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Modified SEIR and machine learning prediction of the trend of the epidemic of COVID-19 in Jordan under lockdowns impact

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ABSTRACT

Susceptible exposed infectious recovered (SEIR) is a fitting model for coronavirus disease (COVID-19) spread prediction. Hence, to examine the effect of different levels of social distancing on the spreading of the disease, a variable was introduced in the SEIR equations system used in this work. We also used an artificial intelligence approach using a machine learning (ML) method known as deep neural network. This modified SEIR model was applied on the available initial spread data until June 25th, 2021 for the Hashemite Kingdom of Jordan. Without lockdown in Jordan, the analysis demonstrates potential infection to roughly 3.1 million people during the peak of spread approximately 3 months, starting from the date of lockdown (March 21st). Conversely, the present partial lockdowns strategy by the Kingdom was expected to reduce the predicted number of infections to 0.5 million in 9 months period. The analysis also demonstrates the ability of stricter lockdowns to effectively flatten the graph curve of COVID-19 in Jordan. Our modified SEIR and deep neural network (DNN) model were efficient in the prediction of COVID-19 epidemic sizes and peaks. The measures taken to control the epidemic by the government decreased the size of the COVID-19 epidemic.

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1. INTRODUCTION

Various baffling cases of lower respiratory tract infections were reported in December 2019 in China, leading to the identification of coronavirus with genetic linkage to the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) that the World Health Organization (WHO) called coronavirus 2019 (COVID-19). In mainland China, the spread of the epidemic with a basic R0 (reproduction number) is approximated to be from 2.2 to 3.3 and a death rate of roughly 2.3% [1]–[6]. It was found that in China, COVID-19 patients were mostly males of more than 30 years of age. The general symptoms of COVID-19 include fatigue, dry cough, and fever. Furthermore, laboratory anomalies were primarily in the form of lymphopenia [7]–[9]. A study among COVID-19 patients in Singapore found mild respiratory tract infection as the most frequent occurrence, while few people were needing supplemental oxygen [10]. Effective SARSCoV-2 vaccines and antibody-based treatment medicines are necessary to cope with this disease. At present time, more than 50 antibody approaches, as well as 90 vaccines, have been tested by responsible bodies globally [6], [11]–[13]. Still, there are uncertainties because the virus is still not fully understood [14], [15], and as COVID-19 is spreading fast, finding effective vaccines or other therapeutic agents is rather impossible for the time being [6], [16]. Lockdowns in addition to other stringent measures (e.g., curfews) have been the common measure in many countries worldwide to assure social distancing [16]. The increasing number of COVID-19 cases has burdened the existing health system in many countries beyond its capacity [16], [17]. Without vaccination and appropriate treatment, flattening the pandemic curve is the only option in dealing with it.

The spreading of COVID-19 might be predicted via several types of techniques, like data-driven analysis, soft computing approaches, and more recently, mathematical models [18]–[21]. In this regard, the applications of susceptible infectious removed (SIR) and susceptible exposed infectious recovered (SEIR) models have been comprehensively reported in the literature [17], [20]. Relevantly, in [21], the artificial neural network (ANN), as well as the ensemble empirical mode decomposition (EEMD) based method, was applied by utilizing COVID-19 time series data. Additionally, in [22] in the context of Hungary, the prediction of death rate as well as afflicted persons was demonstrated utilizing machine learning. Pertinently, Bhardwaj and Bangia in [23] applied hybrid soft-computing methods in the determination of COVID-19 spread risks. Artificial intelligence (AI) techniques have been used in many studies for imaging data acquisition, segmentation and diagnosis for COVID-19 [24]. Where these techniques are previously applied to other artificial intelligence problems and demonstrated their effectiveness in solving them [25]–[34] [35], [36]. Lockdowns are an effective strategy in slowing down the transmission of COVID-19. However, the original SEIR epidemiological model overlooks this factor. Meanwhile, the present study illustrates how the lockdown levels can inhibit the transmission of COVID-19 in Jordan. As demonstrated, about 3.1 million individuals may be affected during dissemination peaks around 2 months following lockdown in Jordan without implementation of lockdowns (March 21st). On the other side, with the lockdown approach in Jordan last year (ρ=0.6), the projected peak infections are about 500,000 in 6 months, beginning March 2nd, 2020. Through expanding the classical SEIR model, the current study examined the effect of lockdown on the spreading of COVID-19. Specifically, the present study added the effect of different lockdown levels on virus transmission to the model. Therefore, this study aims to describe the role of lockdowns on COVID-19 transmission in Jordan. The remaining of the article is organized: the existing data for COVID-19 in the Jordan context are presented in section 2, while section 3 presents the materials and methods in the prediction model, whereas the results and discussions of the modified SEIR models application in COVID-19 spread prediction in Jordan discussed in section 4. Lastly, section 5 presents a brief conclusion of the paper.

