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Health system response to the coincidence of the COVID-19 pandemic and disasters: A call for action

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Health system response to the coincidence of the COVID-19 pandemic and disasters: A call for action

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Editorial: Health system response to the coincidence of the COVID-19 pandemic and disasters: a call for action

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Editorial on the Research Topic
Health system response to the coincidence of the COVID-19 pandemic and disasters: a call for action

The COVID-19 epidemic started in the Chinese city of Wuhan in December 2019 (1). According to the last classification of the Center for Research on the Epidemiology of Disasters (CRED) published in EM-DAT, epidemics have been categorized as biological disasters (2) and need urgent preparedness and response actions (3). In the case of COVID-19, healthcare systems across the world tried to manage this pandemic in an effective way. However, new problems and challenges appeared and worsened the situation of the affected communities at the time of the COVID-19 pandemic response. Of these emergent challenges, natural disasters (e.g., earthquakes, floods, and tornadoes) co-occurring with the pandemic were the most important and seriously affected the capacities and capabilities of health systems in several countries (4). Natural disasters have considerable health, social, and economic effects by themselves and their co-incidence with the COVID-19 epidemic imposed multiple pressures and complicated conditions on healthcare systems. Furthermore, the co-incidence of natural disasters and epidemics can significantly influence the vulnerabilities and capacities of health systems and put people's health at high risk. Therefore, facing the dual risk of disasters and epidemics (e.g., COVID-19) can be a vital issue for health systems and needs to be studied and focused on by researchers, scholars, and health system administrators. Thus, the Research Topic "*Health system response to the co-incidence of epidemics and disasters: the importance of lessons learned during the COVID-19 pandemic*" was selected and notified by the journal "*Frontiers in Public Health*" to publish research papers that investigated and reported the different aspects of the health system response to the co-incidence of the COVID-19 pandemic and disasters across the world.

A total of 11 papers related to this Research Topic were accepted and published in the journal. None of the submitted papers addressed the co-incidence of the COVID-19 epidemic and natural disasters but considered the COVID-19 epidemic as a disaster

and reported its various health aspects. For instance, regarding the social health aspect of COVID-19, social vulnerability indicators were developed to highlight the incidence of the COVID-19 epidemic in socially vulnerable regions in Iran (Moslehi et al.). People's risk perception regarding the COVID-19 pandemic was investigated by Chinese researchers. They indicated that the older population, as a vulnerable group, had the highest risk perception score regarding the COVID-19 epidemic in China (Chen C. et al.). Several authors investigated and analyzed the status of healthcare providers at the time of COVID-19. For example, the insufficient preparedness of nurses to respond to the COVID-19 crisis in Iran was extracted and reported (Moradian and Mahmoudi). In Germany, the self-images of ICU clinicians for crisis management during the COVID-19 epidemic were explored and reported as important perceptions that should be notified by policymakers (Piel et al.). NGOs, as one of the important relief providers, can supply emergency relief resources with the support of the government through media publicity and policymaking encouragement in China (Lu and Wang). Regarding post-disaster recovery, resilient communities could cope with the effects of the COVID-19 epidemic better than vulnerable communities, which have insufficient communications and information (Irasanti et al.). The surge capacity of healthcare facilities was an important issue at the time of the COVID-19 epidemic. Accordingly, the Arizona Department of Health Services has designed and implanted a surge line since the COVID-19 pandemic. This line was successful in facilitating patient transfer and benefiting marginalized populations (Villarroel et al.). Medical performance evaluation and COVID-19 vaccination optimization were also investigated by Chinese authors, who published their research in this Research Topic (Chen M. et al.; Wen et al.).

Although the impacts of disasters and epidemics on health systems have been reported by several studies, little is known about how to reduce the dual risk of disasters and epidemics. The COVID-19 epidemic provided a unique opportunity for identifying the emergent challenges and establishing innovative risk reduction and preparedness strategies to respond to similar crises in the future. The health sector has the main responsibility for people's health, and thus, plays special roles during the co-incidence of epidemics and disasters. Applying the lessons learned during the COVID-19 epidemic and establishing resilient health facilities and prepared healthcare staff can reduce deaths, injuries, and health system destruction after epidemics and disasters. Otherwise, all the adverse challenges and issues that the world experienced during the COVID-19 pandemic will probably repeat in any similar pandemic in the future. Thus, health systems need scientific collaborations and policymaking efforts at regional and international levels. The documentation and publication of effective lessons learned by health systems in the areas of prevention and treatment and disaster and emergency management should be considered as important measures and the first steps in future planning and policymaking.

Author contributions

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Medical implementation practice and its medical performance evaluation of a giant makeshift hospital during the COVID-19 pandemic: An innovative model response to a public health emergency in Shanghai, China

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Introduction: In confronting the sudden COVID-19 epidemic, China and other countries have been under great pressure to block virus transmission and reduce fatalities. Converting large-scale public venues into makeshift hospitals is a popular response. This addresses the outbreak and can maintain smooth operation of a country or region's healthcare system during a pandemic. However, large makeshift hospitals, such as the Shanghai New International Expo Center (SNIEC) makeshift hospital, which was one of the largest makeshift hospitals in the world, face two major problems: Effective and precise transfer of patients and heterogeneity of the medical care teams.

Methods: To solve these problems, this study presents the medical practices of the SNIEC makeshift hospital in Shanghai, China. The experiences include constructing two groups, developing a medical management protocol, implementing a multi-dimensional management mode to screen patients, transferring them effectively, and achieving homogeneous quality of medical care. To evaluate the medical practice performance of the SNIEC makeshift hospital, 41,941 infected patients were retrospectively reviewed from March 31 to May 23, 2022. Multivariate logistic regression method and a tree-augmented naive (TAN) Bayesian network mode were used.

Results: We identified that the three most important variables were chronic disease, age, and type of cabin, with importance values of 0.63, 0.15, and

0.11, respectively. The constructed TAN Bayesian network model had good predictive values; the overall correct rates of the model-training dataset partition and test dataset partition were 99.19 and 99.05%, respectively, and the respective values for the area under the receiver operating characteristic curve were 0.939 and 0.957.

Conclusion: The medical practice in the SNIEC makeshift hospital was implemented well, had good medical care performance, and could be copied worldwide as a practical intervention to fight the epidemic in China and other developing countries.

KEYWORDS

giant makeshift hospital, performance, TAN Bayesian network, COVID-19 pandemic, China

1. Introduction

Since 2020, Shanghai has been experiencing a COVID-19 outbreak in 2 years. According to the Shanghai Municipal Health Commission, from the beginning of outbreak to May 2022, more than 590,000 cases have been identified, including 538,450 asymptomatic carriers (1). The rapidly increasing number of COVID-19 cases puts healthcare systems under extraordinary stress; epidemiological studies have shown that COVID-19 has a high rate of intrafamily transmission in China (2, 3), and it is especially difficult to monitor disease progress in the community (4, 5).

