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ORIGINAL PAPER

Transmission dynamics of novel coronavirus SARS-CoV-2 among healthcare workers, a case study in Iran

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Abstract One of the main concerns during the COVID-19 pandemic was the protection of healthcare workers against the novel coronavirus. The critical role and vulnerability of healthcare workers during the COVID-19 pandemic leads us to derive a mathematical model to express the spread of coronavirus between the healthcare workers. In the first step, the SECIRH model is introduced, and then the mathematical equations are written. The proposed model includes eight state variables, i.e., Susceptible, Exposed, Carrier, Infected, Hospitalized, ICU admitted, Dead, and finally Recovered. In this model, the vaccination, protective equipment, and recruitment policy are considered as preventive actions. The formal confirmed data provided by the Iranian ministry of health is used to simulate the proposed model. The simulation results revealed that the proposed model has a high degree of consistency with the actual COVID-19 daily statistics. In addition, the roles of vaccination, protective equipment, and recruitment policy for the elimination of coronavirus among the healthcare workers are investigated. The results of this research help the policymakers to adopt the best decisions against the spread of coronavirus among healthcare workers.

Keywords Coronavirus · Mathematical modeling · Vaccination

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1 Introduction

It is more than a year since the first case of the newly emerging coronavirus was reported in Wuhan, China. With increasing corona prevalence, the World Health Organization (WHO) officially declared the COVID-19 outbreak a pandemic in the early March of 2020. According to the official statistics [49], this virus spread to all countries in the globe in a short time.

Due to the virus's high power of transmission, the WHO formally demands social distance as a preventive action to save human lives [36,47,48,50]. During the COVID-19 pandemic, this social distance leads to several personal, social, and economic problems [29,35,38]. For example, the schools and universities classrooms are replaced with virtual learning throughout the world [46,52]. In [43], the authors believe that transition to virtual education has several advantages such as easy access to the course materials and also reduction of student's cost. However, many researchers believe that virtual learning leads to depression and mental illness shortly [12,45]. In terms of the economic point of view, the COVID-19 pandemic leads to several losses, and unemployment [30]. The restrictions on the mobility between the countries highly affected the commercial relations [9]. For example, the COVID-19 pandemic strongly threatens the tourism industry [7,42]. According to the World Tourism Organization, more than 100 million job positions in the tourism industry are at risk in 2021 [51]. These mental, social, and economic problems motivated researchers to model the behavior of COVID-19 in societies [6,28]. These mathematical models are useful to predict the peak and termination of the disease. They also help the policy-makers to take the best action against the disease outbreak. The effect of different measures such as social distance, facial masks, and vaccination in mitigation of COVID-19 can be studied by mathematical models. In this research, the mathematical model of the COVID-19 outbreak between the hospital care team members is derived.

1.1 Literature review

The mathematical modeling of infectious disease has a long history [5]. These models are derived to describe the spread of illness in society. There are two ways to express the epidemiological models by mathematical languages: (a) agent-based modeling (b) compartment modeling. The agent-based models are based on the interactions of the members of the group [27]. In the compartment models, the members of the group are divided into different sections [44].

In [8], the authors proposed a model for the transmission of HIV in society. As a preliminary work, sensitivity analysis is also performed. The results of this paper revealed that the number of deaths declined over time. In [10], authors describe the dynamics of HIV with a set of ordinary differential equations. The therapeutic drugs play the role of the control input signal. The authors try to stabilize the spread of disease in the shortest possible time. Influenza is an infectious disease caused by influenza viruses. The researchers are devoted to model and control the spread of influenza disease in society. In [31], the authors describe the influenza behavior with the SEIAR model. The antiviral treatment and vaccination are considered control input signals. The authors try to prevent the spread of disease through the observer-based sliding mode controller. In [25], the authors describe the spread of H1N1 influenza through the compartment model. The main objective of this study is to develop a novel model for epidemic influenza. The neural network is also utilized to obtain the spread of disease in Indian society. In the last year, several researchers make a great effort to obtain the mathematical model of COVID-19 in society. As a basic model, The SIR model is widely used to describe the evolution of COVID-19 in a variety of communities [13–15]. In this model, the society is divided into three different sections, i.e., Susceptible-S, Infected-I, and Recovered-R. Due to the transmission power of COVID-19, it is not reasonable to adopt the SIR model. In [20], the authors proposed the SIRD model to express the behavior of COVID-19 with four coupled time-delay differential equations. In [17], the authors proposed the modified version of the SEIR model to analyze the propagation of the SARS-CoV-2 virus in eight different countries. The results of this research show that the proposed method is able to predict the progress of coronavirus in other countries. In [21], the authors revealed how restrictions on transportation affect the COVID-19 pandemic in France. In this research, the SIRD model is utilized. It is concluded that the lockdown strategies lead to the elimination of COVID-19 pandemic. As the knowledge about the COVID-19 pandemic increases, more complex models are proposed. These models consider the effect of quarantined and hospitalization. For example, In [41], the authors make a distinction between symptomatic and asymptotic patients. Since asymptotic patients are very prevalent, this model leads to a better understanding of the COVID-19 pandemic in society. In [4], the authors consider the quarantine during the COVID-19 pandemic. Since the patients with mild conditions go into quarantine, this model offers a better understanding of COVID-19 in society. With the development of COVID-19 vaccines, several researchers consider the vaccination effect in the mathematical models [24]. For example, In [16], the authors SIER epidemic model to obtain the optimal control gain under vaccination. In [40], the authors investigate the stability of the COVID-19 SE(Is)(Ih)AR model under combined antiviral controls and vaccination. The authors obtained the equilibrium point, and then its stability is investigated.

