarios: Vaccination's Impact on Covid-19 Trajectories in Jordan

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ABSTRACT

Introduction: The novel coronavirus Severe Acute Respiratory Syndrome (SARS)-Coronavirus-2 (CoV-2) has resulted in an ongoing pandemic and has affected most of the countries around the world. Mathematical epidemic models can be used to predict the course of an epidemic and ensure the significance of vaccination by comparing it to no vaccination. **Materials and methods:** Extended SIR models were used to show and understand the predicted progression of Covid-19 with and without vaccination strategy. SEIRD model was used to predict Covid-19 cases and deaths in the no vaccination scenario while SEIRDV model was used for the vaccination scenario. Parameters were taken from published articles and reports. **Results:** SEIR models indicated higher infection and death rates without vaccination. Number of infected cases reached its peak in the first 100 days of 2021, with a gradual declining in the number of infections and becomes plateaued after day 100 which approximately at the end of March. At its peak, the infection could affect up to about 10% of the population leading to 109,671 deaths in the absence of vaccination but with the effect of social distancing and control measurements taken in Jordan in 2020. Number of infected cases with the effect of vaccination and maintaining social distances reached its peak in the first 10 days of 2022. At its peak, the infection could affect up to approximately 15,629 cases leading to 746 death cases which makes the total of deaths 13,399 cases. **Conclusion:** Vaccination significantly reduced Covid-19 impact, leading to fewer cases and deaths compared to no vaccination.
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Keywords: Covid-19 disease progression, SEIR model, Decision-tree model, Covid-19 vaccination, Jordan

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INTRODUCTION

The Covid-19 pandemic, which began in 2019, was a catastrophic global event that has significantly impacted our lives. In response to its rapid spread, extensive measures have been implemented to manage and contain the situation (1). In the beginning, the effective management of Covid-19 relied primarily on promptly identifying and isolating individuals who are infected. However, movement of these infected individuals from one place to another directly impacted on the transmission of the disease to others, ultimately driving the spread of the virus (2). Subsequently, healthcare systems globally were faced with a tremendous influx of Covid-19 patients. Making matters worse, at that time, scientists' and healthcare providers' understanding of the disease was limited (3). In the context of middle-income countries, the health and economic burden experienced by these countries during the early phase of the Covid-19 pandemic, were high. Having lower level of resources, coupled with large number of populations, made curbing the pandemic using conventional measures such as mask-donning and isolating infected individuals very challenging.

In 2020, the initial global response to Covid-19 vaccines was a mix of hope, urgency, and logistical challenges. The development and approval of Covid-19 vaccines were unprecedentedly fast. Vaccines such as Pfizer-BioNTech, Moderna, and AstraZeneca received emergency use authorizations within months of the pandemic's onset, thanks to global collaboration and significant funding (4). The initial vaccine candidates, like Pfizer-BioNTech and Moderna, reported high efficacy rates (over 90%) in clinical trials (5). However, the cost of vaccines varied widely. mRNA vaccines like Pfizer-BioNTech and Moderna were more expensive compared to others like AstraZeneca and Johnson & Johnson, raising concerns about affordability for low- and middle-income countries (6). The cost-effectiveness of the vaccine rollout also depended on the healthcare infrastructure's ability to handle mass vaccination campaigns, including cold chain storage and distribution logistics (7). While the upfront costs of purchasing and distributing vaccines were high, the long-term economic benefits of controlling the pandemic were also considered, because the vaccines were expected to reduce the burden on healthcare systems and enable the reopening of economies (6).