2. THE COVID-19 SPREAD IN JORDAN

Jordan is a Middle Eastern country. It is the home of 11 million people. Following WHO's announcement of COVID-19 as a pandemic, a health alert was issued by the Jordanian Ministry of Health, requiring SARSCoV-2 infection to be tested for individuals with flu-like symptoms and those who have recently visited endemic countries [37]. The first case of COVID-19 in Jordan was confirmed on March 2, 2020. Following that, Jordan launched extensive contact tracing policy, screening of symptomatic contacts, hospital isolation, and asymptomatic contacts' quarantine. Nationwide stringent lockdown, as well as a nightly curfew, were also imposed as additional measures. Additionally, Jordan sealed off its borders and all travels in and out of the country were prohibited beginning March 15, 2020 [37]. Then a Royal Decree was issued on March 17, 2020 to sanction the enactment of the National Defense Law. Owing to their robustness, these measures were able to flatten the curve and decrease the impact of the disease on public health. History has taught mankind that pandemics would usually reach peak points and then disappear. Somehow, COVID-19 might be an exception because the human population is now double the size compared to 5 decades ago. This means that COVID-19 has a higher potential of people-to-people disseminates and can cause early peak hit that is too much for the current health infrastructure of many nations to handle [6], [38]–[40], and the problem is exacerbated by the density of urban areas -3/4 of the world's population resides in urban regions-making the people especially in these areas even more vulnerable to pandemics [41], [42]. To efficiently handle the spread of the disease, future infrastructure developments need to be more efficient in detecting, reporting, and analyzing numerous symptoms of the disease so that spreads on-premises can be prevented [6].

The spread of COVID-19 is primarily caused by population density, local progression of COVID-19, society lifestyle, in addition to other factors. In Jordan for instance, there were 10.2 million people, 90.5% [43] of which, living in urban areas. On the other hand, in Japan, there were 126.4 million people, and 92% of them resided in urban areas [6]. Based on these comparisons, it can be presumed that the spread of disease would be faster in Japan as opposed to in Jordan. Similarly, in Saudi Arabia, 84% of 38.8 million people live in urban areas. Correspondingly, 83.9 million people were living in Iran and 76% of these people were urbanites, while 76% of Turkey's population of 84.3 million were urbanites [6], [44]. It is difficult to determine the exact spread rate of COVID-19 and its spread is at different rates at different geographical localities [17], [45]. Somehow, on average, the human-to-human spread of this disease is by a factor of 1.5-3.5 [6], [17], [46], and with the presumption of the consistent case increase at the pace recorded for June 2020, hospitals at Jordan may face immense strain for per peak cases. On March 2nd, 2020, Jordan documented its first confirmed COVID-19 case [47] and by April 3, 2020, there were 310 cases [48] as shown in Figure 1. On the other hand, Japan saw a much slower rate of spread whereby it took 71 days, as opposed to 31 days for Jordan, for Japan to record 2400 confirmed cases-on 16th January 2020, Japan reported the first COVID-19 confirmed case [6]. Similarly, Saudi Arabia recorded 2400 cases within 34 days. As opposed to Jordan, Saudi Arabia, and Japan, the disease spread in Iran and Turkey was much faster, whereby both countries documented 2400 confirmed cases only within 14 days. By April 5, 2020, 36 countries had documented at least 2400 cases, with an average of roughly 39.1 days for these countries [6]. However, considering the different policies for testing and reporting of countries, the available data may not reflect the real number of cases that these countries have.

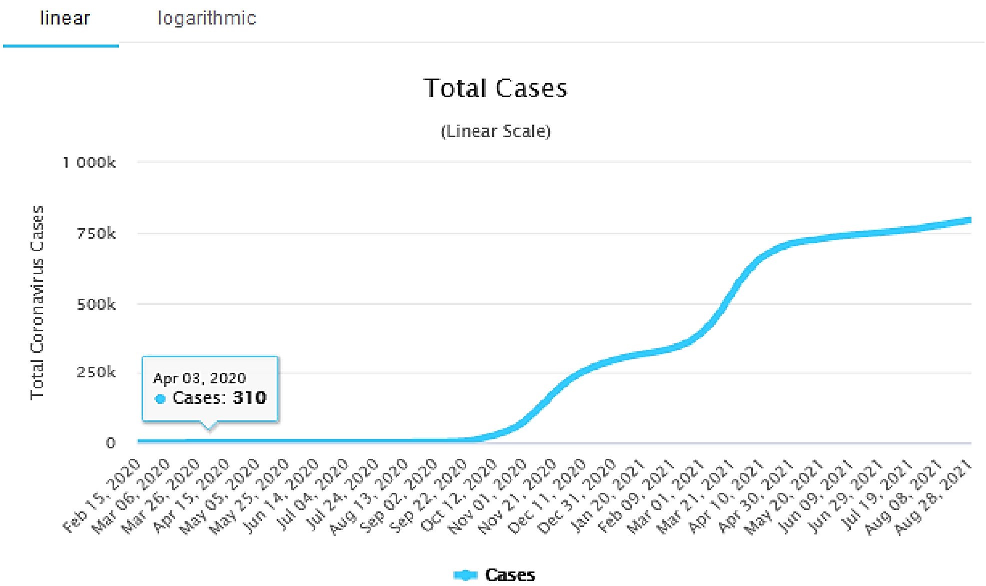

Figure 1. Total COVID-19 cases in Jordan [48]

