Simulation of the Progression of the COVID-19 Disease in Northwest Syria Using Basic and Adjusted SIR Model

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Editors' office
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Dear Editor-in-Chief,

Please find enclosed our manuscript entitled "**Simulation of the Progression of COVID-19 Outbreak in Northwest Syria Using Basic and Adjusted SIR Model**" For consideration by your journal. This research could be **the first-ever COVID-19 progression simulation in a conflict-affected area using the SIR model**. Furthermore, this study is among the few studies, if not the only one, that **adjusts the SIR model with a confounding factor** to deduce more realistic and intuitive results, on which the hospital utilization was projected in Northwest Syria (NWS). The research results indicate the required resources based on the simulation according to the basic and adjusted SIR model and compare them with the existing resources.

The situation in Syria is very particular. While the number of cases globally increases, the incidence rate of COVID-19 in NWS is dramatically decreasing according to the surveillance system. There is no rigorous evidence that the majority of people in NWS had contracted the diseases, and the number of cases, therefore, is expected to increase, especially with the collapsed health system and lack of basic health determinants. Nonetheless, **the current figures in NWS are far away from the expectations. This study is a valuable initiative to systematically look at the progression of the outbreak in NWS to understand the relevant context of the outbreak in a conflict context**. Furthermore, the research is a fundamental building block from which multiple research questions and assumptions would erupt.

In this study, the evolution of COVID-19 disease in Northwest Syria (NWS); **a protracted conflict area**, and how the SIR model (Susceptible S, Infectious, and Removed R cases) could simulate the progress of the outbreak was discussed over the period from July 9, 2020, when the first COVID-19 case was confirmed, until July 8, 2021. **The study's primary objective is to provide evidence-based answers for burning questions raised by humanitarian actors and decision-makers since the start of the outbreak in NWS**. The research results and recommendations are considered to be crucial for donors and stakeholders to efficiently utilize and channel resources for COVID-19 response in a region witnessing a noticeable decrease in financial and human resources for many years.

Yours sincerely on behalf of all authors,

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Abbreviations:

COVID-19 Community Treatment Centers (CCTCs), Early Warning, Alert, and Response Network (EWARN), Government of Syria (GoS), Intensive Care Unit (ICU), Internally Displaced Persons (IDPs), Northwest Syria (NWS), Ordinary Differential Equations (ODE), Polymerase Chain Reaction (PCR), Preparedness and Response Plan (PRP), Susceptible S, Infectious, and Removed R cases (SIR)

1- Abstract

Background: Syria has been experienced an armed conflict since 2011. At the time of writing, Northwest Syria is outside governmental control and facing the challenges of the COVID-19 pandemic. In this research, we studied the progression of the COVID-19 pandemic in northwest Syria. We studied the impact of wearing facial masks and discussed the results compared to the existing figures and facts.

Methods: Based on available data and using the basic and adjusted SIR model, we estimated the value of the basic reproduction number (R_0) which gives an initial

prediction of the disease progression. We studied the disease progression for one year (from July 2020 to July 2021) and simulated using the basic and adjusted SIR models.

Results: We estimated that the R_0 for 2019-nCoV was 2.38, and the resulted figures were overestimated compared to the reported numbers and data concerning the COVID-19 pandemic. However, when adjusting the model by a preventive measure (in this case, wearing face masks), the results were significantly less and closer to the actual reported numbers.

Conclusions: Hospital utilization throughout 365 days was projected depending on the basic and adjusted SIR model. The pandemic's peak in the studied area was predicted to arise in December 2020. The expected number of cases to be infected and admitted to hospitals and ICU in 365 days was 633636, 1901, and between 1141 and 2090, accordingly.

Keywords: COVID-19, coronavirus, SIR model, pandemic, Northwest Syria, emergency, humanitarian, conflict

2- Introduction

Pounding with limited information and under extreme pressures on the healthcare system since late 2019, the world has been facing the rapid spreading of a novel viral infection, Coronavirus disease (COVID-19), provoked by a new strain of coronavirus, severe acute respiratory syndrome coronavirus 2 (SARS-COV-2). The World Health Organization (WHO) declared a pandemic on 12 March 2020 [1].

The first COVID-19 case in Northwest Syria (NWS) was reported as of July 9, 2020 [2]. NWS refers to the geographical areas controlled by i) the opposition armed groups allied with the Government of Turkey in northern Aleppo, and ii) the Syrian Salvation Government in western Aleppo and Idleb, which is closely affiliated with Hayat Tahrir al-Sham [3].