This article will discuss projection of Covid-19 pandemic, with and without the use of Covid-19 vaccine, in Jordan. Jordan is a middle-income country located in the Middle East. It occupies an area of approximately 92,000 km2 (4). The total population above 18 years old at the end of 2021 was 6,611,180 (8). The first confirmed case of Covid-19 was recorded in Jordan on March 3,2020 (9, 10). Due to strict measures adopted by the government, the Covid-19 cases at the early stage were under control, and outcomes of the pandemic were relatively trivial. These measures include mandatory home quarantine and movement restriction, closure of the country's borders, universities, schools, restaurants, and tourist sites; screening of symptomatic contacts, and also night-time curfew (11,12). The Jordanian military and police were requested to oversee the execution of the laws requiring the use of masks, gloves, and social separation in public areas (13). Government hospitals in Jordan were completely in charge of caring for Covid-19 patients at the start of the epidemic, and these facilities were already at capacity before the pandemic. However, early in September, land boundaries were opened for trucks importing goods from neighboring countries, and truck drivers could mix with the population without taking quarantine measures seriously, which led to an aggressive first wave in September 2020, and resulted in 170 000 cases and 2000 deaths (14). By autumn 2020, Covid-19 positivity rates in Jordan reached high levels. A more aggressive second wave of Covid-19 transmission started late January and peaked in mid-March 2021 resulting more than 9,500 cases during peak days (10). The Covid-19 cases in Jordan reached their peak between the first and second quarter of 2021, with daily registered cases first reported in the hundreds and then in the thousands (15). At the peak of the pandemic, the lack of beds and ventilators, as well as the paucity of nurses and other qualified medical professionals in public hospitals, as well as worker burnout and psychological suffering, put a burden on the health system (16).

Similar scenarios were observed in the Arab region, where neighboring countries also implemented strict measures to control the spread of Covid-19. For example, in Saudi Arabia which located to the south of Jordan, the first Covid-19 case was reported on March 2, 2020. As the virus spread, the government implemented stringent measures to control its transmission. These included partial lockdowns, curfews, suspension of religious activities such as prayers in mosques, and a complete lockdown during the Eid holidays. The economic impact of these measures was significant, leading to job losses and reduced incomes for many businesses. The lockdown period lasted approximately three months in some sectors, while other sectors experienced longer duration. Employees were encouraged to work from home until August 2020 to facilitate social distancing (17). However, 262,772 confirmed cases of Covid-19 with 2672 deaths were reported up to July 25, 2020 (18).

Jordan was among the countries that got a head start on immunization efforts, which began in January 2021. Given that older people over the age of 70 years were at a significant risk of serious disease and death in case they contract Covid-19, they were prioritized for vaccination. Healthcare professionals were also picked for vaccination based on their age as there were some Covid-19-related deaths among them (19). Initially aimed at vaccinating 20% of the population, the program's goal expanded to over five million residents, representing more than 80% of the population over 18 years old. This increase was facilitated by securing bilateral agreements and ensuring additional vaccine supplies. Consistent with Jordan's commitment to an equitable Covid-19 response, the vaccination plan encompasses all segments of the population, including refugees and migrants (20). However, no studies comparing the Covid-19 progression with and without the effect of vaccination in Jordan.

In order to project or predict the progression of the Covid-19 pandemic, epidemiological models that employ mathematical techniques can be used. An example is the SIR (Susceptible, Infectious, Recovered) model. The SIR model divides the population into three compartments, namely Susceptible (S) comprising of individuals who are at risk of contracting the disease, Infectious (I) comprising of individuals who have contracted the disease and can transmit it to others, and Recovered (R), comprising of individuals who have recovered from the disease and are assumed to be immune (21).

This model has several varieties and are extensively used in epidemiology to simulate the spread of epidemics (22). Other compartments can be added to formulate more comprehensive model such as SEIRD model, in which each individual is either susceptible (S), exposed (E), infected (I), recovered (R), or dead (D). These models can be used to show and understand the variations of diseases transmission among different scenarios or communities, such as estimating epidemiological parameters like the basic reproduction number and infection fatality rate, simulating the impact of interventions like quarantine and isolation, and making short-term forecasts of confirmed cases and deaths (21). Nonetheless, there are several limitations of the SEIRD model, such as it assumes homogeneous mixing of the population, ignoring network structure, difficult to identify all model parameters from short-term data on confirmed cases and deaths, sensitive to initial conditions and may produce different long-term forecasts even if short-term fits are similar, and deterministic in nature making it unable to capture irregular patterns like multiple peaks in some regions.