Stringent restraint policies have been imposed by Jordan in controlling the spread of COVID-19 [49]. Utilizing the dataset provided by John Hopkins University [44], the spread of the is reported in this study. Notably, no model can accurately predict its spread, but according to simulations performed, this study shows that even partial lockdowns in Jordan may delay with no lockdown in the projected 3 months by 5-6 months. Furthermore, the model shows that effective lockdowns can reduce the number of infected cases in Jordan to less than 0.5 million. Further, when the government imposes social distance to inhibit the spread, the actual cases may significantly differ from the projection, and this becomes the study's shortcoming. Notably, the rapidly spreading COVID-19 has significantly burdened the current health infrastructure of many nations, and the system was unable to handle an increasing number of patients confirmed with COVID-19. Cities struggle to compress the pandemic curve while planning to deal with the epidemic.

As of April 9th, 2020, Jordan was seeing a growth in the number of COVID-19 cases. In addition, the number of people losing their life to COVID-19 was increasing. As of the date mentioned, the reported number of deaths in Jordan was in 1 digit but it was expected to increase. The unprecedented global spread of COVID-19 and non-availability of vaccine or correct treatment have placed nations, Jordan included, in a hard situation in their attempts to delay the spread. Most of these countries have opted for the imposition of lockdowns and other preventative measures. The present study predicts that, with a precarious supposition of no-social distancing, after 3 months of the date of the first reported case, up to 3 million people would be expected to get infected in Jordan. However, considering the imposition of an appropriate night curfew and lockdown policy in main cities in the kingdom to confine the transmission, such is not likely to happen. Based on the features of the Jordanian region and considering the population flow, the SEIR model and deep learning model were applied. The actual data were utilized referring to the latest literature and reports, the new model's parameters were fitted. Lastly, the model was applied to analyze and estimate the epidemic trend.

3. MATERIALS AND METHODS

In the last three decades, several mathematical models have been developed or applied to analyze the spread of infectious diseases. The main aim is to predict the spread within a population in a certain region or country. Some of which are stochastic models and others are deterministic models. As Nakamura *et al.* [50] stated that when random inputs variation is required, a stochastic method can be used as a tool to estimate probability distributions of potential results. It depends on the chance variations of exposure to the virus and other pathological factors. So, a stochastic method determines statistical disease transmission for small or large populations. On the other hand, Brauer and Castillo-Chávez [51] stated that deterministic methods and compartmental mathematical models are used when coping with large populations, as in the case of COVID-19. A deterministic model allocates people to various areas of the population, each representing a certain phase of the disease. Using differential equations, the model is formulated as derivatives from a mathematical expression of transition rates from one class to another. Considering the time and deterministic disease process such models are built based on the differentiability of the population size in a certain compartment. Therefore, for COVID-19, in this study, we will use the compartmental (e.g., deterministic-based) models for predicting the infection rate among the Jordanian population in the coming Autumn season 2021.

3.1. SEIR model

Many derivative models have been applied to analyze the spread of epidemic over 40 years such as SEIR, susceptible exposed infectious susceptible (SEIS), susceptible infectious removed (SIR) and maternally-derived-immunity susceptible infectious recovered (MSIR). Please refer to [41], [52]–[55] for more details. They are based on several compartments, such as the case of SEIR, which is based on four compartments that are discussed: i) $dS/dt = -\alpha SI$; ii) $dE/dt = \alpha SI - \mu E$; iii) $dI/dt = \mu E - \beta I$; and iv) $dR/dt = \beta I$.

S denotes the susceptible populations, *E* is individuals subjected to the illness with no signs (*aka*. latent carriers), *I* is individuals infected of COVID-19, and *R* is individuals who are recovered. Other parameters include $\propto$ is transmission rate; μ is incubation rate, and β is recovering rate (moving infected individuals into recovered compartments). The SEIR model has been previously applied by Naresh *et al.* [56] to predict HIV/AIDS spread and obtained a reasonable accuracy, also it has been lately applied for COVID-19 spread prediction in Saudi Arabia, Spain, and Italy by [6], [57]. So, the SEIR model can be adopted and applied to COVID-19 disease spread prediction among the Jordanian population. The SEIR model is a nonlinear ordinary differential equations (ODEs) system that works arbitrarily: i) deterministically the model assumes that everyone in the population will eventually get infected by COVID-19 and ii) the model considers that the spread remains for a short period, meanwhile, the population is constant. Also taking into account the number of births or deaths. Thus, it can be said that: *S*+*E*+*I*+*R*=*Total number of populations*=*Constant*.