1.1. Construction of the makeshift hospitals and response to COVID-19 pandemic

Converting large-scale public venues into makeshift hospitals (MHs) is a popular means of rapidly addressing the coronavirus disease 2019 (COVID-19) outbreak and maintaining the smooth operation of a country or region's healthcare system during a pandemic (6). An MH (mobile cabin hospital or fangcang shelter hospital) is a modular health setup that provides multiple functions, including isolation, triage, basic medical care, frequent monitoring, rapid referral, and essential living needs (3). The successful employment of MHs in tackling the COVID-19 epidemic in Wuhan has been acknowledged worldwide (7, 8). The USA, the UK, and other countries have adopted a similar approach (9–11). The largest MHs in the world include Madrid's Ifema Emergency Field Hospital (5,500 beds, the largest in Europe) (12), the Wuhan Optics Valley Rihai MH (3,690 beds, the largest in China), and the Javits New York Medical Station (512 beds, the largest in the USA). China has built 120 MHs in Shanghai, including four giant hospitals (here we set > 10,000 beds as the capacity criterion for a giant MH), to ensure the swift quarantine and treatment of infected people and break the transmission path of COVID-19. Giant MHs can accommodate more infected patients for isolation treatment, and they enable limited medical resources to be centralized and integrated; thus, they play an important role in an epidemic.

Giant MHs also have shortcomings, including a lack of standard hospital medical facilities and that the integrated staff consists of medical professionals from different hospitals among the Chinese provinces. Moreover, a large number of patients are managed by temporarily recruited medical teams using an operative response mechanism catered to the emergency situation. Therefore, giant MHs pose great challenges to the Chinese healthcare system, medical treatment quality, and patient management.

Among the giant MHs, the Shanghai New International Expo Center (SNIEC) MH is the first >10,000-bed capacity MH in the world. It has a total construction area of over 300,000 square meters and 14,054 open beds; it was completed by 6,000 builders in 184 h. There are 10 ward cabins in the N (N1–N5) and W (W1–W5) medical areas. Figure 1A shows an exterior view of the SNIEC MH. During the whole operation stage, from March 31 to June 15, 2022, a total of 47,920 patients have been treated, setting a record of treating more than 14,000 infected patients in 1 day. From April 5, 2022, Renji Hospital affiliated to Shanghai Jiaotong University School of Medicine has been assigned to manage the SNIEC MH. Due to the sudden spike in the number of cases and limited resources designated to hospitals, the SNIEC MH was upgraded to two ward cabins: W1 and W2. Figure 1B shows an interior view of the SNIEC MH. The upgraded W1 and W2 ward cabins are equipped with 1,920 beds, with examination equipment (mobile CTs, ultrasound diagnostic devices, chest X-ray machines) and life support equipment (high-flow oxygen therapy device, ventilator, continuous renal replacement therapy, automated external defibrillator).

Like other large MHs, the SNIEC MH faces two major problems.

FIGURE 1
Exterior birdview **(A)** and interior view in subordinate cabin **(B)** of the SNIEC makeshift hospital.

1.2. Problem 1: How can high-risk patients be identified and transferred to designated hospitals in a timely and effective manner?

COVID-19 is a highly contagious respiratory disease with varying symptoms. According to the eighth edition of the COVID-19 Prevention and Control Plan, COVID-19 cases can be divided into mild, moderate, severe, and critical types (13). However, the symptoms at onset are relatively mild, and a significant proportion of patients do not display symptoms prior to the development of respiratory failure. Clinically, this makes it difficult to predict the progression of disease severity in patients until respiratory failure occurs. The aging rate of Shanghai's population is the highest among megacities in mainland China and internationally. Limited medical facilities make it difficult to allocate advanced life support and primary disease treatment to critically ill patients over extended periods. At the peak of the epidemic, the SNIEC MH had eight ordinary cabins, two subordinate cabins, and more than 10,000 hospitalized patients. The ordinary cabin is referred to a simple basic dwelling in the makeshift hospital, which only receives asymptomatic patients or ones with symptoms of mild severity. Compared with the ordinary cabin, the subordinate cabin (also called sub-designated-hospital-cabin) is the transitional cabin between ordinary cabins and designated hospitals, and is built to receive and treat patients with symptoms of moderate severity. It also has additional functions such as imaging examination, facilitating the treatment of the common and underlying diseases for COVID-19 patients, and alleviating the rokecting demands for beds in designated hospitals. Due to the medical limitations of ordinary makeshift cabins, the theoretical indications for admission were asymptomatic and mildly severe disease. However, in practice, patients were usually admitted in batches; a community-based administrative unit organized transfers, resulting in great differences between the admission criteria and the patients' confirmed conditions. At peak times, thousands of patients per day were admitted in batches to hospitals. Therefore, the challenge arose as to how the SNIEC MH can timely and effectively screen for high-risk patients and refer them to designated hospitals for further medical treatment.

1.3. Problem 2: How can a temporally organized team achieve a homogeneous quality of medical care?

In contrast to traditional medical institutions and small- or medium-sized MHs, a medical team in the giant SNIEC MH includes more than 4,300 medical staff from more than 300 medical institutions among the Tianjin, Hubei, Jiangxi, Shanxi, Henan, Guizhou, and Shanxi provinces. This causes variations in the understanding of patients' conditions among the medical staff. Wearing personal protection equipment can impair the work efficiency of the medical staff. In addition, limited working hours and frequent handovers may cause deviations among the medical staff's familiarity with patients' conditions and full knowledge of the relevant medical procedures.

Existing literature on makeshift hospitals mainly focused on clinical characteristics (14–16), symptom dynamics, treatment strategies (17–19), and psychological distress (20–22) of COVID-19 patients in them. Studies illuminating medical care experiences of the MHs, especially a giant MH, and evaluating the medical care performance with quantitative methods were limited. Understanding the medical implementation practice and its performance evaluation of a giant makeshift hospital during the COVID-19 pandemic will assist in investigating the effectiveness of this novel centralized isolation approach in response to public health emergencies. Though unanimously building large-scale makeshift hospitals to cope with the COVID-19 is unlikely for all the countries worldwide, such possibility should not be excluded in the future. Due to the

capricious trajectory of the COVID-19 pandemic and other potential emergencies accompanied by natural disasters, the healthcare system will be at the frontline of the emergency response team. Therefore, this study analyzed the medical implementation practices of the SNIEC giant MH in Shanghai and evaluated its medical practice performance using two methods. This will hopefully provide a practical reference for China and other countries to prevent and control similar events during public health emergencies.

Based on the aforementioned issues faced with the SNIEC MH in Shanghai, we put forward three research questions for the study: (1) how to identify and transfer COVID-19 patients to designated hospitals timely and effectively in the SNIEC MH? (2) how to ensure the homogeneous quality of medical care when the temporally organized medical team members from different regions cooperated together in the SNIEC MH? and (3) how to evaluate the operational performance of the aforementioned medical care practice in the SNIEC MH?

2. To solve problem 1: Construct two groups and develop a medical management protocol package to implement medical practice in the SNIEC MH

Two medical management organizational groups were constructed: an internal joint medical management group and an external comprehensive coordination group.

2.1. The joint medical management group

In order to achieve a homogeneous management quality, the SNIEC MH set up a joint medical office to be the managing department responsible for making plans, organizing, and controlling the medical activities in the entire hospital.

2.2. The external general coordination group

To ensure timely and effective communication regarding the discharge of recovered patients and referrals of essential patients, the SNIEC MH set up an external general coordination office. This group was connected with local government offices, health commissions, civil affairs bureaus, medical emergency centers, and major designated hospitals across 16 administrative districts. The external coordination team could coordinate with at least one designated hospital to reserve beds for potentially referred patients, establish a smooth referral system, and allow patients to be transferred quickly for medical emergencies. The work mechanism and organization structure of management groups in the SNIEC MH was displayed in Figure 2.