As of March 2020, the Government of Syria (GoS) controlled more than 60% of Syria [4]. It is estimated that more than three million people are in Idleb governorate, about 1.5 million of whom were internally displaced persons (IDPs) from other governorates and districts. Along with the deterioration of the humanitarian conditions, and by late February 2020, around 940,000 persons displaced from their communities, which were

controlled by the GoS, towards and within Idleb governorate and northern and western Aleppo [5]. The resilience of 4.1 million people living in NWS has been eroded by the prolonged crisis [6]. Governance varies widely across Syria, both within and outside of government-controlled areas.

The health system in NWS has been suffering enormous challenges during the conflict. With many factors weakening its capacities, such as the presence of more than 2.8 million displaced persons, overcrowding and high density of population, and poverty [7].

Attacks against health infrastructure, loss of life, and massive waves of displacements have worsened the humanitarian situation in NWS [8]. Along with the collapse of the health care system, restricted humanitarian access, and overcrowding in IDPs sites, the humanitarian situation in NWS continues to dire, and the number of people in need of aid continues to increase [9]. With the high density of the IDPs in camps, economic collapse, and the lack of sources, many experts and researchers predicted an increased transmission risk, resulting in catastrophic figures overwhelming the ramshackle humanitarian situation in NWS [10]. many studies anticipated that the health system in NWS would not hold for long when the SARS-COV-2 pandemic starts to invade the region [7]

From public understanding to policy legislation, much depends on the data determined by the epidemic progression models that to be interpreted into actionable policies [11]. Epidemiological modeling is a practical approach to simulate disease dynamics. Multiple mathematical models have been used in the literature to understand the epidemiological characters of pandemics [12]. The most common approach to predict epidemic development is the basic SIR model, which is compartmental models of susceptible (S), infectious (I), and removed (recovered and death) (R) cases. This model is composed of a system of differential equations used to predict the dynamics of an epidemic based on predefined parameters, such as the transmission and removal rates [13]. The transmission rate of the disease is significant compared to other types of coronavirus [14]. SARS-COV-2 is described to be very contagious. In fact, COVID-19 is two to three times more contagious than influenza, and infected individuals, even if they are asymptomatic, can transmit the disease to susceptible individuals [15].

The paper explores the progression of COVID-19 disease in NWS over 365 days (from July 9, 2020, when the first COVID-19 case in NWS was confirmed, until July 8, 2021)

employing SIR model. Syria has been announced as a disaster area in 2011 [16], since when there has been a collapse in the health system [17].

Based on SIR model, the study provides an understanding of the progress of the COVID-19 pandemic in NWS and required case management resources (hospitals and Intensive Care Units ICU). The research contributes to the literature of simulating the dynamics of the COVID-19 pandemic, particularly in a conflict emergency setting - Syria. The ultimate objective of this study, besides the added value to the pool of relevant studies, is to provide evidence-based results for the decision-makers, including humanitarian actors, authorities, UN agencies, and donors, to rationally utilize the resources available for COVID-19 response and subsequently, not losing sight of other life-saving services in the conflict-affected region of NWS.

While the number of confirmed COVID-19 cases and deaths has been dramatically increasing globally [18], the figures from NWS might be slightly different. This difference in figures is attributed to various factors that should be investigated more in detail. As a result of the Preparedness and Response Plan (PRP) for COVID-19 in NWS, multiple COVID-19 Community Treatment Centers (CTCCs) and hospitals were established in the area. As of December 15, there are seven hospitals dedicated for COVID-19 cases admission in NWS, with a total capacity of 670 beds and 197 ICU beds [19] [33]. The method of blood sample collection from suspected individuals was, to some extent, explained in the PRP. The blood samples are collected by nurses from the COVID-19 Community Treatment Centers CCTCs and hospitals where susceptible subjects could be detected. Thus, people seeking PCR tests are referred to the nearest CCTC or hospital [20]. NWS Early Warning, Alert, and Response Network (EWARN) relayed that the total number of PCR tests from July 9 to December 15, 2020, was 65637, along with a total of 18949 confirmed SARS-COV-2 cases [21]. It is evident from figure (1) that the more PCR tests, the more positive cases. By referring to figure (2), it could

be inferred that there is a significant correlation between the number of daily PCR tests and positive cases (The value of the coefficient of determination $R^2 = 0.964$ extrapolates a significant linear correlation, and $p < 0.01$). We transformed the number of positive cases to standardized values per 100 PCR tests per day to explore the changes in the number of positive cases on a daily basis. Figure (3) illustrates a peak in the number of standardized positive tests throughout the month of November, which, to a certain extent, matches the predicted peak based on SIR models in this study (figure 4).