1.2 Motivation

The healthcare workers are at the frontline of the war against the COVID-19 pandemic. On the one hand, their valuable medical services to society are vital. On the other hand, they are one of the most vulnerable groups against COVID-19 pandemic. This motivated us to express the spread of COVID-19 among the healthcare workers against the COVID-19 with mathematical languages. The mathematical model is utilized to analyze the spread of COVID-19 between the healthcare worker and also the effect of vaccination.

The initial efforts to derive the model of the spread of COVID-19 between the healthcare workers are done by German epidemiologists [22]. In this research, the authors divided the healthcare workers into the eight stages i.e., Susceptible (S), healthy individuals without immune memory of COVID-19, Exposed (E), who already carry the virus but are not yet infectious to others, Carriers (C), who carry the virus and are transferable to others but do not yet show symptoms, Infected (I), who carry the virus with symptoms and are infectious to others, Hospitalized (H), who experience a severe development of the disease, transferred to intensive care unit (U), Dead (D), and finally Recovered (R), who acquired immune memory and cannot be infected. However, the SECIR model is not able to reflect the spread of COVID-19 between the healthcare workers. The healthcare workers are in direct contact with the infected, and also their knowledge of COVID-19 pandemic is higher than the average of society. These issues motivated us to derive a novel mathematical model to express the spread of COVID-19 between the healthcare workers team. The advantages of the proposed SECIRH model over the SECIR model are the different rates of susceptible and exposed cases. Inspired by the above discussion, the novelties of this research can be summarized as follows;

- A novel epidemiological model is introduced to express the spread of COVID-19 between the healthcare workers by mathematical language.
- The official data provided by the Iranian ministry of health is utilized to investigate the precision and accuracy of the proposed model.
- The effects of recruitment of new nurses and doctors on the spread of COVID-19 pandemic among the healthcare workers are studied.
- The effect of global vaccination on the mitigation of COVID-19 between the healthcare works is analyzed.

The rest of this paper is organized as follows: In the next section, the proposed SECIRH model is introduced, and the mathematical equations are derived. In the third section, different simulation scenarios are suggested. In the next section, the simulation results are presented. In the last section, some comparative studies are presented. The concluding remarks and future works are discussed in conclusion.

2 The SECIRH epidemiological model

In the proposed SECIRH epidemiological model, the healthcare workers are divided into eight groups, including susceptible-HS, exposed-HE, carriers-HC, infected-HI, hospitalized-HH, admitted to intensive care unit-HU, dead-HD, and recovered-R. According to Fig.1, the healthcare workers who have not caught coronavirus are members of the susceptible group. The susceptible cases move to the exposed group at the rate of ϕ, which defined as follows;

$$\phi = -rate_p R_1[HC + HI + \beta(HH + H)]\frac{HS}{HS_0} \quad (1)$$

where $rate_p$ is protection rate and take the discrete values $rate_p = [0, 1]$. The values of 1 and 0 are equivalent to the non-protection and full protection conditions. The parameter R_1 presents the transmission probability of coronavirus in each contact of a susceptible person with the infected, carrier, and hospitalized cases. The parameter β is isolation rate and takes discrete values $\beta = [0, 1]$. The values of 0 and 1 are equivalent to the full isolation and non-isolation conditions. The parameter HS_0 is the total number of healthcare workers under study. The parameter H is equivalent to the hospitalized cases that are not members of the healthcare workers.

The exposed cases move to the Carrier group with the rate of R_2. The carriers move to the infected group with the rate of $(1 - \alpha)R_3$ if the symptoms such as fever appear. Otherwise, they pass to the recovered group with the rate of αR_9. The parameter α is the rate of asymptomatic cases. The inverse of R_3 depicts the period of being infectious before disease onset. The inverse of R_9 is the duration for which the asymptomatic infected individuals remain infectious following their latent non-infectious period.

The infected cases are admitted to the hospitals if they suffer from advanced symptoms of coronavirus such as shortness of breath with the rate of ρR_6, otherwise move to the recovered group with the rate of $(1 - \rho)R_4$. The parameter ρ is the possibility of an infected case admitted hospital. The inverse of R_4 is the duration for which the infected individuals with mild symptoms and not requiring hospitalization, remain infectious after their disease onset. The inverse of R_6 denotes the time that a patient with mild symptoms

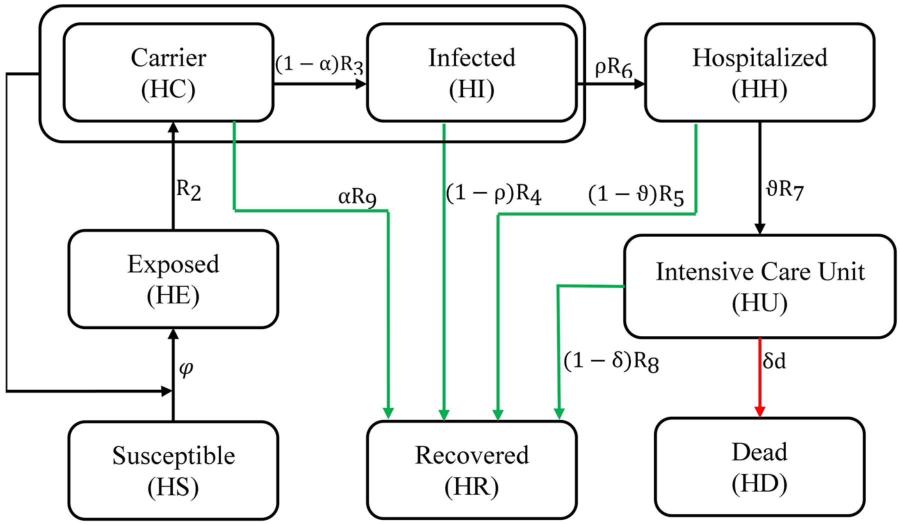

Fig. 1 The proposed SECIRH model

spends at home before hospital admission due to worsening of the disease condition.