2.3. Developing a medical quality management package

The SNIEC MH formulated a series of core management systems to ensure medical treatment quality, safety, and homogeneity of medical care. The core medical management systems included admission, referral, discharge, doctor rounds, consultation, assessing the conditions of elderly patients, nursing, duty and shift handover, case discussion, critical patient rescue, patient identity verification, medical record management, and management of antimicrobial drug classification. A flowchart of the patient screening and criteria for admission, discharge, and referral is shown in Figure 3.

2.3.1. Admission criteria for ordinary cabins in the SNIEC MH

Generally, only asymptomatic patients and confirmed cases with mild severity could be accommodated (see the specific rules in Table S (A) of the Appendix file).

2.3.2. Admission criteria of subordinate hospital cabin in the SNIEC MH

Generally, patients who are confirmed to have moderate severity can be accommodated (see specific rules in Table S (B) of the Appendix file).

2.3.3. Discharge criteria in the SNIEC MH

See specific rules in Table S (C) of the Appendix file.

2.3.4. Criteria for referral to a high-level designated hospitals

Due to the limited resources of designated hospitals, such as hospital beds and ventilators, clinicians were often faced with difficult decisions in which they must ration resources among patients. Therefore, criteria were formulated for referral to high-level designated hospitals. Generally, patients who are severe or critically ill will be referred (see specific rules in Table S (D) of the Appendix file).

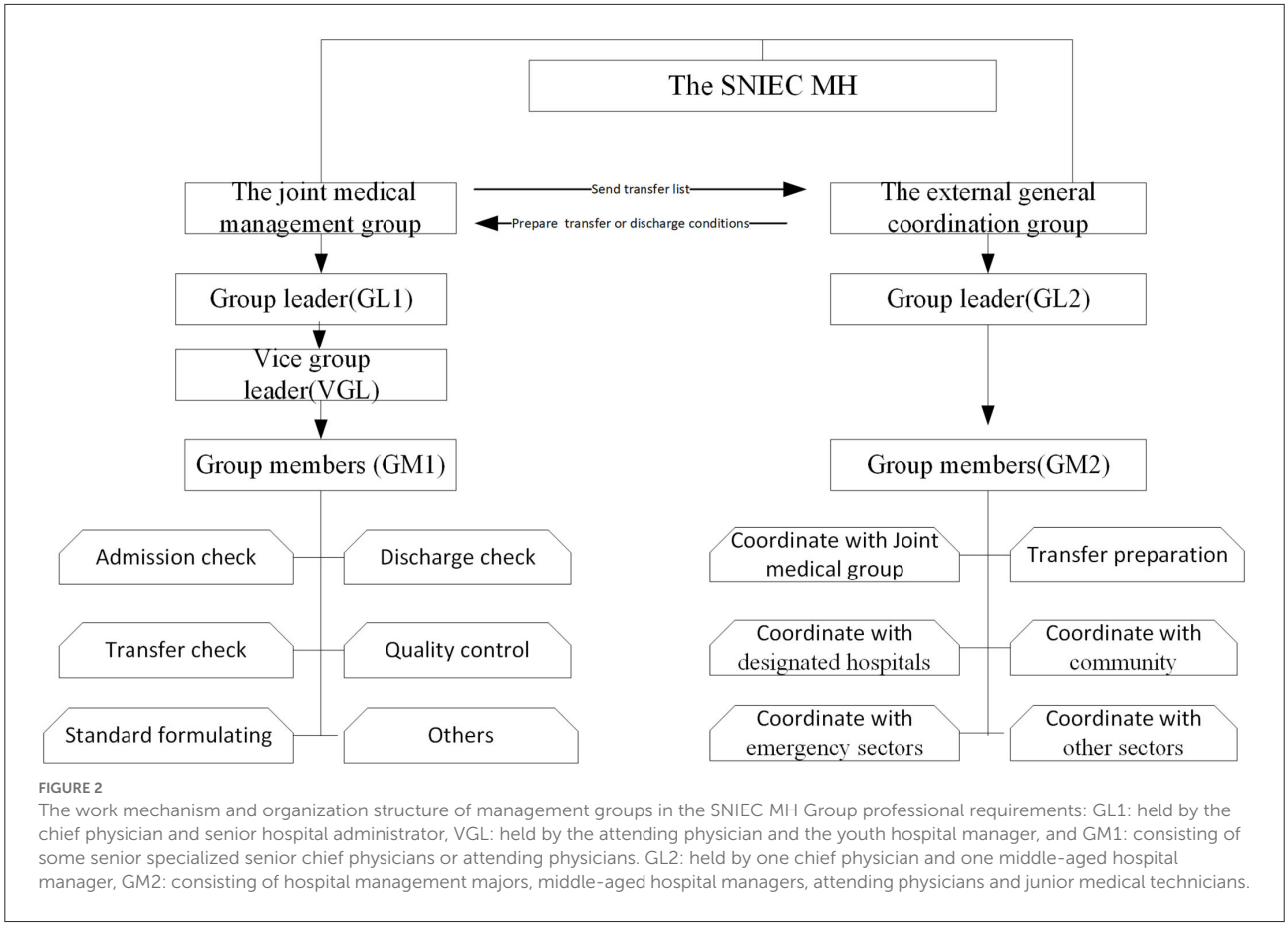

FIGURE 2
The work mechanism and organization structure of management groups in the SNIEC MH Group professional requirements: GL1: held by the chief physician and senior hospital administrator, VGL: held by the attending physician and the youth hospital manager, and GM1: consisting of some senior specialized senior chief physicians or attending physicians. GL2: held by one chief physician and one middle-aged hospital manager, GM2: consisting of hospital management majors, middle-aged hospital managers, attending physicians and junior medical technicians.

3. To solve problem 2: Implement a multidimensional management mode to achieve homogeneous quality of medical care from a temporally organized team in the SNIEC MH

Internationally since 2020, many countries have implemented the integration of temporally-organized medical teams from various countries or regions to achieve the homogeneous quality of medical care to cope with COVID-19. For example, US has recruited volunteered health workers across the country to combat the outbreak of COVID-19. EU sent medical teams to Italy to help fight coronavirus. These medical workers from different regions were similar to the provincial supporting medical teams in our study. Although they did not know each other, and had different dialects, cultural background and medical practice features, they adopted various medical care modes, cooperated smoothly with each other to ensure the homogeneous quality of medical care.

Referring the aforementioned successful cases and experiences on integrated medical care teams of different origins in many countries, the SNIEC MH adopted a multi-dimensional management mode, as follows:

(A) Supervision of medical teams working 4-h shifts was conducted in each cabin. A shift leader was designated for each shift, and each patient was assigned to a clinician and the corresponding upper-level doctor.

(B) A multi-disciplinary cooperation rescue and emergency response team was formed consisting of senior professional physicians, in which medical experts were deployed to respond to emergencies at any time. The system was formulated so that the cabin was passed to a new team at 9 a.m. every day; medical experts discussed key patients at 11 a.m. each day to ensure the scientific nature of their medical treatment.