Figure 1: PCR tests & daily positive cases of SARS-COV-2

Figure 2: A scatter plot diagram of the correlation between daily COVID-19 PCR tests and positive cases

Figure 3: Cases of SARS-COV-2 by date of onset

Materials and Methods

4.1. Differential equation and basic SIR model

The protective measures against COVID-19 are the main control measures to limit disease spread when no vaccination is available [22]. SIR epidemic disease model was utilized in this study to predict and understand the spread of COVID-19 in NWS applying Ordinary Differential Equations ODE:

$$\begin{aligned}\frac{d(S)}{d(t)} &= -\beta SI \quad (1) \\ \frac{d(I)}{d(t)} &= \beta SI - \gamma I \quad (2) \\ \frac{d(R)}{d(t)} &= \gamma I \quad (3)\end{aligned}$$

Based on the SIR epidemic model, the population consists of three groups; suspected, infected, and removals. We denoted the sizes of these subpopulations at time t by S , I , and R , where:

- S refers to the susceptible cases.
- I refers to the infected and exposed cases.
- R refers to the removals, including recovered and death cases. R for removals is different from R_0 and R_e , where the first one denotes the basic reproduction number and the second one denotes the effective reproduction number.
- β refers to the transmission rate constant.
- γ refers to the removal rate constant.
- t refers to time.

Equations 1, 2, and 3 represent the changes in the size of S , I , and R throughout time. The sum of S , I , and R is the total population. We considered several assumptions to find out the values of the parameters of the ODE. The first assumption is that NWS population N remains constant, and non-covid-19-related deaths and new births are not counted throughout the study timeframe. This assumption proffers the fact that $N = S + I + R$ (4), and therefore, $\frac{d(S)}{d(t)} + \frac{d(I)}{d(t)} + \frac{d(R)}{d(t)} = 0$ (5). The second assumption is that the rate of increase in I is due to contact between I and S . The increase rate is constant and is referred to by β ($\beta > 0$), which is the infection coefficient. The third assumption is related to the removal coefficient γ ($\gamma > 0$), which is constant and refers to the rate of recovery and death. We also assumed that everyone who recovers would gain a long-lasting immunity and not be susceptible to the disease anymore.

Based on our assumptions, the final form of equations 1,2 and 3 became:

$$d(S)_{t+1} = S_t - \left(\beta \frac{S_t}{S_0} * I_t \right) \quad (6)$$

$$d(I)_{t+1} = I_t + \left(\beta \frac{S_t}{S_0} * I_t \right) - \gamma I_t \quad (7)$$

$$d(R)_{t+1} = R_t + \gamma I_t \quad (8)$$

$$S_t = S_0 e^{-R_0 \frac{R_t - R_0}{N}} \quad (9)$$

- S_0 refers to the number of susceptible cases on the first day of the epidemic. Normally, $S_0 = S - 1$ (S_0 is the number of susceptible people at the initial phase of the pandemic. In the context of COVID-19 disease, the whole population is susceptible to the virus at the initial phase without extrinsic factors such as immunization or control measures) [23].

Using the ODE-derived SIR model, we predicted the progression of the COVID-19 pandemic in NWS in this study.

4.2. The basic reproductive R_0 and effective reproductive R_e numbers

The basic reproduction ratio, R_0 , is the classical epidemiological scale associated with the reproductive power of the disease. R_0 tends to be used to refer to the number of secondary infections in a population caused by one initial primary infection. In other words, if a person has a particular disease, then the R_0 value gives how many infections, on average, that person will cause, or how many individuals that person will give the disease to, within the population [24]. For the SIR model, the values of R_0 is calculated based on the equation (10)

$$R_0 = \beta D = \beta / \gamma \quad (10)$$

- D is the average duration of infection and $D = 1/\gamma$, Thus $\gamma = 1/D$ (11)

$$\beta = \tau c \quad (12)$$

- τ : is the transmissibility rate of the disease, i.e., the probability of transmitting the disease.
- c : is the contact rate.

In other words, the transmission rate β is related to the infector's contact rate with susceptible subjects and the probability of transmitting the disease to them.

Regarding the value of the parameter R_0 , the severity of an epidemic can be summarized into two turns:

- $R_0 > 1$: The epidemic increases exponentially. In other words, one infected individual infects more than one individual on average.
- $R_0 \leq 1$: The epidemic will not occur, and the disease will die out without affecting a large portion of the population [25].

Simulating the dynamics of an epidemic through a specific time period can be achieved by estimating the effective reproduction number, R_e . The effective reproduction number is the average number of secondary infections caused by one infection in the same period. , R_e is a variable number that shows time-dependent variation due to the decline in susceptible subjects and the implementation of preventive and control measures. The pandemic is increasing exponentially as long as the value of $R_e > 1$. In return, when $R_e < 1$ it means that the epidemic is dying out [26].