The objective of this study is to provide evidence on the effectiveness of vaccination for Covid-19 pandemic comparing the projection in the number of deaths due to Covid-19, without and with the effect of vaccination in Jordan.

MATERIALS AND METHODS

Study setting

The study location was the Hashemite Kingdom of Jordan. Its neighbors are Syria to the north, Iraq to the east, Saudi Arabia to the south, and Palestine to the west. The total land area of the country is approximately 89,342 square kilometers, and the population (all residences including refugees) was estimated to be 11,057,000 people as the end of 2021 according to the Jordanian department of statistics. Jordan is an upper-middle-income country with an estimated JOD 31,014.496 billion gross domestic product (GDP) per capita in 2019 (24)

Study design

This study was divided into two parts: first part involved the disease progression without considering the effect of vaccination and the second part forecasted the disease progression with the effect of vaccination. In the first part, the model considered the susceptible population, individuals in the exposed and infectious stages, as well as those who had recovered, in addition to the those who died. Key parameters such as the transmission rate, incubation rate, recovery rate and death rate were incorporated to estimate the spread and dynamics of the disease.

In the second part, the model was used to incorporate the effect of vaccination on Covid-19 progression. The extended SEIR model in this part accounted for the additional compartment of vaccinated individuals. The vaccination rate and efficacy were considered in the model to assess their impact on reducing susceptibility and curbing the transmission of the disease. The data of both models were analyzed by using R software version 4.3.1.

Models used

Two models, both extensions of the SIR model, were used in this study. The first model, the SEIRD model, was employed to predict Covid-19 cases and deaths without the influence of vaccination. The second model, the SEIRDV model, was utilized to predict Covid-19 cases and deaths with the effect of vaccination. These models were adapted from previous studies (20,32). The dynamics of these models are governed by a system of ordinary differential equations (ODEs) that describe the rates at which individuals transition between compartments. These models are preferred over others because they allow for the inclusion of additional compartments or modified parameters, enabling better adaptation to specific disease characteristics or population dynamics, thus making them flexible tools for epidemiological modeling.

Part one: Covid-19 progression without vaccination
The SEIRD model divided the Jordanian population into five compartments: S(t), E(t), I(t), R(t) and D(t). S(t) represents the number of persons in the population who are susceptible to the Covid-19 but have not yet contracted it at time (t), E(t) represents the number of persons that have been exposed to the virus at time (t), and they move to I(t) at the time (t) when they became infectious. I(t) represent the infected persons with the Covid-19 virus at time (t), and they can infect those who are in S(t). R(t) represents the recovered persons who have been infected and then recovered at time (t), and D(t) represents the number of deaths who were infected with Covid-19 virus and die at time (t). Figure 1 below shows the compartments of the SEIRD model and the movement of individuals between these compartments.

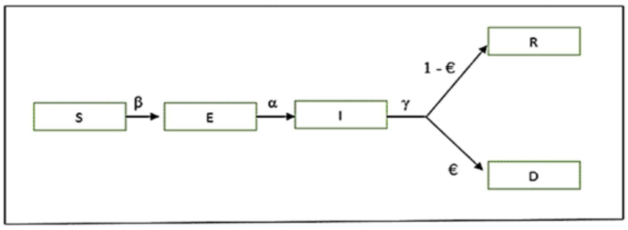

Figure 1: SEIRD model

The relationship of these compartments is controlled by the following ordinary differential equations (21):

$dS/dt = (-\beta S I) / N$
$dE/dt = (\beta S I)/N - \alpha E$
$dI/dt = \alpha E - \gamma I$
$dR/dt = (1 - €) \gamma I$
$dD/dt = € \gamma I$

The used parameters in these equations are as follows. The beta (β) is the rate at which people an infectious person infected per unit of time (transmission rate). To comprehend the infectious disease, a critical parameter of the pandemic which is the basic reproduction number R_0 was used. R_0 is the number of secondary people in a susceptible population infected by a single infected person over the virus's life cycle. It indicates how infectious is the Covid-19. If R_0 more than one, the pandemic is spreading to a wider population and when R_0 less than one, the pandemic is dying out (22) ($R_0 = \beta / \gamma$) (22). R_0 is directly proportional to β(t) and inversely proportional to γ(t) (28) Then β value was obtained.