The SEIR model can be applied to a large population such as the Jordanian population which is 10,203,134 as of July 3, 2021 [58]. In our simulations we use the exact number of the population for *S*, then initializing *I*=12 (confirmed infected cases at the starting of lockdown on 21st of March 2020) and initializing *R*=0 (sum of 0 recoveries and 0 death s). Then, as Hamzah *et al.* [17] suggested, the initial *E*=2.399*12 (exposed population) is calculated using 2.399*number of patients who get infected in the previous six days. We also assumed that *D*=2.3 and *Y*=5.2 as recommended in [17]. Our simulation ignores birth rate for *S*, and death rates for *S*, *E*, and *R*. Therefore, the projections are just approximated values and not precise figures. Other predicted factors such as the probability of transmission of the virus from an infected to a susceptible person ($\propto$) are evaluated. The estimated reproductive number is used to compute this value (2.3) which lies between [2, 2.5]. Using $R_0=\propto/\beta$ we obtain $\propto=1$. In addition, parameter μ is the rate of exposed persons becoming contagious. It equals 1/*Y* whereas the average incubation duration is denoted by *Y*. $\beta=1/D$, whereas the average duration of infection recovery is denoted by *D*. Since symptoms can take up to fourteen days to occur post-exposure, the main factor that transmits the virus is the affected group [38], [40].

3.2. SEIR and DNN model

The SEIR and deep neural network (DNN) model was developed: using a systematic observation, the time series analysis (trend prediction) was accomplished using the data. It aimed to predict the factors sequence, such as the number of infections over time. Based on the employed analysis methods, the time series prediction model is divided into simple sequential average, market life cycle prediction method, seasonal trend prediction method, exponential smoothing method, trend prediction method, weighted sequential average, weighted moving average, and moving average. Recently, with the emergence of machine learning (ML), particularly deep learning theory, DNN has been used to predict and process many time series problems. Considering the traditional time series model that was utilized to fit the process of spread of similar pneumonia cases, this study used the Jordanian infection statistics, using the SEIR model to adjust the probability of spread, rate of incubation, the probability of death or recovery to obtain a basic training data set. Therefore, the DNN model was utilized to study and predict the trend of COVID-19 transmission.

DNN is composed of highly correlated processing and computing units, that are similar to the biological nervous system. Though the simple structure of the single neuron, the behavior of the nervous system which is composed of a huge number of interrelated neurons is very rich. The DNN has the ability of parallel adaptive learning and computing. The DNN is more efficient and accurate compared with the traditional prediction methods e.g., decision trees and linear regression, this is mostly because of its characteristics. DNN is efficient in describing the complex system characteristics that are adaptive, strongly nonlinear, and difficult to be expressed by a precise mathematical model. The DNN model was initially trained on a huge dataset to decrease the loss function, Then the parameters in the network were calculated and updated to predict the new data. The equation (1) represents the linear relationship between output and input, where xi denotes the input data, *wi* denotes the weight parameter, and *b* denotes the bias [59].

$$Y = \sum_{i=1}^{m} wixi + b \tag{1}$$

In this study, the DNN model is composed of a nine-node input layer, a 32-node hidden layer and a 1-node output layer. The Tanh activation function was utilized to increase the model fitting degree to the nonlinear model. Furthermore, dropout was employed to alleviate the overfitting phenomenon of the model, the Tanh activation function's formula is described [59].

$$f(x) = \frac{1 - e^{-2x}}{1 + e^{2x}} \tag{2}$$

The architecture of the DNN model used in this study is illustrated in Figure 2. The loss function can determine the model quality quantitatively to choose the optimal model. This study used the mean square error loss function as illustrated by the (3) [59].

$$SE(y_{\_}, y) = \frac{\sum_{i=1}^{n}(y - y_{\_})^2}{n} \tag{3}$$

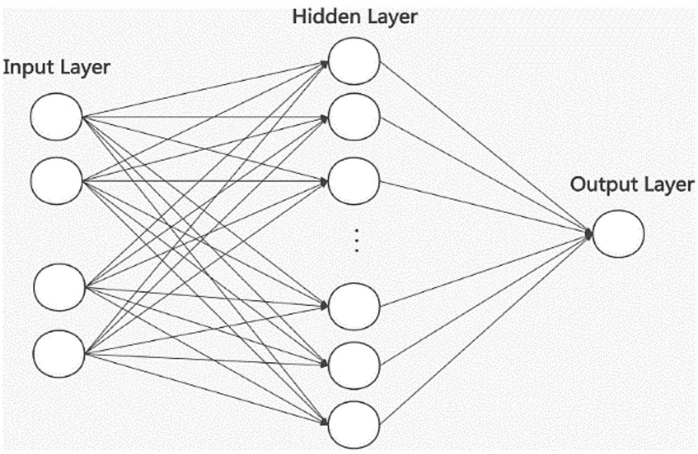

Figure 2. A generic DNN model architecture

Based on the loss function, the weight in the minimum loss direction must be updated for obtaining the optimal model, for this purpose the adaptive moment estimation (Adam) optimizer was employed to update the weight. which is an adaptive learning rate optimization algorithm. By computing the gradient's first-moment estimate and the second raw moment estimate, an independent adaptive learning rate is constructed for different parameters. The formula is addressed [59]:

– Update the biased first-moment estimate

$$m_{t,i} = \beta_1 . m_{t-1,i} + (1 - \beta_1) . g_{t,i} \tag{4}$$

– Update biased second raw moment estimate

$$V_{t,i} = \beta_2 \,.\, V_{t-1,i} + (1 - \beta_2) \,.\, g_{t,i}^2 \quad (5)$$

– Update parameters

$$w_{t+1} = w_t - n_t = w_t - l_r \,.\, \frac{m_{t,i}}{1-\beta_1^t} / \sqrt{\frac{V_{t,i}}{1-\beta_2^t}} \quad (6)$$

We employed the DNN model to process and predict time series problems for predicting new infections number over time. The epidemiological parameters of COVID-19 are incorporated, such as the transmission probability, incubation rate, the probability of death or recovery. Because of the relatively small dataset, we developed a simpler network structure to prevent overfitting. Also, the Adam optimizer was used to optimize the model with the batch size of one, mean square error as the loss function, and iterated for 500 times.

4. RESULTS AND DISCUSSION

Neural networks are more accurate in prediction compared with traditional prediction methods. So, in this study, the DNN model was used to assist the prediction process of the traditional SEIR model with more parameters and meaningful correlations between significant attributes from the dataset. DNN model must train the bias parameter and the weight parameter *w*, out of a total of 60 attributes, the following 15 attributes were normalized and selected for the data inputs of the predictive model based on the dataset's labels: confirmed total cases, new daily cases, total death cases, new daily death cases, total cases per million, new cases per million, total deaths per million, new deaths per million, reproduction rate, total population, population density; cardiovascular death rate; diabetes prevalence; hospital beds per thousands; total vaccinations per hundred. Other unutilized attributes are incomplete (e.g., vaccination rate or the total number of vaccinated people: 2,215,882) or still unavailable for Jordan including intensive care unit (ICU) patients, hospital patients, weekly ICU admissions, weekly hospital admissions, people fully vaccinated, total vaccinations (3,378,945), and people fully vaccinated per hundred. Seeking accurate classification task for the prediction model, it is needed to be selective in considering a handful number of attributes that are significant for the classification. This can be achieved by applying a filter to determine the correlation among those 15 attributes as well as parameters of the neural network training phase. Hence, after passing 15 inputs into the input layer within the DNN model, it selects only highly correlated attributes to assist the SEIR model's prediction onwards into the hidden and output layers of the DNN. Here, using the principal component analysis (PCA) method, further selections are employed for 6 attributes out of 15 where they showed a significant impact on the prediction. These attributes are: confirmed total cases (749,046), total death cases (9,710), reproduction rate (0.55-1.8), total population (10,203,140), population density (109,285), and total vaccinations per hundred (between 12/1/2021-26/6/2021).

The DNN's output layer will provide 6 outputs for the SEIR model (*S*: susceptible, *E*: exposed, *I*: infectious, *R*: recovered, *H*: healer, *D*: death) based on the following parameters: *alpha*: healing rate, *beta*: infection rate, *gamma*: inverse of the average latent time, *delta*: the rate at which people enter in quarantine, *lambda*: cure rate, *kappa*: mortality rate, *N*: the total population of the sample, *E0*: initial number of exposed cases, *I0*: initial number of infectious cases, *Q0*: initial number of quarantine cases, *R0*: initial number of recovered cases, *D0*: initial number of death cases, *t*: vector of time, *lambdaFun*: anonymous function giving the time-dependent recovery rate, and *kappaFun*: anonymous function giving the time-dependent death rate.

First, the data were normalized by min-max normalization excluding the number of epidemic cases. In (7), X_{max} is the sample data maximum value and X_{min} is the sample data minimum value. Also, an appropriate scale was set to scale the cases number to match the range of 0 to 1.

$$X = \frac{X - X_{min}}{X_{max} - X_{min}} \quad (7)$$

After that, the normalized number of cases X was entered into the model for training and calculating the loss by SE equation. And the parameters w and b were updated. After 10,000 epochs training, loss tends to be stable. The network output for that day is the new cases that were locally scaled down. We restored the number of cases is restored by scaling the previous cases. Then the results are obtained. The proposed model predicted new cases continuously in each region over the next three days. Then, the previous data was summarized and the capital city Amman was selected with strong representation.