The equation of the effective reproductive number is given as:

$$R_e = \frac{S(t)}{N} R_0 (13), \text{ where } S_0/N \approx 1$$

4.3. Growth Rate

The spread of an epidemic disease depends on the amount of contact between individuals and the possibility of an infected person transmitting it to another person [27]. The parameter λ is a measure of the rate at which new cases are arising. It can be a positive number (the number of new infections is increasing) or a negative number (the number of new infections decreases). The growth rate is driven by a combination of R – the higher the number of cases caused by each infectious individual, the faster the epidemic will grow – and the timescale over which infections occur (generation time or serial interval) [28]. The transmission dynamics of SARS-COV-2 which is attributed to two key parameters, R_0 and the serial interval SI (time delay between the symptom onset of an index infector case and secondary infectee case). The high reproductive number and short serial interval deduce an exponential growth of the pandemic. In the initial phase, the epidemic commonly spread exponentially. The effective reproduction number R_e is a function of the exponential growth rate (λ) and the serial interval [29].

$$R_e = e^{\lambda\mu - \frac{1}{2}\lambda^2\sigma^2} \quad (14)$$

λ is the exponential growth rate.

μ and σ^2 are the mean and variance, respectively, of the serial interval.

3- Results

5.1. Estimating the basic reproductive numbers without control measures

The next step to simulate the progression of COVID-19 is to determine the parameters β and γ that best describe the current evolution of the disease. The estimation was imitated by applying the basic SIR model of Kermack and McKendrick to predict the variation in the differential equations parameter.

For COVID19, the best information on recovery speed comes from a World Health Organization study examining more than 55000 cases in China. They found that for mild illness, the time from the onset of symptoms to natural recovery is, on average, 14 days for mild cases and 6-8 weeks for severe infections [30]. These estimates were also supported in other published studies. Because I is dominated by mild cases, $D = 14$ days is selected in this study. Therefore, it could be said that $\gamma = \frac{1}{D} = \frac{1}{14} = 0.071$.

We reviewed the data of confirmed cases due to infector-infectee contact based on data shared by EWARN in NWS during the period from July 9, 2020, when the first confirmed case appeared until December 4, 2020. The average value of β was 0.17 (min= 0.04 – max= 0.28, with SD= 0.05, CI: 95%). As a result, the value of $R_0 = \frac{\beta}{\gamma} = \frac{0.17}{0.071} \approx 2.38$. The SIR model based on the values of β , γ , and R_0 is illustrated in figure (4).

5.2. The impact of using face masks on the effective reproductive number

COVID-19 has a very high infectivity rate. Two modes of transmission exist: direct and indirect. The transmission via aerosols and droplets is the primary direct mode. In order to control the spread of the virus, it is imperative to reduce human-to-human contact, disinfection of day-to-day objects, and proper self-hygiene (washing hands regularly, proper coughing and sneezing techniques, and use of face masks). Social distancing plays a crucial role in reducing transmission [31]. According to the figures outlined on the COVID-19 response tracking dashboard, Face masks are widely available nowadays in NWS [32]. In this study, we addressed the impact of using face masks on the spread of the virus by investigating how the value of R_e could be changed due to face mask-wearing (R_α : The adjusted value of R_e). In an evidence review study, it was found that wearing masks reduces the effective reproduction number by a factor $\delta = (1 - e\rho_m)^2$, where e is the efficacy of trapping viral particles inside the mask, and ρ_m is the

percentage of the population that wears masks [33]. Thus, it could be concluded that $R_\alpha = R_e \delta$ (15).

Studies tackling the efficiency of the preventive measures against SARS-COV-2 virus are still scarce, according to a literature review research [34]. In this research, fabric and surgical mask performance was evaluated based on their filtration efficiency and mask pressure drop. The filtration efficiency reflects the mask's ability to filter particulates and microorganisms with a cut-off point of $0.072 \mu\text{m}$ (assuming that the size of the SARS-COV-2 virus was $0.09 \mu\text{m}$ [35]). The pressure drop reflects how comfortable the mask is. According to a recent assessment by REACH in NWS, less than 30% of the population uses face masks [36]. Nevertheless, we took into account other factors that could reduce the mask efficiency (pressure drop, the bias in the assessment results, improper using of the mask, those who claimed using masks do not use it continuously when they are in touch with other people). Therefore, the filtration efficiency value was adopted to be $\rho_m = 0.2$ as an average. Thus, $\delta \approx 0.92$. As a magnitude of the impact of wearing face masks rendering the virus spread, the value of R_α will decline from 2.38 to 2.19 and reach its minimum value (0.26) by April 2021. Considering that $R_e = R_0$ at the initial phase of the epidemic when everyone in a population is susceptible [37], and positing that the adherence to face masks is constant and started from the beginning of the epidemic, and recalling the equation (10), $\beta = R_0 * \gamma$, we assumed that $R_\alpha =$

Figure 4: Basic SIR model

Northwest Syria NWS
from July 9, 2020 to July 8, 2021

$R_{0\alpha}$ ($R_{0\alpha}$ is the adjusted basic reproductive number), and adjusted the value of β to $\beta_\alpha \approx 0.16$. The adjusted SIR model was predicted on this basis, as depicted in figure (5).