Moreover, if a hospitalized cases health condition deteriorates and needs intensive care, they admitted to the ICU at the rate of ϑR_9. Otherwise, the hospitalized cases discharge from the hospital and join the recovered group with the rate of $(1-\vartheta)R_5$. The parameter ϑ is the probability that a hospitalized case needs to be admitted to ICU. The inverse of the parameter R_5 depicts the duration for which the hospitalized patients not requiring further intensive care remain under general hospital care before getting a discharge. The inverse of the parameter R_7 presents the period spent following hospitalization to admission in an intensive care unit. Finally, the cases in the ICU group move to the dead group with the rate of δd if the death of a case takes place. Otherwise, they discharged from ICU if they are cured of the disease and joined the recovered group with a rate of $(1-\delta)R_8$. The parameter δ is the death possibility of a case, who is admitted to the ICU. The inverse of R_8 depicts the period spent in the ICU before the discharge. The inverse of the parameter R_9 is primarily the duration for which the asymptomatic infected individuals remain infectious following their latent non-infectious period.

2.1 The mathematical equations of the SECIRH model

In this subsection, the mathematical equations of the SECIRH epidemiological model are introduced. This mathematical model is a set of eight coupled ordinary differential equations as follows:

$$\frac{d}{dt}HS = -rate_p R_1[HC + HI + \beta(HH + H)]\frac{HS}{HS_0} \tag{2}$$

$$\frac{d}{dt}HE = rate_p R_1[HC + HI + \beta(HH + H)]\frac{HS}{HS_0} - R_2 HE \tag{3}$$

$$\frac{d}{dt}HC = R_2 HE - [(1-\alpha)R_3 + \alpha R_9]HC \tag{4}$$

$$\frac{d}{dt}HI = (1-\alpha)R_3 HC - [(1-\rho)R_4 + \rho R_6]HI \tag{5}$$

$$\frac{d}{dt}HH = \rho R_6 HI - [(1-\vartheta)R_5 - \vartheta R_7]HH \tag{6}$$

$$\frac{d}{dt}HU = \vartheta R_7 HH - [(1-\delta)R_8 + \delta d]HU \tag{7}$$

$$\frac{d}{dt}HR = \alpha R_9 HC + (1-\vartheta)R_5 HI + (1-\vartheta)R_5 HH + [(1-\delta)R_8 HU \tag{8}$$

$$\frac{d}{dt}HD = \delta d HU \tag{9}$$

With the spread of COVID-19, some countries such as Iran and Italy decide to recruit new nurses and doctors. For example, it is also observed that the final year nursery and medical students were recognized as graduates and start to work in health systems. Recently,

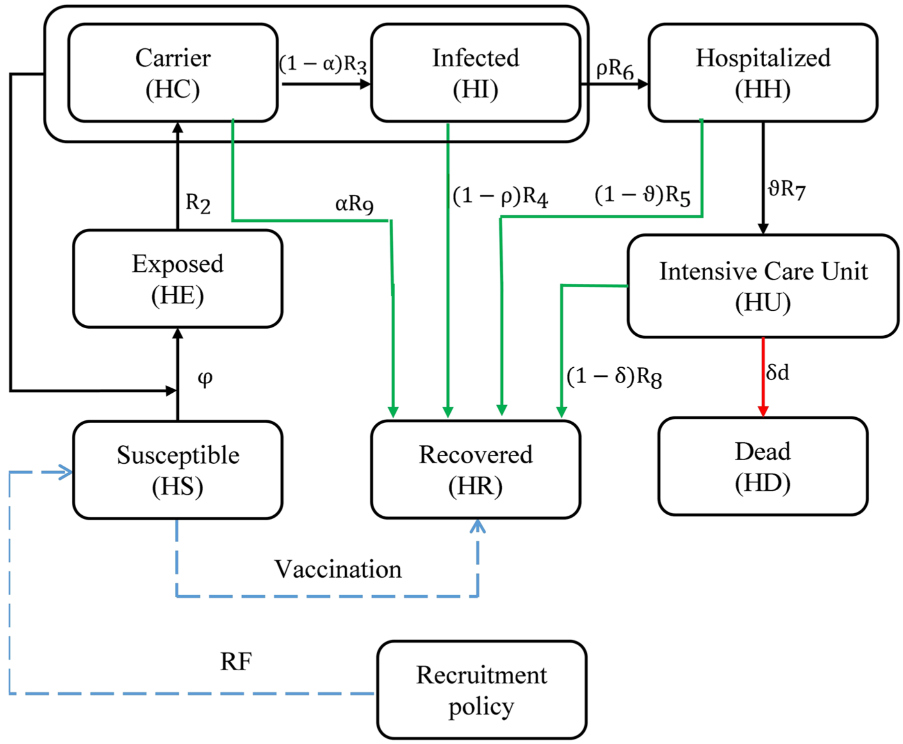

Fig. 2 The scheme of the SECIRH model under recruitment policy and vaccination

vaccination plays a vital role against the coronavirus. The global vaccination generates immunity against the coronavirus. During the COVID-19 pandemic, one of the first groups vaccinated is healthcare workers.