(C) A daily "observer" inspection system was established in which on-site screening of key patients, treatment guidance, coordinative examination, referral, and other medical affairs were conducted. The medical observer system can compensate for the early identification and

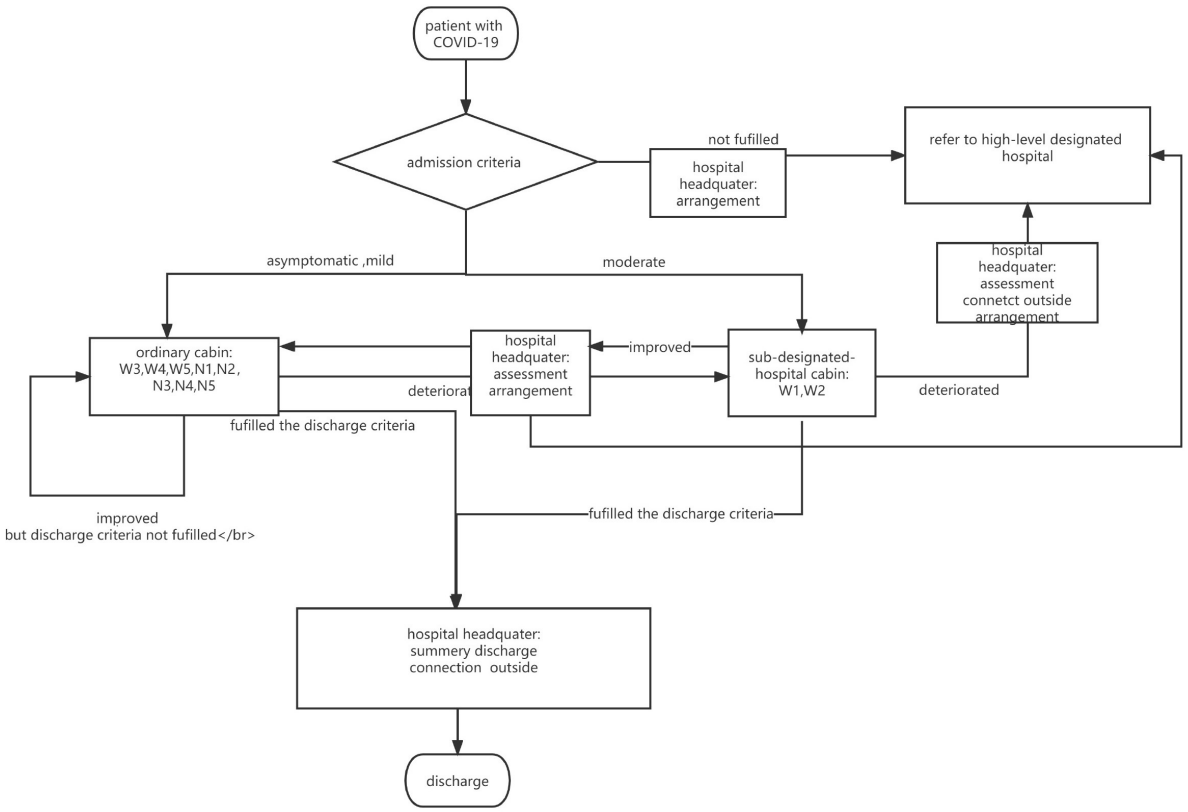

FIGURE 3
Procedure of patient screening and infow in the SNIEC makeshift hospital.

diagnosis rate of critical patients and early treatment through daily inspection of key patients. Moreover, the medical observation system can overcome disadvantages in care heterogeneity (due to medical teams being from various provinces) and in the referral process by communicating with patients and their families. This improves the referral procedures and staff communication, which reduces the occurrence of medical disputes.

4. Evaluating the medical practice performance of the SNIEC MH using two methods

4.1. Data resource and variables

We retrospectively reviewed patients' data, which were randomly collected from the health information system (HIS) of the SNIEC MH, and eligible patients were selected if meeting the inclusion criteria as follows: 1 year and older; admitted up to May 23, 2022 (the final date of the data statistics); either discharged with recovery or referred to designated hospitals from March 31 to May 23, 2022. The patient outcomes were dichotomized into *discharge* (=0) or *referral* (=1) as the dependent variable. According to the existing literature (17, 23, 24), we considered some variables including demographic characteristics of the patients, such as age and sex, and their health-related profiles, including type of cabin, chronic disease, classified severity types, and length of stay as independent variables of interest in the study. Ethical approval was obtained through the University Human Research Ethics Committee (KY2022-102-B).

4.2. Analysis strategy

4.2.1. Multivariate logistic regression method

All continuous variables were tested for normality. Means ± standard deviation were used for variables that fit a normal distribution; medians and interquartile ranges (IQRs) were used for variables with a skewed distribution. After univariate analysis identified significant contributors, a multivariate backward

TABLE 1 Patient characteristics, univariate and multivariate logistic regression analysis of factors related to the outcome of COVID-19 patients in SNIEC makeshift hospital.

Items	Patient characteristics		Discharge patients ($N = 41,558$)	Referral Patients ($N = 383$)	Univariate *Chi square*		Multivariate logistic regression	
	Variables	Patients, *n* (%)			χ^2	*P*	*OR* (95% *CI*)	*P*
Outcome	Discharge	41,558(99.1)	41,558	0	/	/	/	/
	Referral	383(0.9)	0	383	/	/	/	/
Type of cabin					$\chi^2 = 968.118$	$P < 0.001$		
	Ordinary cabin	37,393(89.2)	37,240(99.6)	153(0.4)			1.000	
	Subordinate hospital Cabin	4,548(10.8)	4,318(94.9)	230(5.1)			0.041 (0.012–0.148)	<0.001
Gender					$\chi^2 = 39.557$	$P < 0.001$		
	Male	23,628(56.3)	23,473(99.3)	155(0.7)			1.000	
	Female	18,313(43.7)	18,085(98.8)	228(1.2)			1.602 (1.267–2.026)	<0.001
Age (years)					$\chi^2 = 4,707.840$	$P < 0.001$		
	1–56	33,191 (79.1)	33,028 (99.5)	163 (0.5)			1.000	
	57–72	8,112 (19.3)	8,010 (98.7)	102 (1.3)			0.687 (0.522–0.905)	0.007
	73–81	504 (1.2)	45 (8.9)	459 (91.1)			1.565 (1.043–2.350)	0.031
	Above 82	134 (0.3)	73 (54.5)	61 (45.5)			17.393 (10.550–28.676)	<0.001
Classified for severity types					$\chi^2 = 1,025.791$	$P < 0.001$		
	Asymptomatic	29,250(69.7)	29,162 (99.7)	88 (0.3)			1.000	<0.001
	Mild	8,116(19.4)	8,056(99.3)	60(0.7)			1.872 (1.331–2.641)	<0.001
	Moderate	4,575(10.9)	4,340(94.9)	235(5.1)			100.528 (28.005–260.862)	<0.001
Chronic disease or not					$\chi^2 = 1,726.967$	$P < 0.001$		
	No	35,597(84.9)	35,562(99.9)	35(0.1)			1.000	
	Yes	6,344(15.1)	5,996(94.5)	348(5.5)			36.364 (25.113–52.656)	<0.001
Length of hospital stay	/	/	/	/	/	/	0.728 (0.697–0.759)	<0.001

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stepwise logistic regression method was used to predict the outcomes of patients.