Based on the modified SIR model, the total number of people in NWS who will get infected with SARS-COV-2 from July 9, 2020, until July 8, 2021, is $\sum_{d=1}^{d=365} I = 633636$, where d denotes the year days since the detection of the first confirmed COVID-19 case.

5.3. *Pandemic peak, growth rate, and adjusted growth rate of COVID-19 disease in NWS.*

In fact, ample scientific evidence and information have been provided about serial interval for COVID-19 using multiple methods. After reviewing three meta-analysis studies, tackling the serial interval SI for COVID-19 globally, and with 95% CI, we adopted a value of 5.2 days for SI , and 4 days for the standard deviation SD [38] [39] [40]. Recalling the equation (14): $R_e = e^{\lambda\mu - \frac{1}{2}\lambda^2\sigma^2}$, we found that when $R_e = 2.38$ in July 2020, the value of λ was 0.22, which surmises an exponential growth rate of the disease. The value of λ declines to reach (0) in the middle of December and becomes negative afterward. When $R_0 = 2.38$ and $\lambda \approx 0.22$, it is expected that the peak of the disease in NWS occurred on December 20. When we adopted the value $R_\alpha = 2.19$, we found that the value of λ declined to be $\lambda_\alpha = 0.20$. Although this difference did not significantly change the period of the predicted peak (21 December for the adjusted model), it noticeably changed the outputs of SIR model and reduced the severity of the pandemic (figures 4 & 5). While the number of infected cases on the peak day based on the basic model is 902580, it is 156843 cases based on the purpose-built model (figure 6).

5.4. *Projecting hospital utilization during the COVID-19 pandemic in NWS*

There are no available data from NWS about the length of stay LoS of hospitalized and ICU cases. Based on EWARN data, about 97% of coronavirus cases in NWS are not severe [41]. Due to the limited capacity in terms of PCR tests, the method of samples collection, and the fact that many suspected cases could not be covered by the tests, we did not calculate the percentage of hospitalized patients and ICU patients from the total confirmed cases during the date of data extraction (The total confirmed cases in NWS from November 1st until December 15th was 13113) [12]. Therefore, we relied on the adjusted SIR model to estimate the percentages of cases that need hospitalization and intensive care. We studied the number of cases admitted to hospitals and ICU throughout three periods of 14 days ($D = 1/\gamma$), from November 1 until December 12,

2020, and compared the number of infected cases in consonance with the adjusted SIR model with the number of hospitals and ICU admitted cases. The anticipated number of daily cases based on the adjusted SIR model versus the actual number of hospital and ICU admitted cases is delineated in table (1).

Figure 5: Adjusted SIR model ($R_0=2.19$)

Figure 6: Infected cases based on the adjusted SIR model

Table 1: Predicted admission rates of COVID-19 cases to hospitals and ICU in NWS based on the total number of daily cases based on the adjusted SIR model

Period	Total number of daily cases (Adjusted SIR model)	Number of Actual cases admitted to hospitals	% of actual cases admitted to hospitals out of the total daily cases	Number of Actual cases admitted to ICU	% of actual cases admitted to ICU out of the total daily cases
1/11–14/11	40381	236	0.6%	134	0.33%
15/11–28/11	101916	227	0.2%	148	0.15%
29/11 – 12/12	175020	185	0.1%	111	0.06%
Total/ Average	317317	648	0.3%	393	0.18%

It is anticipated that about 0.3% and 0.18% of COVID-19 cases in NWS might need hospitalization and ICU beds, respectively. Based on the total anticipated number of patients who will get infected with SARS-COV-2 virus (633636). The predicted number of patients who need hospitalization and ICU admission from July 9, 2020, until July 8, 2021, is elaborated in table (2).

Table 2: Predicted number of COVID-19 cases that need hospital and ICU admission in NWS from June 9, 2020, until June 8, 2021, based on the adjusted SIR model

Predicted number of COVID-19 cases from July 9, 2020, until July 8, 2021 (Adjusted SIR model)	% of actual cases admitted to hospitals out of the total daily cases	Predicted number of cases that need hospital admission	% of actual cases admitted to ICU out of the total daily cases	Predicted number of cases that need ICU admission
633636	0.3%	1901	0.18%	1141 (2090 if the percentage of ICU admitted cases is 0.33%)

The expected numbers of hospitalization and ICU admitted cases throughout 365 days were projected using the customized SIR model to understand their load on the current capacity of COVID-19 hospitals in NWS (Figure 7).