For the purpose of this study, R0 of 2.16 (29) was used which was calculated in Jordan. This R0 indicated that every infected person can transmit the Covid-19 virus to 2.16 people every 6 days (incubation period which is explained below), and it reflected social distancing and control measurements implemented in 2020 in Jordan. Hence, β was calculated based on the relationship between the R0 and the removal rate (γ) ($\beta = R_o \gamma$) (30). R0 = 2.16 therefore, $R_o = \beta / \gamma$ then, $\beta = R_o * \gamma$ at the end, β = 2.16 * 0.1 hence, β = 0.216

The alpha (α) is the rate at which exposed individuals become infectious (latent-to-infectious rate) (incubation rate). (α = 1/ average incubation period) (2). The incubation period was 6 days (26) Hence, α = 1/6 = 0.1666. The gamma (γ) is the rate at which infected individuals recover or die (removal rate) (γ=1/ F, whereas the average duration of infection removal is denoted by F (27) According to a review paper conducted between January to august 2020, the average duration of infectiousness is 10 days (32). Hence, γ = 1/10 = 0.1

The epsilon (€) is the rate at which infected individuals die (death rate) which was calculated by dividing the total of deaths due to Covid-19 by the total of confirmed cases. Hence, € = 0.0130

The equation of each compartment illustrates how the persons move from one compartment to the following one. The SEIRD model started from S(t) to E(t) to I(t) and then either to R(t) or D(t). This makes sense because an individual can either be recovered or dead, but not both. Therefore, βSI, as shown in the dS and dE equations, demonstrated the number of susceptible persons who got infected with Covid-19 virus, however, they still in the incubation period (before the onset of symptoms) and the negative sign at S compartment indicated that these number of persons were deducted from the total number of susceptible and added to the E compartment which lies behind the reason of having positive sign of the βSI in E compartment. The α E demonstrated the number of exposed persons who became infectious after completed the incubation period and the onset of symptom started (i.e., they moved from E to I). γ I demonstrated the number of persons who got removed either because of recovery or death. Those people were divided into two compartments, they die (that is why in dD a positive sign for the rate of death (f) due to Covid-19 multiplied by rate of removals multiply by number of infected people). The remaining of (γ) apart from (f) which equals (1-f) multiply by the rate of removals and then multiply by the number of infected, were added to R compartment representing the number of recoveries.

The last required issue to complete the model was the initial numbers of compartments:
• The total population (N) is the sum of all compartments which can be illustrated by the following formula N = S + E + I + R +D
• Total population of Jordan as of the end of 2020, 10,511,553 (33)
• Initial number of susceptible (S0) = 10,511,553 (total population) – (22,574 (E0) +20,109 (I0) +270,551(R0) +3,801 (D0)) = 10,194,518.
• Initial number of exposed (E0) = 22,574 (it was calculated based on a suggestion from (34) that initial E = the total of infected persons in the last six days which was taken from an online opensource database * 2.399. Hence, 9,410 * 2.399 = 22,574.59) (35)
• The initial number of infected I0 = 20,109, is number of active confirmed cases taken from daily report of MoH Jordan on 31 December 2020 (36)
• Initial number of recovered (R0) = 270,551, which is total number of recoveries taken from daily report of MoH Jordan on 31 December 2020 (36)
• Initial number of deaths (D0) = 3,801, is total number of deaths due to Covid-19 on 31 December 2020 taken from an online opensource database. The reason behind using this date is that in January 2021, Jordan has started the vaccination campaign against Covid-19. So, the goal was to include data before the effect of vaccination.

Part two: Covid-19 progression with the effect of vaccination
Alongside the SEIRD model described earlier, an additional compartment, denoted as V (SEIRDV in Figure 2), has been introduced to account for the impact of vaccination on the progression of Covid-19. V(t) denotes the proportion of individuals who have been vaccinated and transitioned from the susceptible (S) compartment to the vaccinated (V) compartment. Figure 2 below shows the compartments of the SEIRDV model and the movement of individuals between these compartments.