4.2.2. Tree-augmented naive Bayesian network method

Bayesian networks are suitable for multivariate analysis. A Bayesian network is a probabilistic graphical model for representing knowledge about an uncertain domain; each node corresponds to a random variable, and each edge represents the conditional probability for the corresponding random variables. A directed acyclic graph (DAG) is often used to represent complex variable relationships for a specific problem in a network structure, the directed edges of connected nodes represent causal relationships among variables. Conditional probability table (CPTs) are used to evaluate the correlation and intensity of variables (25). In recent years, Bayesian networks have been widely used for multivariate analyses in the medical field, including for analyzing clinical diagnoses and risk prediction (26–31). A tree-augmented naive (TAN) Bayesian network is a form of classic Bayesian network model that can deal with relevant variables and has good predictivity for multidimensional data (32). The TAN Bayesian network in this study uses a graphical diagram to provide a comprehensive way of representing relationships and influencing paths among variables of interest. The receiver operating characteristic curve (ROC) and area under the ROC curve (AUC) were used to evaluate the validity of the model.

All statistical analyses were performed using the SPSS version 23.0 statistical package (IBM Corp., Armonk, NY, USA). IBM SPSS Modeler 18.0 was used to build the TAN Bayesian network model.

5. Evaluation results

5.1. Basic characteristics

There were 41,941 eligible patients selected from the SNIEC MH. Among them, 41,558 (99.1%) were discharged with recovery, and 383 (0.9%) were referred to designated hospitals for further treatment. During the whole operation period of the SNIEC MH, no medical accidents or mortality occurred in the SNIEC MH. The Kolmogorov-Smirnov method test results (both the values of Asymp. Sig. $=0.000 < 0.05$ for age and length of stay in hospitals) showed that none of the continuous features exhibited a normal distribution; therefore, medians and IQRs are reported. The median age was 43 years (IQR: 24, range: 1–102). The median length of stay was 8 days (IQR: 5). Of the 41,941 patients, 23,628 (56.3%) were male and 18,313 (43.7%) were female (Table 1). There were 4,575 (10.9%) moderate cases, 8,116 (19.4%) mild cases, and 29,250 (69.7%) were asymptomatic; 35,597 (84.9%) patients had no chronic disease, and 6,344 (15.1%) reported having a chronic disease. We divided the patients into four age-based groups. The groups included 33,191 (79.1%) of age ≤56 years, 8,112 (19.3%) of age 57–72 years, 504 (1.2%) of age 73–81 years, and 134 (0.3%) of age ≥82 years (Table 1). The other details are listed in Table 1.

TABLE 2 Predictor importance of Bayesian network.

Variables	Predictor importance
Having a chronic disease	0.63
Age	0.15
Type of cabin	0.11
Gender	0.05
Length of hospital stay	0.04
Classified severity types	0.02

5.2. Results of univariate and multivariate logistic regression analysis

The characteristics of the discharged and referred patients were compared using univariate analysis (Table 2). The factors associated significantly with the outcome of patients were type of cabin ($P < 0.001$), sex ($P < 0.001$), age ($P < 0.001$), severity type ($P < 0.001$), and chronic disease ($P < 0.001$). Multivariate logistic regression analysis, using the backward stepwise method in the two groups of patients, showed that the risk factors associated significantly with referral were female sex (OR: 1.602, $P < 0.001$), age 73–81 years (OR: 1.565, $P = 0.031$), age ≥ 82 years (OR: 17.393, $P < 0.001$), mild disease (OR: 1.872, $P < 0.001$), moderate disease (OR: 100.528, $P < 0.001$), and chronic disease (OR: 36.364, $P < 0.001$). The protective factors for referral patients were age 56–72 years (OR: 0.687, $P = 0.007$), subordinate hospital cabin (OR: 0.041, $P < 0.001$), and length of hospital stay (OR: 0.728, $P < 0.01$) (Table 1).

5.3. Results of TAN Bayesian network method

SPSS modeler 18.0 was used to establish a Bayesian network model of factors that influence patients' outcomes. We randomly divided the dataset into training and test sets at a 70:30 ratio (29,272 and 12,669 records, respectively). We set sex, age, type of cabin, presence of chronic disease, classification of severity type, and length of stay as import variables; the outcome (discharge or referral) was the target variable. DAGs and CPTs were mined using the TAN model of the Bayesian network. In a DAG, each node representing an occurring event represents a variable, and all nodes pointing to node X are called the parent nodes of X. A Bayesian network edge indicates the probability that the event

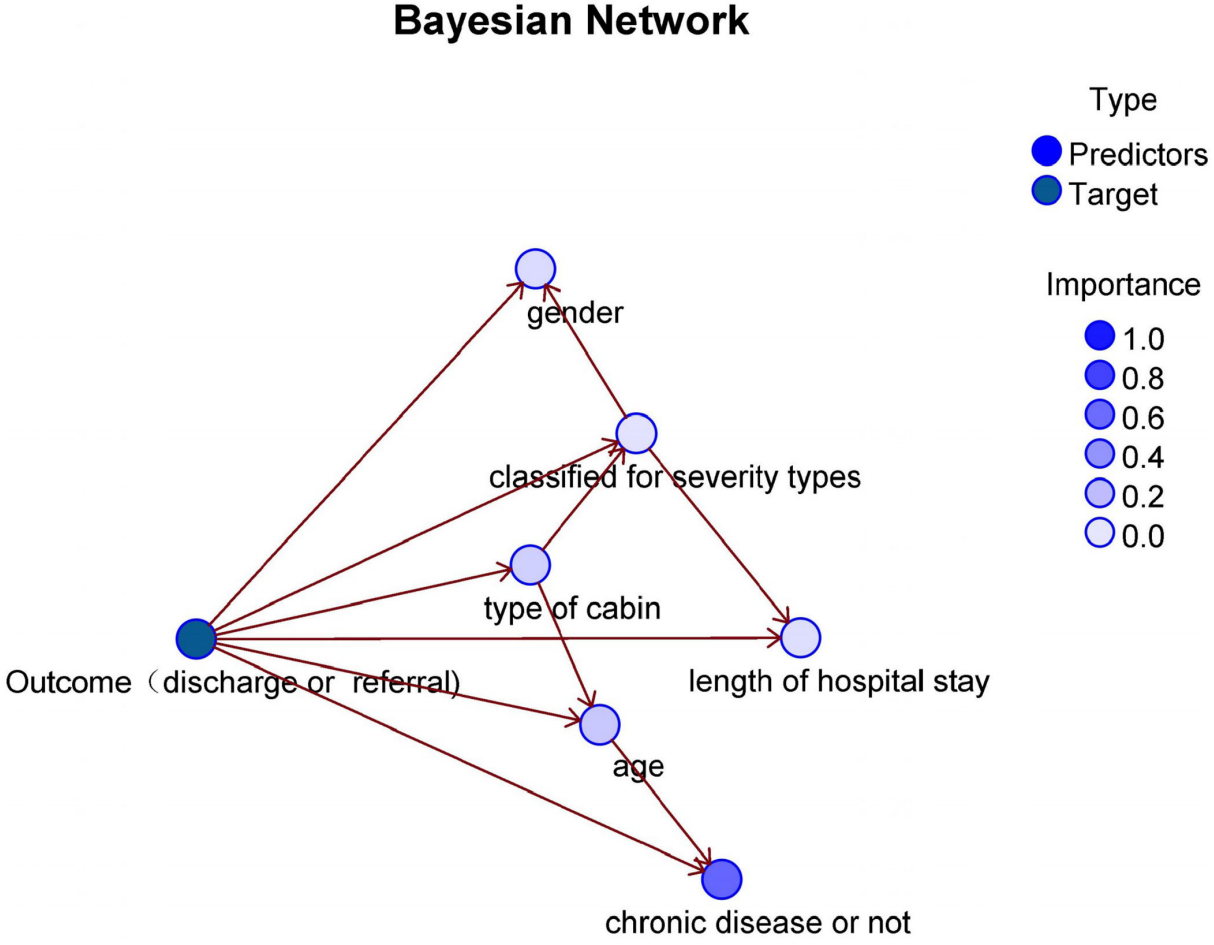

FIGURE 4
Directed acyclic graph of Bayesian network.