We have extracted the Jordanian COVID-19 instances from the dataset of John Hopkins University's and analyzed the trends started from March 2nd, 2020 (the first identified positive case confirmed in Jordan). To include the effect of social distancing in COVID-19, we next utilized a modified SEIR model and made predictions for the same preemptive measures. The number of confirmed cases and infection rates vary significantly. It is understood that these numbers were perturbative because of preventive actions and avoiding social interaction. Jordan is known as a tourism and regional transit hub which makes the country even more vulnerable to foreign visitors' infections. Jordan has forced lockdowns and suspended many events and activities to limit the chance of social interactions. We estimate the spread of these spread measures and the consequences of them in the following days after June 25th, based on current data up to June 25th, 2021, including the spread peak in the first quarter of 2021. This summer, the number of positive cases rapidly started to decrease and therefore the country ended the strict lockdown and moved into a partial lockdown (mere nightly hours). However, considering the critical number of cases climbing rapidly in the past 6 months, it is feared that the situation repeats its massive pressure on the Jordanian hospitals from per peak cases. So, the third wave of spread is expected in the coming October 2021. In addition to considering social distancing, the only hope for the situation to get better and eliminating the spread is by vaccinating the majority of Jordanians as well as non-Jordanians, which is currently well-performed by the Ministry of Health (around 3,617,998 administered doses until mid-June 2021 including 1,246,619 people fully vaccinated, 12.34% of the population fully vaccinated) [60].

We used the SEIR model for Jordan ignoring social distancing, the prediction is shown in Figure 3 where the peak is expected 35 days after implementing the lockdown, while in reality, the number increased greatly at the beginning of 2021 due to the implementation of the lockdown at the right time. Figure 3 shows the prevalence rate for only 4 parameters (S, E, I, R) across 70 days, where time is days by the fraction of the population.

On the other hand, using the SEIR/DNN prediction model, Figure 4 shows the prediction for the incidence rate across 70 days with 6 parameters (or rather attributes: S, E, I, R, H, D). It shows that the peak would be within the first 30 days when forcing partial or no lockdowns. The death rate would be very small across 70 days, and the whole situation would be stable in 11-11-2021 for all parameters.

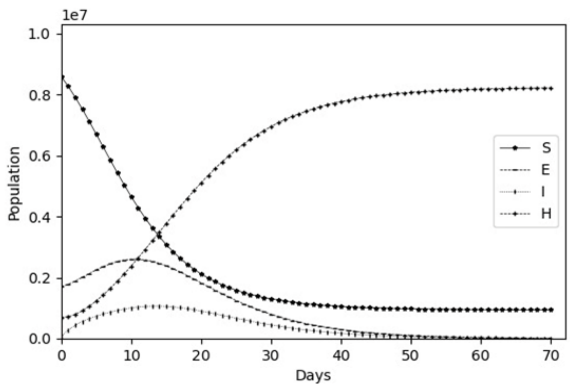

Figure 3. SEIR/DNN predictions for Jordan without social distancing (prevalence rate)

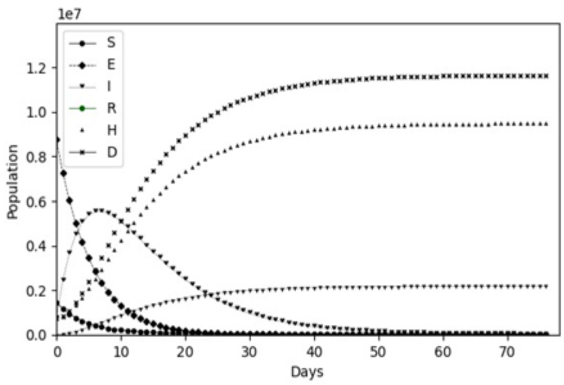

Figure 4. SEIR/DNN predictions for Jordan with 6 parameters (incidence rate)

Again, if SEIR/DNN prediction model applies 7 parameters including ΔI (the mode for I0-I), Figure 5 shows the prediction for the incidence rate across 70 days with 7 parameters. It shows that the peak would be within the first 30 days when forcing partial or no lockdowns. Death rate would be very small across 70 days, and the whole situation would be stable in 3-11-2021 for all parameters a week earlier than using 6 parameters.