In Fig. 2, the SECIRH epidemiological model is modified to include the recruitment of new nurses and doctors and vaccination. To consider the effect of recruitment of nurses and doctors, Eqs. 2 and 3 are replaced by Eqs. 10, 11, and 12. The effect of vaccination is considered in the SECIRH epidemiological model by substituting Eqs. 2 and 8 with Eqs. 13 and 14, respectively.

$$\frac{d}{dt}TH = RF \tag{10}$$

$$\frac{d}{dt}HS = -rate_p R_1[HC + HI + \beta(HH + H)]\frac{HS}{TH} + RF \tag{11}$$

$$\frac{d}{dt}HE = rate_p R_1[HC + HI + \beta(HH + H)]\frac{HS}{TH} - R_2 HE \tag{12}$$

$$\frac{d}{dt}HS = -rate_p R_1[HC + HI + \beta(HH + H)]\frac{HS}{TH} - V \tag{13}$$

$$\frac{d}{dt}HR = \alpha R_9 HC + (1-\vartheta)R_5 HI + (1-\vartheta)R_5 HH + [(1-\delta)R_8 + V \tag{14}$$

where the parameters RF and TH are the rates of recruited nurses and doctors and the total number of healthcare workers. The parameter V is the vaccination rate.

3 Simulation

In this section, different scenarios are introduced to investigate the factors of COVID-19 prevalence among healthcare workers in Iran. For this purpose, the proposed SECIRH model is utilized. The simulations are carried out with the Python programming language in the Colab environment. In this research, the formal confirmed data provided by the Iranian ministry of health are used to simulate the accuracy and precision of the proposed model [1,2]. The SECIRH model parameter values are presented in Table 1. In the this table, the parameters of R_1, R_2, ..., R_9 and also d are extracted

Table 1 The list of SECIRH model parameters

Parameters	Value
R_1^{-1}	0.3
R_2^{-1}	1
$R_{3^{-1}}$	4.2
R_4^{-1}	14
R_5^{-1}	16
R_6^{-1}	5
R_7^{-1}	3.5
R_8^{-1}	8
R_9^{-1}	11.2
d^{-1}	6.92
ρ	0.07
α	0.5
ϑ	0.09
δ	0.05
β	0.75

from the median of fitted data in [22]. The parameters ρ, α, ϑ, β, and δ are obtained from [19].

In the first step, the authors estimate the development of COVID-19 pandemic between healthcare workers from the beginning day of the pandemic in Iran (February 20, 2020) until February 8, 2021. Since health workers' vaccination started on 9 February in Iran, and this event can affect model results. Also, the authors have not accessed to daily vaccination rate; therefore, February 8, 2021, selected as the final day of simulation in this step. In order to simulate this step, a scenario is utilized, namely realistic. In the realistic scenario, the healthcare workers get access to the protective equipment gradually. In the initial days of the COVID-19 pandemic, the rate of protection is equivalent with ($rate_p = 1$) and gradually decreases to ($rate_p = 0.1$) as shown in Fig. 3.

In the second step, the authors investigate how protective equipment such as facial masks, protective eyewear, gloves, and long-sleeved gowns prevent infection to coronavirus among healthcare workers. In this step, another scenario is considered, i.e., idealistic. In the idealistic scenario, it is assumed that the healthcare workers have full access to the protective equipment from the initial days of the COVID-19 pandemic. As shown in Fig. 3, in the idealistic scenario, the rate of protection is considered a constant ($rate_p = 0.1$).

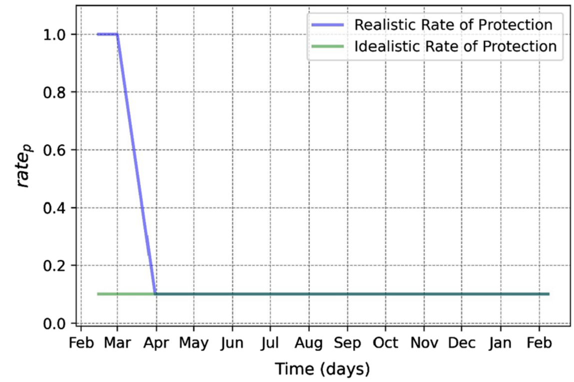

Fig. 3 Rates of protection for idealistic and realistic scenarios

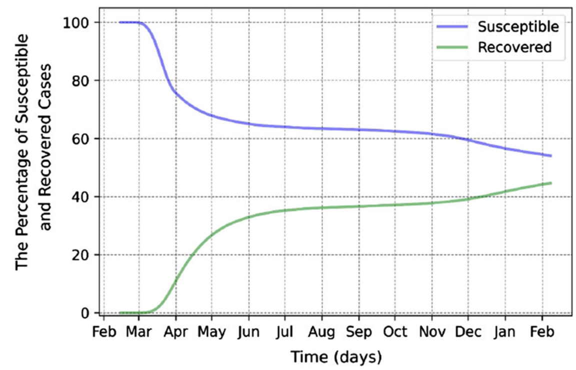

Fig. 4 The susceptible and recovered results under the Realistic scenario

In the third step, the authors discovered how vaccination develops immunity for the healthcare workers against the novel coronavirus. For this purpose, different rates of vaccination 2000, 4000, and 8000 (people per day) are considered. In the fourth step, the authors discover how recruitment of new nurses and doctors impacts the spread of coronavirus among the healthcare worker during COVID-19 pandemic. According to the official data of the Iranian health ministry, 20,000 nurses and doctors in their final year of education are called to join the healthcare workers in the initial days of COVID-19 pandemic. Subsequently, 1200 nurses and doctors are recruited monthly.