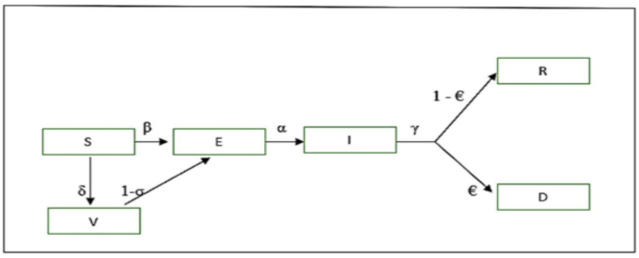

Figure 2: SEIRDV Mode

These compartments are controlled by the following ordinary differential equations (32):

$dS/dt = (- \beta SI)/N - \delta S$

$dE/dt = (\beta SI)/N - (\alpha E) + ((1-\sigma) \beta VI)/N$

$dI/dt = \alpha E - \gamma I$

$dR(t)/dt = (1 - €) \gamma I$

$dD/dt = € \gamma I$

$dV(t)/dt = \delta S - ((1-\sigma) (\beta VI))/N$

$N = S + E + I + R + D + V$

dS/dt represents the rate of change of susceptible individuals (S) over time. It is influenced by βS(t)I(t) which represents the number of susceptible persons become infected by encountering infectious individuals (I) (negative sign) and δ S represents the number of susceptible individuals got vaccinated (V).

dE(t)/dt represents the rate of change of exposed individuals (E) over time. It is influenced by the following factors: βS(t)I(t) which represents the number of susceptible individuals become exposed by meeting infectious individuals (positive sign). α E(t) represents the number of exposed individuals progress to the infectious state. (1-σ) βVI represents the number of vaccinated persons who were inefficacy (σ represents the efficacy of vaccine, then 1- σ represents the remaining of population whose vaccines were ineffective).

dI(t)/dt represents the rate of change of infectious individuals (I) over time. It is influenced by α E represents the rate at which exposed individuals progress to the infectious state and γ I represent the rate at which infectious individuals recover or die.

dR(t)/dt represents the rate of change of recovered individuals (R) over time. It is influenced by the rate of recovery (1 - €) multiplied by the removal rate (γ), then multiplied by the infected people (I), which ultimately represent the number of infectious individuals recovered and transitioned to the recovered compartment.

dD(t)/dt represents the rate of change of deceased individuals (D) over time. It is influenced by the death rate (€), multiplied by the removal rate (γ), multiplied by the infected people (I), which represent the number of infected individuals deceased.

dV(t)/dt represents the rate of change of vaccinated individuals (V) over time. It is influenced by δ S represents the number of susceptible individuals become vaccinated and (1-σ) βVI represent the number of vaccinated individuals become exposed to an infected person (due to inefficacy). Table I below shows the summary of the parameter values for the SEIRDV model.

Table I: Summary of parameter values for the SEIRDV model

Parameter	Value	Remark	Source
Basic reproductive number (R_0)	1.3	This R_0 represents the situation of implementing vaccination with social distancing	(29)
Transmission rate (β)	0.13	Transmission rate (β) is the rate at which people an infectious person infected per unit of time	$\beta = R_0 * \gamma$
Incubation rate (α)	0.1666	Incubation rate (α) is the rate at which exposed individuals become infectious (latent-to-infectious rate) (incubation rate)	
Removal rate (γ)	0.1	Removal rate (γ) is the rate at which infected individuals recover or die (removal rate)	

CONTINUE

Table I: Summary of parameter values for the SEIRDV model (CONT.)