The effect of prediction of the DNN model is illustrated in Figures 4 and 5. It is noted that the ML model with the data of population can predict the epidemic situation well in Jordan. Our simulation shows that the peak would have dramatically increased within the time window of exactly 22 days (from June 26 to July 11, 2021) without the lockdown, and the health system would be under great pressure. The reproduction rate has a significant impact when the rate is less than one, the spread vanishes quickly. In contrast, if the rate is higher than one, the spread increases extremely quickly. Frequently handwashing lowers the likelihood of infections and proper social distancing ensures containment of the exposed population. The SEIR/DNN model shows that the number of cases can be lowered to below 1 million if social distancing is imposed properly in Jordan. The nature of COVID-19 is, however, more complex and a prediction model must consider more significant factors such as death rates and rate of vaccination for more accurate predictions [61], [62]. Therefore, we have considered these factors in our model. Due to insufficient information on the daily vaccination rate or vaccination per million in Jordan, the rate of vaccination is thus implicitly included in susceptible and recovered individuals. Table 1 shows the detailed parameters setting used in our simulation for the SEIR/DNN model. They are categorized into 3 classes: group parameters, natural propagation parameters, and artificial parameters. Figure 6 shows the prediction for the next 6 months of 2021 after halting the lockdown measures and without social distancing.

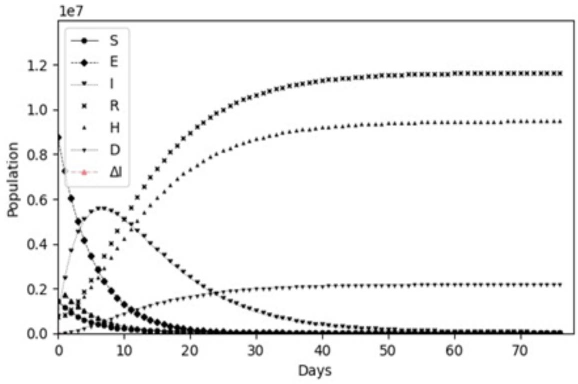

Figure 5. SEIR/DNN predictions for Jordan with 7 parameters (incidence rate)

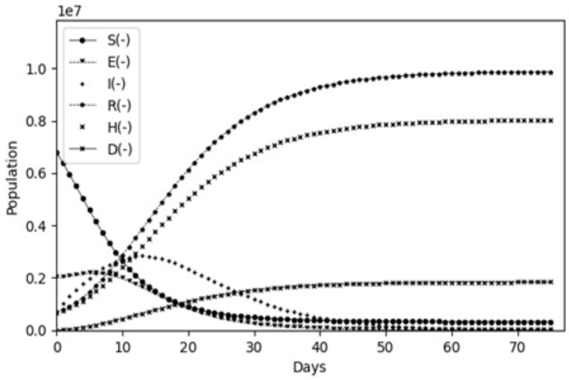

Figure 6. Modified SEIR/DNN model for COVID-19 spread predictions for the next 70 days

Table 1. Initial parameters setting for the SEIR model starting from June 26, 2021

Category	Parameter	Value
Group	Total (N)	10203140
	Susceptible (S)	1444384
	Exposed (E)	8758756
	Infective (I)	749046
	Healer (H)	739336
	Recovered (R)	739336
	Death (D)	9710
Natural propagation	Infection rate (λ)	0.231
	Incidence rate (σ)	0.2
	Healing / Recover rate (γ)	0.1
	Loss antibody rate (μ)	0
	Latent days (day)	5
	Healing rate (α)	0.8
	Death rate (β)	0.2
Artificial	Quarantine (Q)	0.7
	Medical ability	1.2
	Cure gain	1.250

Under no lockdown in Figure 6, during the peak spread around three months from the date of initial lockdown in Jordan about 3.1 million individuals are possibly infected (March 21st, 2021). In Figure 6, It is clear that the death rate increases dramatically within the period of 40 days, and the peak of deaths persists at the same rate for the following 30 days or so. So halting lockdowns is not an option that reflects the medical ability or cure or care of infected people. To better understand the impact of lockdown in Jordan, we run our experiments on infections under different levels of lockdown commencing from no lockdown to partial to strict as shown in Figures 7 and 8.

The limitation of our approach is that lockdown levels may vary, thus substantially interrupting results. A heavily strict lockdown (which is currently not an option) means that the number of peak infections may reach fewer than half a million and would come after 9 months. In the case of a partial lockdown, around 500,000 individuals may be infected within 1 month, beginning on June 26th, 2021. Figure 7 showed the infection rate is decreasing for about 1 week, then rising again after 1 month with 1 million infections in total, and eventually decreasing significantly with additional 2 months to mere hundreds of infections. Lastly, in the case of a strict lockdown, Figure 8 showed the infection rate is decreasing rapidly within three months, and eventually the infection fades away. In addition, the death rate is decreasing rapidly in both partial and strict lockdowns. Taking into consideration vaccinating individuals, the exposed population is quickly decreased, and the curve is flattened. When decreasing the infection rate and vaccination, medical infrastructure and capabilities have much space and time to take care of critical infection cases, thus lowering the death rate caused by the COVID-19.