4 Results

In this section, the simulation results are presented to disclose how coronavirus spread among healthcare workers. According to the realistic scenario, the per-

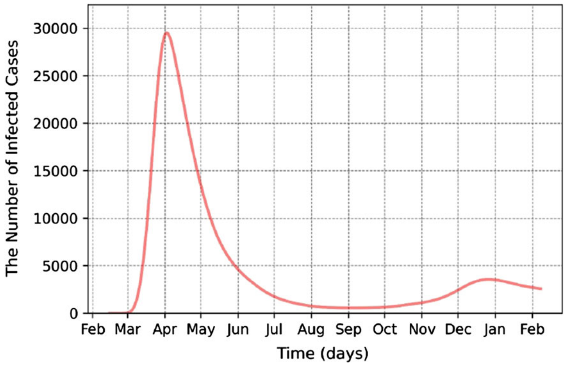

Fig. 5 Infected results under the Realistic scenario

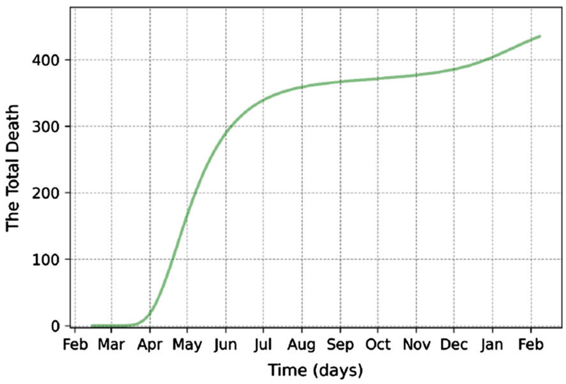

Fig. 6 The total number of death under the Realistic scenario

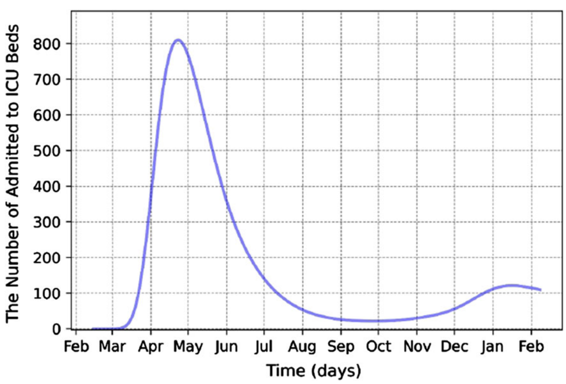

Fig. 7 The cases admitted to the ICU bed under the Realistic scenario

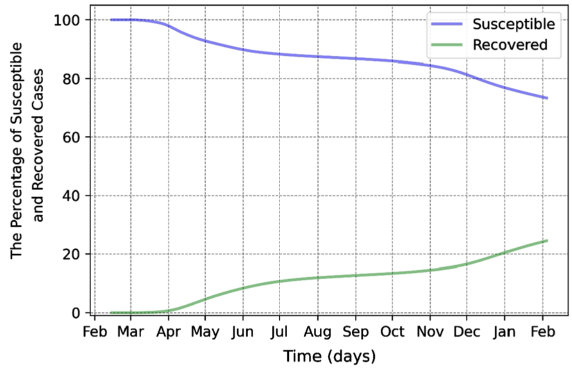

Fig. 8 The susceptible and recovered results under the idealistic scenario

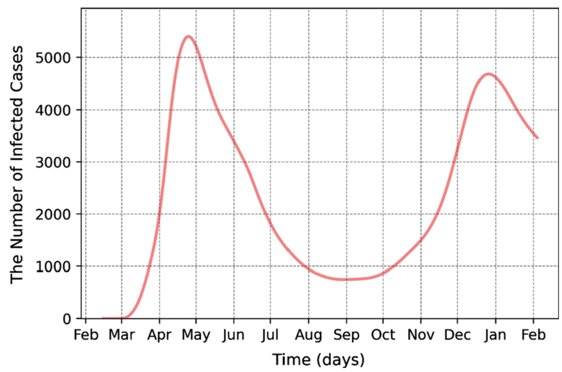

Fig. 9 The infected cases under the idealistic scenario

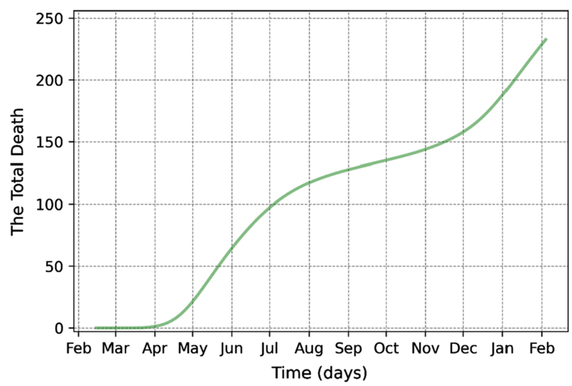

Fig. 10 The total number of death under the idealistic scenario

centages of susceptible and recovered with immunity groups are presented in Fig. 4. In the period of mid-March 2020 until early June 2020, both groups experience a sharp slope. In Fig. 5, the number of infected healthcare workers under a realistic scenario is presented. In early April 2020, a sharp peak is observed. The fatality cases under realistic scenario are presented in Fig. 6. According to this figure, from late March 2020 until July 2020, the fatality cases experience an increasing slop. As shown in Fig. 7, the cases admitted to the ICU bed under the realistic scenario experience a very sharp peak in late April 2020.