Parameter	Value	Remark	Source
Death rate (€)	0.011883	Death rate (€) is the rate at which infected individuals die (death rate)	Calculated by dividing the number of deaths over the number of confirmed cases.
Vaccination rate (δ)	0.014 per day of susceptible persons	Vaccination rate (δ) is the rate of vaccination per day among susceptible	Assumed
Vaccine efficacy (σ)	mRNA = 0.95	Vaccine efficacy (σ) is the rate at which vaccinated people develop immunity against virus	(30)
N	11,057,000	N is the population size	Jordanian department of statistics
S_0	6,028,073	S_0 is initial number of susceptible individuals	Calculated based on the other initial numbers
E_0	27,737	E_0 is the initial number of exposed individuals	2.399 * number of infected cases in last six days from year 2021 in Jordan
I_0	1,845	I_0 is the initial number of infected individuals	Infected at the end of 2021
R_0	1,018,896	R_0 is the initial number of recovered individuals	Total recoveries
D_0	12,653	D_0 is the initial number of dead individuals	Total deaths in Jordan in 2021
V_0	3,967,796	V_0 is the initial number of vaccinated individuals	Vaccinated people at the end of 2021

The reason behind selecting the study of R0 while reflecting both vaccination and social distancing in this part is due to the conclusion of (39) vaccination with social distancing measures was always preferred to strategies without social distancing.

Ethical Clearance

Ethical approval was obtained from The Ethics Committee for Research Involving Human Subjects (JKEUPM) at University Putra Malaysia (reference number: JKEUPM-2022-289), and the Ministry of Health Jordan (reference number: MOH/REC/2021/255), and permission from Prince Hamzeh Hospital, Jordan.

RESULTS

Part one: Covid-19 progression without vaccination

Using the data and parameters as detailed in the first part above related to the SEIRD model, the following graph was generated (Fig. 3). The graph shows that the number of infected cases reached its peak in the first 100 days of 2021, with a gradual declining in the number of infections and becomes plateaued after day

100 which approximately at the end of March. At its peak, the infection could affect up to about 10% of the population leading to 109,671 deaths in the absence of vaccination but with the effect of social distancing and control measurements taken in Jordan in 2020. Figure 3 below which was generated by the SEIRD model, shows the evolution of the different compartments (S, E, I, R, D) over time. Each compartment represents a certain population which represented by a specific-colored line.

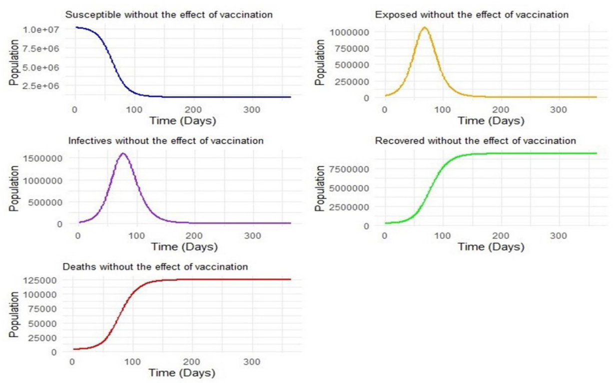

Figure 3: Evolution of the different compartments (S, E, I, R, D) over time.

Part two: Covid-19 progression after vaccination

By using the data and parameters, as detailed in the method section above, in the SEIRDV model, the following graphs was generated (Figure 4). This figure shows that the number of infected cases with the effect of vaccination and maintaining social distances reached its peak in the first 10 days of 2022. At its peak, the infection could affect up to approximately 15,629 cases leading to 746 death cases which makes the total of deaths 13,399 cases. Fig. 4 below which was generated by the SEIRDV model, shows the evolution of the different compartments (S, E, I, R, D, V) over time. Each compartment represents a certain population which represented by a specific-colored line.

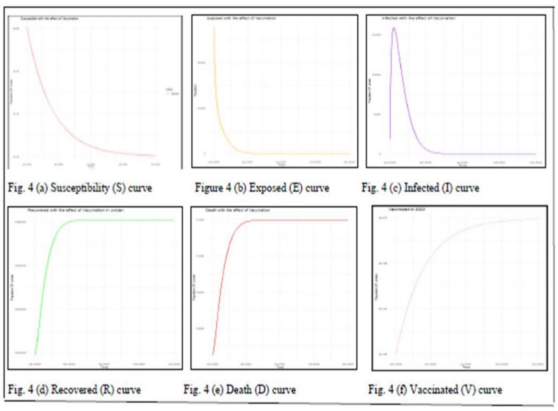

Figure 4: Evolution of the different compartments (S, E, I, R, D) over time with the effect of vaccination.