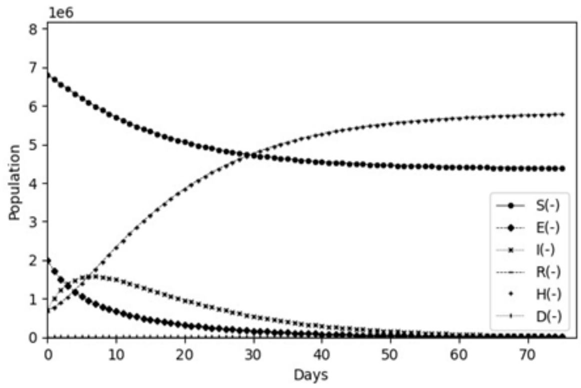

Figure 7. Modified SEIR/DNN model predictions with partial lockdown

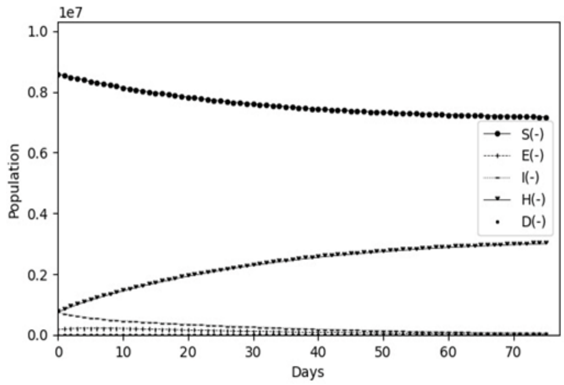

Figure 8. Modified SEIR/DNN model predictions with the strict lockdown

Figures 7 and 8 demonstrate the efficiency and effectiveness of a strict/partial lockdown for the next 70 days starting from June 26, 2021. This simulation has considered quarantine measures, medical ability, and cure gain to achieve the goal of efficiency and effectiveness, please refer to Table 1 for all factors utilized in our simulation. It can be seen that the overall total of infections (including overall score before June 25, 2021) has increased by 281,636 new cases (at its worst), which is better than what is demonstrated in Figure 6 where the infections reached their overall score of 2.4 million. In Figure 3, predictions show that at least 500 thousand cases are possibly infected, while Figure 7 shows half of that score (~200 thousand). Differently, a lockdown would be of a great impact on containment or lowering the rate of infection. Therefore, the government of Jordan could consider partial lockdown in the coming October if the cases relatively increase when schools and universities are fully opened for their staff and students in traditional classes. Nevertheless, a precaution is required by the government and the entire Jordanian residents until the vast majority of the population is vaccinated, which could be achieved by the end of September 2021. Due to the current economic critical situation, the government announced the 1st September will be the end of the current partial lockdown unless the infection situation is changed. Figures 6 and 7 also showed the infection curve is flattened within three months or less depending on whether partial or strict lockdown is implemented.

5. CONCLUSION

The present study applied SEIR (a mathematical spread model) in predicting the COVID-19 spread in the Hashemite Kingdom of Jordan. Before its use for the study purpose, SEIR was modified through the inclusion of lockdowns. It was found that initially, 310 individuals were infected by the 30th day after the date of the first recorded case in Jordan. Taking into account the spread pattern till April 3rd, 2020, the impact of lockdowns, as well as social distancing, was examined. Then, the number of afflicted cases was predicted under different lockdown levels. The results show that with no lockdowns, 3 million individuals were expected to be infected in Jordan by June 2020. Nonetheless, various strategies were being imposed in the Kingdom to restrict the spread. Comparatively, with partial lockdown in Jordan, the number of reported cases was expected to be lower than 500,000 after 5-6 months, beginning March 21st, 2020, and stricter lockdowns can effectively flatten the curve of COVID-19. This also applies to possible situations discussed in the results section starting the simulation on June 25th, 2021 for the next 9 months. The simulation considered a partial lockdown period and vaccination rate. Findings presented that the infection curve will considerably be flattened within 3 months period depending on the lockdown, social distancing, and vaccination rate. The cumulative number of confirmed cases first-order differential analysis was utilized to get the daily number of new cases and interpolation was utilized for outlier’s adjustment. Then the time series data was obtained by setting the step of sequence length time sliding window. Using the data of time slice, the DNN model was the input for training, the training looped 500 times and saved the trained DNN model. The number of new national cases of COVID-19 was then entered into the trained DNN model to get a national forecast for new cases and the trend chart for cumulative cases over 70 days after June 26. Our modified SEIR/DNN model was efficient in the COVID-19 epidemic peaks and sizes prediction. By assisting the SEIR model with more than 4 attributes that are highly correlated through the layers of DNN, the prediction has become more accurate and meaningful deciding the lockdown whether it is partial or strict. Moreover, the AI-based model (DNN) is promising for future epidemics prediction. The control measures implementation after June 26 was predicted to decrease the COVID-19 epidemic size in Jordan, the policy of early detection and strict monitoring must remain in place till the 2021 end.

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