To assess the pandemic impact on the health system in NWS, we used basic equations to calculate the number of required hospital and ICU beds after calculating the total expected number of SARS-COV-2 patients.

$$\text{Number of beds needed} = \frac{\text{bed days}}{365 \text{ days}} \quad (16)$$

The value of bed days was calculated using the equation.

$$\text{Bed days} = \text{average number of patients} \times \text{average length of stay} \quad (17)$$

We adopted systematic-reviewed data because the information about the length of stay for hospitalized and ICU admitted COVID-19 cases in NWS is limited and not reliable. The adopted values of LoS for hospitalized and ICU cases were 15.3 days and 8.8 days, respectively [42]. The predicted number of severe cases (needing hospitalization and ICU) was utilized as an average number of patients. As a result, we found out that the bed days for cases that need hospitalization for 365 days is 29085.3 days and for cases that need ICU admission is 10040.8 days. Accordingly, the number of hospital beds needed is 80, and for the required ICU beds is 28. However, due to the lack of information on the DHIS platform for NWS, we took the average of ICU admitted patients as 0.33%, as it seems to be in line with recently reported numbers of ICU admissions. The predicted number of ICU beds needed, in this case, became 51.

Figure 7: Flow of COVID-19 cases that need hospital and ICU admission based on the adjusted SIR model

4- Discussion

The first case of SARS-COV-2 in NWS was confirmed on July 9 for a doctor in a hospital situated near the Syrian-Turkish border [43]. The date of the first case appearance was late compared to other countries. This delay could be attributed to the aforementioned political conditions besides the limited access and cross-border closure for the past few years [44]. Consequently, the contact rate with cases from outside the region was minimal, resulting in a delayed appearance of the first cases.

Suppositionally, if the initial value obtained from exponential fitting is positive with an increased number of cases over time, the growth is exponential. In confirmation of that, it is concluded earlier that SARS-COV-2 virus typically spreads exponentially in the absence of artificial immunization and preventive measures [18]. Without the COVID-19 PRP and relevant implementation, the significant value of λ would have undoubtedly overwhelmed the capacity of the fragile healthcare system in NWS, highlighting the scarcity of human and financial resources. In fact, digital technologies, data, and cross-border e-health services like telemedicine have become essential support mechanisms in response to the pandemic. Allowing temporary movement of health professionals could also help alleviate capacity constraints on the health systems [45].

In this study, the progress of the COVID-19 pandemic in NWS was researched to reveal its epidemiological characteristics in a prolonged emergency-affected region, Syria.

The setup we used in this study bears a close resemblance to many other approaches that highlighted COVID-19 dynamics. Nonetheless, dissimilarly, the methodology of this research appraises one of the most widely followed preventive measures (face mask using), which would significantly change the disease spread and development. On this basis, the SIR model for NWS has been customized and put forward, and on which we relied to predict hospital utilization during the COVID-19 pandemic in NWS. This research generates noteworthy interest in terms of outbreak simulation methods by tailoring the SIR model to a confounding factor.

During the literature review, we noticed that quite a number of articles and papers researching COVID-19 progression in different countries based on SIR model had been published. However, not all of them addressed preventive measures and how they influence disease development. Preventive measures like face masks wearing, lockdown, and social distancing reduce both transmissibility and contact rates, which will, consequently, reduce the values of β , R_e , and R_0 . Most of the published papers concerning the COVID-19 pandemic relied on the value of R_0 to utilize SIR model without further adjustment to the values of β or R_e . The higher the value of R_0 , the

more severe impact of the pandemic based on SIR model [46], and thus, the extracted results and information expected severe outcomes that seem overestimated and divorced from reality, and, as a result, a large proportion of resources that would be utilized might be unnecessary, and humanitarian settings are subjected to this fact [47]. In consonance with these facts, we found that the number of infected cases during the peak day was 902580 pursuant to the basic SIR model. However, based on the adjusted SIR model, the number of infected cases during the peak day was 156843, which seems more relevant to the reported data from NWS, and incomparably less than the same number resulted from the basic SIR model. Furthermore, the number of patients who needs hospital and ICU admission on the peak day was 2708 and 1625, respectively, without customization. These numbers, nonetheless, enormously decreased after adjusting the model and predicting the hospitalization and ICU admission rates, as elucidated explained in section 3.4. Moreover, when reviewing the literature, we noticed that most of the studies about COVID-19 came from China, and their results have been adopted by many other studies to predict and understand the disease progression in other countries. Resultantly, these studies overestimated the severity of the disease on the health system, bearing in mind that the response to the disease in China was delayed until realizing the novel virus, which exaggerated the situation and increased the transmission rate before enacting prevention measures and response plan. In contrast, many other countries prepared adequately and appropriately before the appearance of the first case in these countries. Although the region of NWS is affected by a prolonged war and the health system is fragile [48], the preparation and response plan for COVID-19 was drafted, and the health cluster task force was formed four months before detecting the first case in July [49].