DISCUSSION

These models showed the predicted projection of Covid-19 infection, with and without the effect of vaccination in Jordan. In the situation where vaccination was not used, the SEIRD model showed that at the peak of infection, it was estimated that approximately 10% of the population was affected by Covid-19, and leading to 109,671 deaths.

With the incorporation of the vaccination, the SEIRDV model estimated that the infection could affect up to approximately 15,629 individuals, bringing the total number of fatalities to 13,399 cases. In short, the vaccination against Covid-19 could avert over one million infected cases and 96,272 deaths compared to without vaccination.

The results of these SEIRD and SEIRDV analyses have important implications for public health in the future in a number of ways. Firstly, the results may be used in policy development. With the help of the study, policymakers may understand the possible effects of vaccination campaigns on a quantitative basis, where decision-makers can gain a better understanding of how crucial it is to maintain high vaccination rates in order to contain future outbreaks by contrasting scenarios with and without vaccines. Secondly, the results may aid in the allocation of resources, as the forecasts emphasise how vital vaccinations are to halting the spread of disease and lowering the cost of healthcare. The allocation of resources, such as money, healthcare infrastructure, and workforce planning, to locations where they can have the biggest effects is made possible by the information provided. Thirdly, the knowledge gained from the SEIRD and SEIRDV models can help shape future pandemic preparedness plans. Timing and prioritisation of vaccine distribution are two examples of more effective intervention strategies that public health officials can create by having a better understanding of how immunisation affects disease dynamics. Fourth, the results show the critical role immunisation plays in the prevention and control of infectious illnesses, which can be used to highlight the benefits of immunisation in lowering morbidity and transmission, so strengthening public health message and overcoming vaccine scepticism. Additionally, this research offers insightful information on the epidemiological dynamics of Covid-19 progression in various settings, which may improve models and forecasts for upcoming infectious disease outbreaks and advance our understanding of disease dynamics in general.

This study has several limitations. Firstly, the models (SEIRD and SEIRDV) assume homogeneous mixing of the population, meaning that every individual has an equal chance of coming into contact with any other individual. This ignores the complexities of real-world social networks and varying contact rates among different groups. Secondly, the basic SEIRD model typically does not account for the possibility of re-infection. In reality, immunity may wane over time, and individuals who have recovered from the disease may become susceptible again. Thirdly, this model often does not incorporate age-specific transmission and progression rates, which can be crucial for diseases that affect different age groups differently Lastly, relying on data from the region which might be different from real-data in Jordan which was due to the scarcity of data at that time.

CONCLUSION

The SEIRD and SEIRDV models for Covid-19 in Jordan highlighted vaccination's critical impact. Without vaccination, the SEIRD model predicted 109,671 deaths and over 1 million Covid-19 cases, hence overwhelming the healthcare system. With vaccination, the SEIRDV model projected 746 deaths and 15,629 cases, preventing over one million Covid-19 cases and 96,272 deaths. These findings point out the vital role of vaccination and effective healthcare planning in managing public health crises.

Based on these findings, it is recommended that vaccination efforts are prioritized to mitigate the spread of the virus and reduce its overall impact on public health. It is also recommended to maintain adherence to public health measures even with widespread vaccination. This is essential because the long-term effectiveness of vaccination depends on factors such as vaccine coverage, the emergence of new variants, and the duration of immunity. Therefore, sustaining vaccination efforts, monitoring the evolving situation, and adapting strategies accordingly are crucial for a successful transition towards post-pandemic normalcy. Additionally, efforts should be made to ensure that all demographics, including marginalized communities, refugees, and migrants, have equal access to vaccination. This requires implementing policies that remove barriers such as cost, transportation, and misinformation, ensuring that no group is left behind in the vaccination effort. Additionally, it is recommended to invest in strengthening healthcare systems to handle potential future outbreaks. This includes training healthcare workers to manage vaccination programs and sharing data, resources, and best practices to enhance the worldwide response to Covid-19 and ensure widespread vaccine distribution.

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