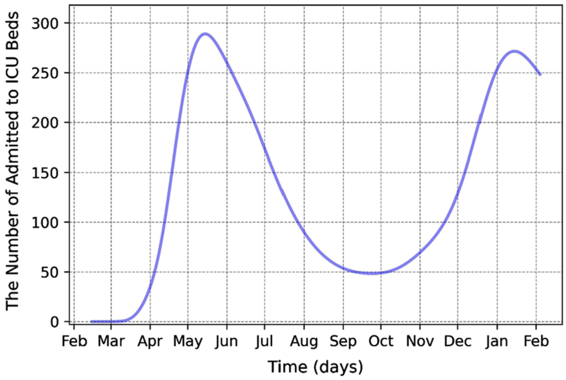

Fig. 11 The number of admitted to the ICU beds cases under the idealistic scenario

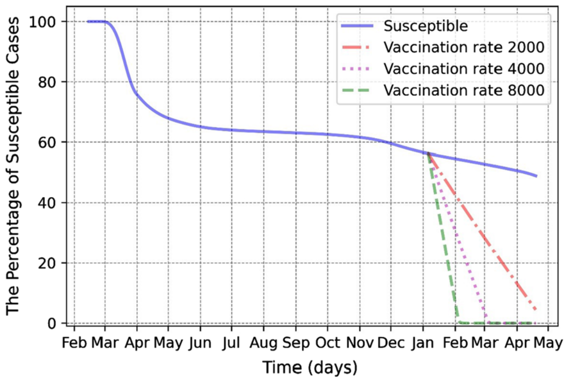

Fig. 12 The percentage of the susceptible cases under the vaccination

As shown in Fig. 8, the percentage of the susceptible and recovered with immunity are decreasing and increasing under the idealistic scenario, respectively. According to this figure, the susceptible and recovered groups under idealistic scenario are experiencing a slow rate. In Fig. 9, the infected cases under the realistic scenario are presented. According to this figure, in late April and mid-December 2020, two peaks are observed. The fatality cases under the idealistic scenario are depicted in Fig. 10. Unfortunately, the fatality cases of healthcare workers under realistic scenario experience an increasing slope from April 2020 until mid-July 2020 and from November 2020 until February 2021. However, from mid-July 2020 until November 2020, the fatality cases experience a mild slope. In Fig. 11, the number of healthcare workers admitted to the ICU bed under the idealistic scenario is depicted. According to this figure, in mid-May 2020 and mid-January 2021, two peaks are observed.

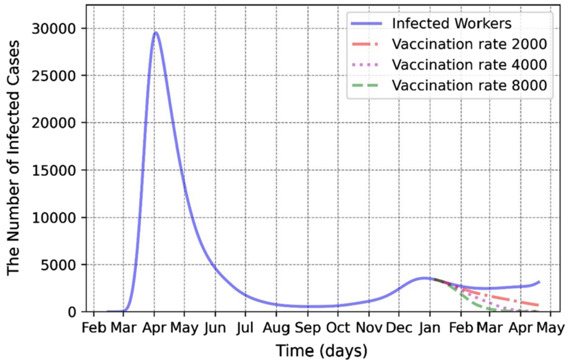

Fig. 13 The number of infected cases under vaccination

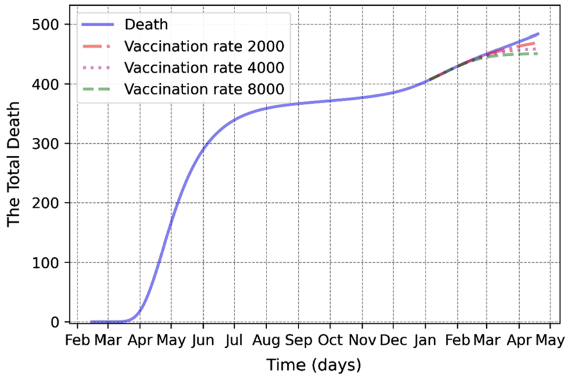

Fig. 14 The total number of death under vaccination

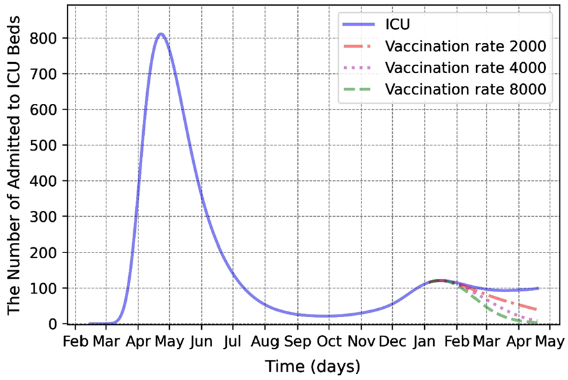

Fig. 15 The number of admitted cases to the ICU beds under vaccination

The effect of vaccination on the percentage of susceptible healthcare workers is presented in Fig. 12. It is assumed that the vaccination of the healthcare worker is initiated on December 8, 2020. It is concluded that healthcare workers' vaccinations with the rate of 8000 people per day lead to full immunity against coron-