of the child node will occur if the event of the parent node has occurred (the root node has no probability). Parent and child nodes must be directly related. The DAG is shown in Figure 4. In the DAG, the darkness of the input variable's color indicates the importance of the prediction of the target variable. The input variable with the darkest color is a chronic disease, the nodes in the DAG correspond to the variables in the model, and each node has a CPT (Figure 4). Figure 4 and Table 2 demonstrate the importance of these variables. We found that all six input variables had effects on the target variable; the most important variables were chronic disease, age, and type of cabin (0.63, 0.15, and 0.11, respectively). The TAN Bayesian network not only computes the probability distributions of the child nodes given the values of their parent nodes, but also the distribution of the parent nodes given the values of their children. That is, they can both proceed from causality and deduce the probabilities of different causes given the consequences. The conditional probability tables present all possible conditional probabilities when each node is conditioned on its parent node (Tables 3A–C).

5.4. Model validation

The performance of the model was assessed using the AUC of the ROC curve. The ROC was plotted by obfuscation matrix. In the field of machine learning, the confusion matrix is a situation analysis table that summarizes the prediction results of the classification model. It is a visualization tool used to test the effects of the classifier. In the form of a matrix, the records in the dataset were predicted based on real classification values and classification models. The classification results were compared and summarized; each row of the matrix represents the real category, and each column represents the predicted category. The AUC represents the ROC curve and has a value between 0 and 1. The closer the ROC curve is to the upper left corner,

TABLE 3 Conditional probabilities of having a chronic disease or not, age and type of cabin.

(A) Having a chronic disease or not			
Parent nodes		Probability	
Age	Outcome	Chronic disease (No)	Chronic disease (Yes)
1–56	Referral	0.15	0.85
57–72	Referral	0.11	0.89
73–81	Referral	0.04	0.96
No less than 82	Referral	0.05	0.95

(B) Age					
Parent nodes		Probability			
Type of cabin		Age			
Outcome		1–56	57–72	73–81	No less than 82
Ordinary	Referral	0.67	0.26	0.06	0.01
Ordinary	Discharge	0.81	0.18	0.00	0.00
Subordinate	Referral	0.26	0.31	0.15	0.28
Subordinate	Discharge	0.63	0.30	0.07	0.01

(C) Type of cabin		
Parent nodes	Conditional probability	
Outcome	Ordinary cabin	Subordinate Hospital cabin
Referral	0.42	0.58
Discharge	0.90	0.10

the greater the AUC value is; this indicates that the greater the prediction capability, the better the model. The constructed Bayesian network model had a good predictive value (Figure 5, Table 4). The overall correct rates of the model-training dataset partition and test dataset partition were 99.19 and 99.05%, respectively; the respective AUC values were 0.939 and 0.957.

6. Discussion

COVID-19 has upended myriad aspects of life, particularly the receipt of usual medical care. Routine medical observation and treatment might not be available during the pandemic, especially in developing countries, because medical interactions often violate social distancing protocols, and people in need of medical care are often at risk for adverse outcomes from COVID-19. To cope with and adapt to this situation, giant MHs are specially constructed to respond to COVID-19 and other public health emergencies. They need to be able to screen out COVID-19-infected patients at risk of deterioration and transfer them to high-level designated hospitals. However, it is also necessary to alleviate pressure on high-level designated hospitals for admission and treatment. Achieving this trade-off is a challenge for medical managers in MHs. Moreover, it is crucial to implement homogeneous cabin management among the different temporally organized medical teams in this large medical setting, especially for standardizing the criteria for admission, discharge, and transfer of patients.

In the SNIEC MH, we constructed two groups and developed a medical management protocol to conduct patient screening and treatment. A multi-dimensional management mode was designed to achieve homogeneous quality of medical care by a temporarily organized team. To evaluate the operational medical performance of the SNIEC MH, we constructed a TAN Bayesian network model to assess the outcome of COVID-19–infected patients and the model was validated. It was shown in the DAG that the *type of cabin* is the parent node of the *classified severity types*. This means that the patients in the SNIEC MH were screened for suitability of transfer to an ordinary cabin or a sub-designated–hospital cabin according to their severity type classification. Consequently, the results were consistent with the operational principals of the SNIEC MH, identifying that the admission standards for ordinary cabins and the sub-designated–hospital cabins were implemented well in practice. DAG showed that *length of stay* and age, and *type of cabin* and *chronic disease*, had no direct linear segments. This indicates that these contributors were independent of each other. Furthermore, the DAG identified that the parent node of the *length of stay* is *classified severity types*, indicating that the discharge standards formulated by the SNIEC were implemented appropriately.

Through the multivariate logistic regression model, our research showed that gender, age (73–81 years and $\geq$ 82 years), severity type (mild disease and moderate disease), and chronic disease were risk factors for the referral of COVID-19 patients, while age 56–72 years, and type of cabin (subordinate hospital cabin) were protective factors for referral. Furthermore, the predictive importance of the Bayesian network showed that having a chronic disease was the most important indicator for predicting the outcome of patients. The importance of influencing factors was 0.63; the importance of age was 0.15, which was higher than that of other factors. These findings were in concordance with some previous studies (23, 33–40). A retrospective study found that the patient's age, hypertension and heart disease are independent risk factors for the progression of COVID-19 patients in Fangcang shelter hospitals (33). A study found older age (over 65 years) was associated with higher odds of progression to severity of COVID-19 (34). Many studies have shown that COVID-19 patients with a history of chronic diseases were more difficult to cure, and the underlying chronic disease was also more likely to develop into a severe disease or even causing death (35–38). These studies have shown that for the elderly patients and patients with potential comorbidities, more attention, early referral or timely intervention are needed to avoid the

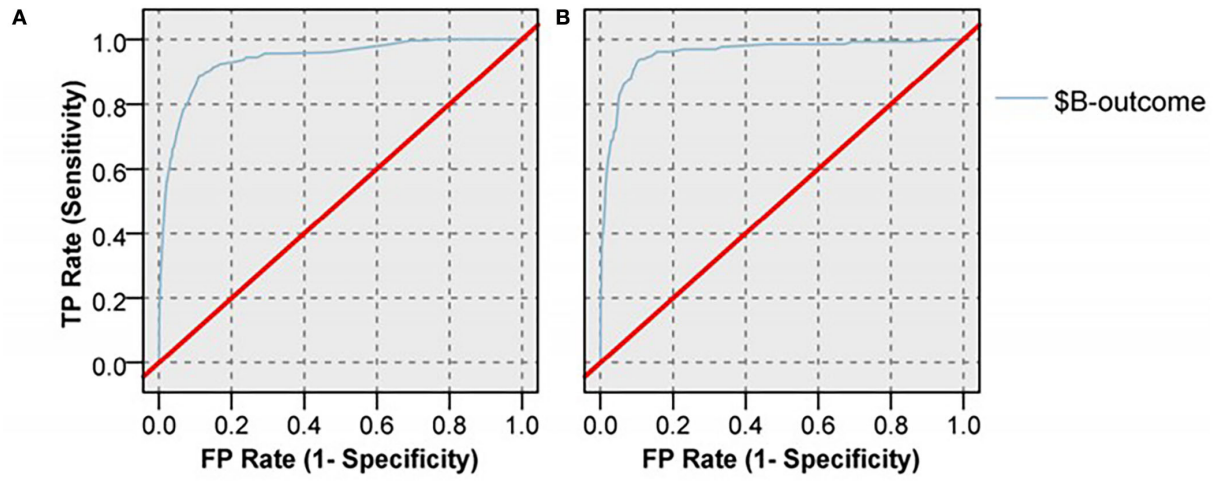

FIGURE 5
ROC curve of Bayesian network model in training dataset **(A)** and test dataset **(B)**.