The value of R_0 and λ in NWS was 2.38 and $\lambda = 0.22$ at the initial phase of the pandemic. Because there is no scientific basis on which we can rely to compare this value to other values of R_0 from other places. Furthermore, the value of R_0 varied from one region to another based on our revision of 34 recently published or submitted.

In annex (1), we summarized the value of R_0 in several reviewed research studies. The mean of R_0 values across the 34 reviewed studies was 3.2, and the median 2.97. Figure (8) shows a boxplot of 77 values of R_0 according to the revised studies from several countries. The value of R_0 of this study is within the Inter Quartile Range IQR of the boxplot, which is not unexpected because the modality of these studies is to a far extent similar to our study. However, the value of $R_{0\alpha}$ of this study was below the 1st IQR.

Figure 8: Boxplot of 77 values of R_0 according to basic SIR model from different countries

Out of the total reviewed studies, only two presented the value of R_0 in Syria without any further political or humanitarian determinations [62] [72]. The value of R_0 in these studies was 2.79 and 3.99, which is remarkably higher than the R_0 and $R_{0\alpha}$ in this study (2.38 and 2.19, respectively).

The adjusted growth rate value is $\lambda_\alpha = 0.20$, and relevantly, $R_{0\alpha} = 2.19$. There are enormous disparities between the outputs of the basic and adjusted SIR models. While the preliminary results of the adjusted SIR model sound acceptable and relatively close to the actual figures, the SIR model-resulted data seem overestimated and exaggerated compared to the actual figures. This statement could be verified by the current existed data and observations reported by humanitarian actors in NWS. In both models, the peak is predicted to take place between December and January. The current figures and reports are definitely more relevant to the parameters and results of the adjusted SIR model (table 3).

While there is a slight difference between the actual and predicted figures based on the adjusted SIR model, the variation is tremendous when considering the model without modification. Apart from the discordance between the findings of this study and the

actual counterpart numbers, the results are confirmation of a conclusion raised by John Hopkins University experts in a webinar held in October 2020. The conclusion states that many studies and assessments have exaggerated and overestimated COVID-19 transmission and impact in humanitarian settings [47].

Table 3: Actual and predicted data based on the basic and adjusted SIR model

Predicted data and figures	Basic SIR model	Adjusted SIR model	Actual data and figures
Total number of infected cases	3608441 (88% of the total population)	633636 (15.45% of the total population)	18949 [21] (28.86% of the total PCR tests, as of December 15)
Total number of the hospital-admitted cases	151537	1901	740 [19] (as of December 15)
Maximum number of ICU-admitted cases from June 9, 2020 until June 8, 2021	90922 (166675 when ICU admission rate is 0.33%)	1141 (2090 when ICU admission rate is 0.33%)	465 [19] (as of December 15)
Maximum number of infected cases during the peak day	902580	156843	NA
Maximum number of hospitals admitted cases during the peak day	2708	471	98 [19] (the highest admitted cases in hospitals on one day, between 10 and 20 Dec)
Maximum number of ICU admitted cases during the peak day	1625	282	89 [19] (the highest admitted cases in ICU on one day, between 10 and 20 Dec)
Number of beds needed/available for hospitals	6352 (needed)	80 (needed)	670 [32] (available as of 15 Dec)
Number of beds needed/available for ICU	2192 (needed)	52 (needed, when the ICU admission rate is 0.33%)	212 [32] (available as of 15 Dec)

5- Recommendations

- a. Support and improve the current DHIS for the COVID-19 epidemic in NWS to immediately reflect the accurate data from the COVID-19 health facilities in NWS. Stakeholders who are engaged in COVID-19 response must be committed to sharing data with the DHIS unit regularly using a unified health information system.
- b. The number of admissions does not represent only the confirmed cases. Instead, it represents suspected, probable, and confirmed cases [19]. As a result, the reported impact of the disease on the health system might be overestimated. Applicable

admission and discharge protocols are therefore of critical importance for efficient utilization of available resources.

- c. Re-estimate the appeal for NWS COVID-19 strategic PRP, including but not limited to required financial resources for the different scopes of response, deployment of human resources, actors, and stakeholders' commitment to the plan, and keeping abreast of global and local changes and adaptability to cope with them.
- d. To avoid any potential deviation –due to bias– from the actual future and current figures, the projected hospital utilization rates could be increased by 10% or 20%.
- e. In an area affected by a protracted armed conflict, NWS, where the available resources are scarce, it is necessary to mention that, by completing this research, there was only one actor performing PCR tests with a capacity that does not exceed 1700 tests per day [2]. The limited laboratory capacity contends that not all COVID-19 suspected cases could be covered by these tests, which means that not all positive cases had been recorded.