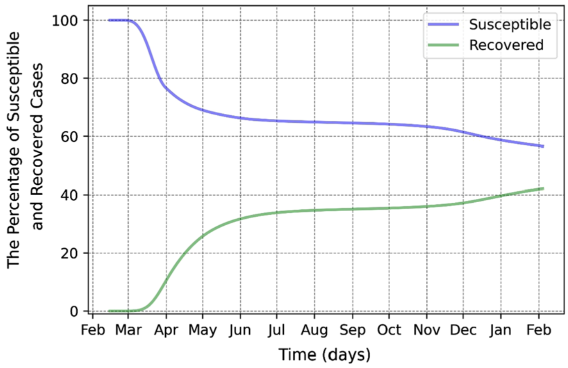

Fig. 16 The number of the susceptible and recovered under recruitment policy in the realistic scenario

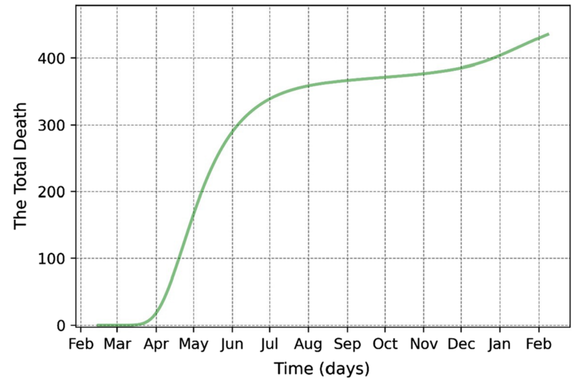

Fig. 18 The total number of death under recruitment policy in the realistic scenario

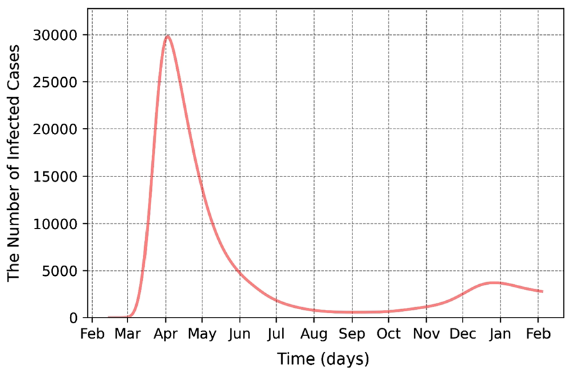

Fig. 17 The number of infected cases under recruitment policy in the realistic scenario

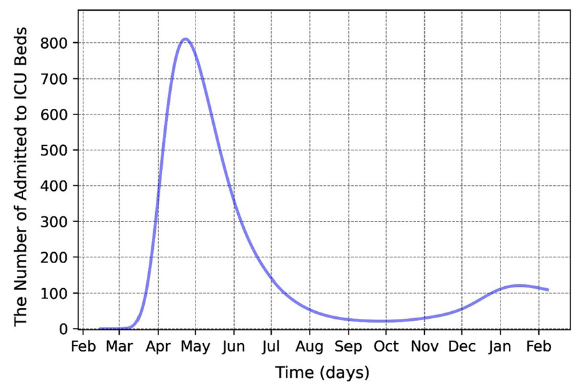

Fig. 19 The number of cases admitted to the ICU beds under recruitment policy in the realistic scenario

avirus in early February 2021. According to Fig. 13, the number of infected cases reaches zero in early March 2021 under vaccination with the rate of 8000 people per day. As shown in Fig. 14, the total number of healthcare workers' death reaches a constant value under vaccination with the rate of 8000 people per day. In other words, the daily deaths of healthcare workers become zero in mid-March 20201. It is clear from Fig. 15 that the ICU beds are not occupied by the healthcare workers under vaccinations with the rate of 8000 people per day.

The effects of recruiting of new nurses and doctors during the COVID-19 pandemic on the number of susceptible and recovered, infected, the total death, and admitted to ICU bed cases are shown in Figs. 16, 17,18 and 19 , respectively. According to these figures, the recruitment of nurses and doctors did not change the pattern of coronavirus spread among the healthcare workers.

5 Discussion

In this section, the results of the proposed model under realistic scenario are compared with official reports statistics. In addition, the differences between active cases in Iran and infected healthcare workers' estimation under realistic scenario are discussed. Finally, several comparative studies are carried out to reveal how protection, vaccinations, and recruitment of nurses and doctors help the healthcare workers overcome the COVID-19 pandemic.

In [3], 130 death of healthcare works caused by COVID-19 is reported. The proposed SECIRH model under realistic scenario estimates 144 deaths among healthcare workers in the same day the report was conducted. In November and December, health Authorities in province and country-level in multiple interviews expressed that almost half of nurses and health workers have infected by COVID-19 [23,26,32–34,39]. In

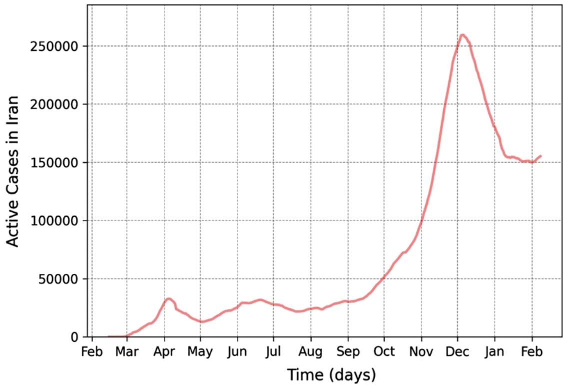

Fig. 20 The number of active cases in Iran

the same period, the proposed model under realistic scenario predicts more than 41% of healthcare workers have recovered from COVID-19. In [18], one of the deputy chiefs of the Iranian Medical System Organization revealed statistics of mortality among healthcare workers, caused by COVID-19, and added: " Nurses account for 22% of all deaths among health workers." Besides, the head of the Nursing System Organization reported 100 death tolls caused by COVID-19 between nurses from the start of the outbreak until December 2020 [33]. If 100 deaths of 22% are used, it will reach about 450 deaths caused by COVID-19 among healthcare workers until December. At the same time, the model under realistic scenario forecasts 375 deaths. These evaluations prove that the realistic scenario accurately estimates the transmission dynamic of COVID-19 among healthcare workers in the real world.