TABLE 4 The validation of TAN Bayesian network.

	Training dataset		Test dataset	
Correct	29,036	99.19%	12,549	99.05%
Wrong	236	0.81%	120	0.95%
AUC	0.939		0.957	

AUC, Area under the ROC curve.

development of severe illness or death. However, the association between gender and COVID-19 patients' outcomes is currently inconclusive in the field of COVID-19 research. In our study, female sex was a risk factor associated with referral of patients with COVID-19. This may be due to the distribution of patients' age with 70.9% females were in the age group of ≥ 82 years in the study. Conversely, some studies found male sex was associated with a worse outcome of patients with COVID-19 in an elderly hospitalized population (23, 39). Although the reasons for this gender difference are unknown, it has been suggested that males and females differ in their immunological responses and in their susceptibility to infection (40, 41).

This result confirms that the transfer criteria were implemented well-regarding team management at the SNIEC MH. During the entire operational stage of the SNIEC MH, there were zero deaths and zero medical accidents. It was shown that, in response to the aforementioned challenges of the SNIEC MH, the medical management quickly established an adaptable organizational system that allowed team members to dilute their previous medical roles in their original hospitals. This enabled them to smoothly adapt to the new organizational structure, give priority to teamwork efficiency, and work with the various medical rules and regulations to achieve homogeneous management of the medical staff in the SNIEC MH.

This study has several strengths that contribute to the existing literature. First, the study established a mechanism, verified by the TAN Bayesian network model, to predict referrals of patients that can assist doctors in making decisions and improve referral efficiency. To the best of our knowledge, this is the first study to focus on the medical practice of a giant MH and describe how it works in response to a public health emergency. The management mode has been successfully carried out, proven to be effective, and can be copied and utilized worldwide. Second, although we included only six characteristic variables, our model achieved a trade-off between the minimal number of features and the capacity for good prediction by avoiding overfitting. This finding shows that evaluation of a small number of patient characteristics, such as chronic disease or age, by the TAN Bayesian network model could help medical staff rapidly screen patients to determine whether they should be discharged or transferred, making full use of the current healthcare infrastructure in the event of public health emergencies. Third, this research contributes to the development of medical quality management tools for giant MHs, which will help clinicians conduct decision-making analyses and risk assessment during a pandemic or for other illnesses or injuries caused by large-scale public emergencies, including a mass poisoning or natural disaster.

6.1. Limitations

This study had some limitations. First, the study was conducted at a single center. Although the dataset contained more than 40,000 cases, a further prospective multicenter study using external validation methods could be needed to assess the

medical care performance of the model for the generalizability of the study findings. Second, although most parameters were documented objectively, some independent variables were self-reported, such as a history of chronic diseases; this may have introduced a recall bias in the study.

7. Conclusion

A public health emergency in a megacity with a population over 10-million will likely see the number of patients spike swiftly during a pandemic outbreak. Therefore, it is important to construct giant MHs to accommodate infected cases and relieve the strain on regular healthcare services. MHs played an important role as an intermediate platform for COVID-19 patients. As the biggest MH in China, the SNIEC MH developed a medical management protocol package and a multi-dimensional temporally organized integrated team to screen patients and transfer them effectively and achieve homogeneous quality of medical care. This was confirmed by multivariate logistic regression analysis and the TAN Bayesian network method to be implemented well and have good performance.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by the Renji Hospital Affiliated to the Shanghai Jiaotong University School of Medicine's Institutional Review Board. Written informed consent was not required in accordance with the ethics approval.

Author contributions

MC, JQ, JZ, and ED designed the study together, acquired the data, and developed the statistical plan, performed the statistical analysis, and interpreted the analysis. QX, YF, DX,WF, HH, and XZ carried out the survey. MC, JZ, and ED drafted and revised the manuscript. All authors read and approved the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.1019073/full#supplementary-material

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Optimizing COVID-19 vaccine allocation considering the target population

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Vaccine allocation strategy for COVID-19 is an emerging and important issue that affects the efficiency and control of virus spread. In order to improve the fairness and efficiency of vaccine distribution, this paper studies the optimization of vaccine distribution under the condition of limited number of vaccines. We pay attention to the target population before distributing vaccines, including attitude toward the vaccination, priority groups for vaccination, and vaccination priority policy. Furthermore, we consider inventory and budget indexes to maximize the precise scheduling of vaccine resources. A mixed-integer programming model is developed for vaccine distribution considering the target population from the viewpoint of fairness and efficiency. Finally, a case study is provided to verify the model and provide insights for vaccine distribution.

KEYWORDS

COVID-19, vaccine allocation, the target population, multiple-dose vaccine, mixed-integer programming

1. Introduction

The novel coronavirus pneumonia (COVID-19) began ravaging the globe in 2019 and became a public health emergency. The COVID-19 pandemic threatens global health and economic development. Vaccination is one of the most effective solutions. Rapid development, distribution, and vaccinating the global population may be the most effective way to quell the epidemic (1). The United Nations highlights the importance of providing COVID-19 vaccine as a global public good that is globally accessible and affordable (2). However, the early production capacity of the COVID-19 vaccine has not been able to meet the actual demand, which means that not everyone will be able to get the vaccine immediately in the early stages of use. How to properly distribute COVID-19 vaccines among different geographic regions with limited production capacity has become an urgent scientific issue.

When a major public health emergency occurs, optimization of vaccine allocation is vital to ensuring the safety of people's lives and property (3). COVID-19 vaccination is a large-scale social activity. This nationwide vaccination campaign is unprecedented. However, the distribution of COVID-19 vaccines as special medical supplies is different from ordinary emergency relief supplies such as tents and food. When natural disasters

occur, the affected areas, especially those that are more severely affected, need emergency supplies to ensure their safety, and rescue operations cannot be delayed. When the epidemic occurs, not everyone is willing or able to receive the vaccine. Therefore, policy makers need to consider the vaccination willingness and physical fitness of members of the society when allocating vaccines. It is foreseeable that there will remain a significant gap in global production capacity for COVID-19 vaccines over the next 2 to 3 years, and COVID-19 vaccines will remain a scarce resource with limited supply for some time to come (4). In the early stages of the vaccine in use, the number of vaccines may be more nervous, not everyone can be vaccinated. Dividing the priority groups for vaccination and ensuring that those with higher priority levels are the first to receive the vaccine are conducive to the prevention and control of the epidemic. In addition, the government should take some regulatory actions and restrictions to achieve a better epidemic control effect. Therefore, it is essential that policy makers consider prioritization, social policy and other factors. Obviously, the vaccine distribution strategy is very complicated in the selection of target population and the distribution of quantity.