6- Annexes

<i>Annex 1: R₀ value according to COVID-19-related studies</i>			
No	R_0	Place	First author
1	2.2	Wuhan – China	Li Q [50]
2	2.6	China	Zhao S [51]
3	4.6	Hubei – China	Anastassopoulou C [52]
4	4.7	Wuhan – China	Zhao S [53]
5	1.52	China	Zhao S [53]
6	2.79	China	Dur-e Ahmad M [54]
7	5.2	Wuhan – China	Mizumoto K [55]
8	7.9	Wuhan – China	Zhu H [56]
9	5.06	Heilongjiang – China	Sun T [57]
10	3.2	Wuhan – China	Davies N [58]
11	2.7	Wuhan – China	Wang L [59]
12	2.55	China	Aghaali M [60]
13	2.1	Wuhan – China	Jung [61]
14	1.72	China	Al-Raei M [62]
15	2.24	China	Zhao S [63]
16	3.11	Wuhan – China	Read [64]
17	5.93	Hubei – China	Zhao S [53]
18	2.68	Wuhan – China	Wu J [65]
19	3.2	Wuhan – China	Jung S [61]
20	3.15	China	Tian H [66]
21	2.2	Wuhan – China	Riou J [67]
22	3.58	China	Zhao S [63]

23	2.97	Anhui – China	Tian J [68]
24	2.6	S. Korea	Zhuang Z [69]
25	3.2	S. Korea	Zhuang Z [69]
26	1.78	S. Korea	Aghaali M [60]
27	1.59	S. Korea	Xu C [70]
28	2.6	Japan	Kuniya T [71]
29	2.79	Syria	Al-Raei M [62]
30	3.99	Syria	Rahman B [72]
31	2.37	Africa	Musa S [29]
32	1.56	Cameroon	Nguemdjo U [73]
33	1.00	Nigeria	Al-Raei M [62]
34	1.06	Iraq	Ibrahim M [74]
35	3.5	Iraq	Rahman B [72]
36	1.03	Egypt	Ibrahim M [74]
37	3.47	Qom – Iran	Aghaali M [75]
38	4.86	Iran	Sahafizadeh E [75]
39	1.82	Iran	Aghaali M [60]
40	4.13	Iran	Rahman B [72]
41	2.7	Shahroud – Iran	Khosravi A [76]
42	3.37	Italy	Aghaali M [60]
43	3.3	Italy	Zhuang Z [69]
44	2.3	Italy	Zhuang Z [69]
45	2.38	Italy	Giordano G [77]
46	4.9	Italy	Ke R [78]
47	4.08	Israel	Rahman B [72]
48	2.28	Pakistan	Noreen N [79]
49	2.28	Malaysia	Alsayed A [80]
50	5.25	Brazil	Crokidakis N [81]
51	4.05	Cyprus	Rahman B [72]
52	2.3	Ontario – Canada	Tuite A [82]
53	3.8	Belgium	Ke R [78]
54	4.4	France	Ke R [78]
55	2.72	France	Al-Raei M [62]
56	4.7	Germany	Ke R [78]
57	3.7	Netherlands	Ke R [78]
58	6.1	Spain	Ke R [78]
59	3.6	Switzerland	Ke R [78]
60	3.9	The United Kingdom	Ke R [78]
61	5.8	The United States	Ke R [78]
62	1.61	The United States	Al-Raei M [62]
63	1.29	Russia	Al-Raei M [62]
64	7.41	Turkey	Rahman B [72]
65	2.7	Kuwait	Rahman B [72]
66	3.39	Bahrain	Rahman B [72]

67	4.18	Qatar	Rahman B [72]
68	4.45	Saudi Arabia	Rahman B [72]
69	2.73	The United Emirates	Rahman B [72]
70	2.6	Oman	Rahman B [72]
71	3.52	Jordan	Rahman B [72]
72	3.35	Egypt	Rahman B [72]
73	3.16	Lebanon	Rahman B [72]
74	2.89	Palestine	Rahman B [72]
75	1.4	Yemen	Al-Raei M [62]
76	1.66	Sri Lanka	Dharmaratne S [83]
77	1.25	India	Al-Raei M [62]

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Declaration

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 - Agneta Kallström: Literature search, writing original draft, review and editing
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Figures

Figure 1

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Figure 2

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Figure 3

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Figure 4

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Northwest Syria NWS
from July 9, 2020 to July 8, 2021

Figure 5

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Figure 6

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Northwest Syria NWS July 9, 2020 until July 8, 2021

July 9, 2020 until July 8, 2021

Figure 7

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Figure 8

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