In Fig. 20, the active cases of COVID-19, extracted from the world-meters Web site [1], are demonstrated on daily basis. From Fig. 20, it can be seen that Iran faces three waves. The first wave starts mid-February and ends in early May. The second wave commences in early May and finishes in late July. Finally, the third wave starts mid-August and ends in early January. During the first wave, Iran's health organizations suffer from a limited number of RT-PCR kits and diagnostic laboratories. Owing to this fact, most people are tested who have severe symptoms of COVID-19 and need hospitalization. Since WHO and Iran health administration report, only those have positive RT-PCR test; during the first wave, the actual number of active cases are several times the official statistics [11,37]. According to Fig. 5, almost one-third of Iranian healthcare works get COVID-19 in the first wave. This occurrence can be explained twofold: lack of protective equipment and high-level of hospitalized cases. During the second wave, infected cases among healthcare works continue to decrease because of sufficient protective equipment and a low rate of hospitalization. In the first months of the third wave until early October, infected cases among healthcare works remain steady. However, active cases in Iran experience an up-trend. In the continuation, active cases in Iran increase significantly and reach the highest point in early December. But, infected cases among healthcare works rise mildly and reach the highest point in mid-December which is very lower than the first peak in early April. This occurrence can be explained twofold: partial herd immunity and sufficient usage of protective equipment.

In Table 2, a comparison study is carried out between the idealistic and realistic scenarios. Clearly, the occupied ICU beds in the realistic are significantly higher than the idealistic scenario. Besides, the total number of death in the realistic is more than idealistic scenario too. It is easy to conclude that protective equipment such as facial masks, protective eyewear, gloves, and long-sleeved gowns can be recognized as a preventive action for healthcare workers against the novel coronavirus.

The infected cases under idealistic and realistic scenarios are compared in Table 3. According to Table 3, the protective equipment did not affect the occurrence time of the first and second peaks. However, the amplitude of the first peak in the realistic scenario is considerably higher than the idealistic scenario. During the first wave of the COVID-19 pandemic, herd immunity takes place among the healthcare workers in the realistic scenario. This leads to the lower infected cases in the realistic scenario than idealistic in the second wave of the COVID-19 pandemic.

Table 4 includes an analytical study about the effect of vaccination on the mitigation of coronavirus among healthcare workers. In this table, the effect of vaccination with different rates is compared two months after the vaccine initiation. According to this table, vaccination plays a vital role in the elimination of coronavirus effects among healthcare workers. Besides, the higher rate of vaccination leads to rapid full immunity against the coronavirus.

With a simple comparison between Figs. 16, 17, 18, 19 and Figs. 4, 5, 6 and 7, one can easily conclude that the policy of recruitment did not affect the daily statistics of coronavirus. However, it is not deniable that dur-

Table 2 The comparison between the idealistic and realistic scenarios

Comparison indices	Idealistic	Realistic
Min susceptible percentage	75.35%	54.09%
Max recovered percentage	24.49%	44.63%
Max occupied ICU beds	289	810
The total number of death	232	435

Table 3 The comparison between the infected cases under idealistic and realistic scenarios

Scenarios	Date		Amplitude	
	1st peak	2nd peak	1st peak	2nd peak
Idealistic	25 Apr 2020	25 Apr 2020	5401	4689
Realistic	3 Apr 2020	27 Dec 2020	29512	3553

Table 4 The effect of vaccination two months after vaccine initiation

Comparison Indices	Rate of Vaccination (people per day)			
	2000	4000	8000	No Vaccination
Susceptible	38.45%	22.86%	0.01%	54.03%
Infected	2200	1855	1221	2561
ICU beds	104	100	92	108
Daily death	0.63	0.61	0.58	0.65

ing the COVID-19 pandemic, this policy improves the quality of medical services to society.

6 Conclusion

In this research, a novel epidemiological SECIRH model is introduced to express the behavior of coronavirus among healthcare workers. In order to validate the proposed SECIRH model, the official data provided by the Iranian ministry of health are utilized. Three different factors of protective equipment, vaccination, and recruitment of new nurses and doctors are considered. The results of the simulations revealed that protective equipment is crucial to prevent the spread of coronavirus among healthcare workers. It is also concluded that vaccination is a key solution to eliminate the coronavirus among healthcare workers. Finally, it is observed that the policy of recruitment did not affect the daily statistics of coronavirus. However, this policy leads to better medical services. It should be mentioned that the limitation in vaccine supply and also non-optimal distribution of vaccines among the healthcare workers are the main concerns of this study. According to the results of this research, it is suggested to give the highest priority to the healthcare workers during global vaccination.

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Data and code accessibility The data and code used in this study are available are available in the SECIRH repository, https://github.com/NimaGozalpour/SECIRH.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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