If the society has already entered the vaccination phase when the vaccine is distributed, then the target population includes unvaccinated and vaccinated individuals who have not completed the whole vaccination process. Vaccination adheres to the principle of "informed, consensual and voluntary", and requires the active cooperation of social members to establish a crowd immune barrier. Therefore, we first consider the target population when allocating vaccines and analyze them from multiple perspectives. In the context of limited vaccination capacity, optimizing vaccine allocation and prioritization is critical to achieving herd immunity and restoring normal living standards before the pandemic (5). We are also considering the impact of the COVID-19 pandemic on the mental health of the population (6). With the aim to ensure the fairness and efficiency of vaccination, this paper studies the allocation of vaccines considering characteristics of the vaccinated population, attitude toward the vaccine, priority groups for vaccination, and vaccination priority policy simultaneously. We propose a mixed-integer linear programming model of vaccine distribution considering vaccinated populations to maximize vaccination coverage by combining actual vaccine supply with vaccination policies.

Summarily, the main contributions of this paper can be denoted as follows:

Contribution 1: From the perspective of the vaccinated population, we consider the vaccination willingness, the priority of the target population and the relevant policies of the society on the vaccination campaign when allocating vaccines. We consider that some people cannot or do not want to be vaccinated, divide the vaccinated population into different priority levels, and give priority to people who have received n dose(s) of vaccine following relevant vaccination policies.

Contribution 2: From the perspective of quantity allocation, we use multiple doses of COVID-19 vaccines as the allocated resource, and combine with realistic conditions such as inventory and cost. It is more general and applicable to depict multi-dose vaccine allocation into the optimization model.

Contribution 3: From the perspective of fairness and efficiency of COVID-19 vaccine distribution, this paper considers the particularity of vaccination groups and the efficiency of quantitative allocation of vaccines. We develop a vaccine distribution optimization model under the two-level network of "point-of-supply – point-of-demand". The study follows the forefront, conforms to the reality, and improves the vaccine resources allocation system.

The remaining of the paper is organized as the follows. Section 2 reviews the literature related to the target population, vaccine quantity allocation, and epidemic resource distribution. The problem description and model hypothesis are presented in Section 3. Section 4 develops a vaccine scheduling optimization model under the COVID-19 pandemic. Section 5 uses a real case to verify the model and conduct sensitivity analysis by adjusting the budget. Section 6 discusses the implications of management and the generality of the model. Finally, Section 7 summarizes the research of this study.

2. Literature review

This study is related to three streams of literature, namely, the target population, allocation of vaccines, and resource allocation under the COVID-19 pandemic.

The literature on the attitude and priorities of the target vaccination population is related. Under an epidemic situation, vaccination is an effective plan to prevent infectious diseases. Even in a very severe situation, people still have vaccine hesitancy. Vaccine hesitancy refers to a lack of public trust in vaccination, culminating in delays or refusals to vaccinations, and even boycotts to undermine vaccination efforts. In Mahmud's survey (7), 61.16% of respondents were willing to receive the COVID-19 vaccine. Only 35.14% said they were willing to receive the COVID-19 vaccine immediately in the receiving group. However, 64.86% were likely to delay vaccination until they could determine the effectiveness and safety of the vaccine. Additionally, in a survey in France, Guillon et al. (8) found that only 30.5% of respondents agreed to be vaccinated against COVID-19 in the first phase of 2021, whereas 31.1% expressed uncertainty. Goel's survey (9) shows that more than 60% of respondents in India have negative attitudes toward COVID-19 vaccines. Vaccine

hesitancy exists in all countries and regions, which affects vaccination rates.

Developing and using vaccines for COVID-19 are of great concern to all countries, and different regions affected by the epidemic may require different approaches to prioritize vaccination. In the early stage of vaccine use, the number of vaccines may be relatively tight, not everyone can be vaccinated. Different scholars may use different methods to determine the priority of vaccination population. Hogan et al. (10) found that the impact of SARS-CoV-2 vaccination on health depends on different factors. The best distribution strategy for limited vaccines within a country is to vaccinate the elderly. In contrast, in the case of a large supply, distribution can be shifted to key spenders to protect vulnerable groups indirectly. Emanuel et al. (11) mentioned in their study that equitable distribution of vaccines is a controversial issue of distribution; thus, proposing three fundamental values of vaccine distribution, which are benefiting people and limiting harm, prioritizing vulnerable groups, and equal moral care. Weiss et al. (12) believe that people with moderate vulnerability need to be given higher priority and potentially exposed populations given greater weight. Sabatino et al. (13) suggested that vaccine distribution policies should prioritize individuals at the highest risk of adverse outcomes for COVID-19, provide overall evidence of exposure and clinical risk of patients with adult congenital heart disease (ACHD), and propose to incorporate risk profiles of these patients into vaccine distribution decisions. Furthermore, Wilbrink (14) compared the implementation of different vaccine distribution strategies to analyze which priority strategies introduced would most effectively recover these populations and control COVID-19 outbreaks. Results showed that prioritizing the elderly or high-risk transmission groups is effective. Foy et al. (15) used an age-structured extended SEIR model with a social connection matrix to evaluate age-specific vaccine distribution strategies in India. They found that prioritizing COVID-19 vaccine allocation to older populations led to the greatest relative reduction in the number of deaths. Paloyo et al. (16) pointed out that for the Philippines and some other countries with limited supply, the elderly may not always be prioritized. Moradi et al. (17) used an online survey to assess Iranian population's views on priority individuals and groups for COVID-19 vaccination. They found that healthcare workers, high-risk patients, and the elderly were prioritized vaccination groups. There is a growing consensus that sickest or medically most vulnerable people should be prioritized for vaccination. Studies have shown that priority is based on the vulnerability of social groups, such as the homeless or "hard-to-reach" groups. Vulnerable groups are prone to some difficulties and obstacles in obtaining vaccines, but in fact their living conditions are more in need of vaccine protection. Despite initial limited vaccine supplies, the CDC's phased vaccination guidelines help protect those most vulnerable to COVID-19 (18). Notably, vaccine hesitancy is more pronounced among vulnerable populations. We found that scholars divided priority populations from different perspectives or according to different criteria, resulting in different classification results. In general, when the number of vaccines is limited, the priority group strategy has certain advantages compared with the random vaccination strategy of the whole population.

Our study is closely related to the literature on the allocation of vaccines. Transportation of vaccines can guarantee the safety of the affected people for the first time, which is related to recognizing the national policy by the people of all countries. Some researchers have mainly used epidemiological models to predict the spread of viruses at national and regional levels (19). For example, Yu et al. (20) proposed a new SEIR model, called the hybrid SEIR-V model, which considers the infection status of host populations in different age groups and describes the dynamic characteristics of virus transmission in different geographical locations. However, Enayati and Özaltin (21) focused on the optimal distribution of influenza vaccines in heterogeneous populations and adopted the influenza transmission model to effectively extinguish emerging outbreaks at an early stage. Liu et al. (22) used the SEIR model to describe the dynamic epidemic diffusion process. The goal is to minimize the total logistics cost of healthcare resource allocation, and a heuristic algorithm is designed to solve the proposed model. Lee et al. (23) proposed a new multi-population mean-field control model and explained how population movement and vaccine distribution are integrated into the constraint optimization problem. Additionally, Yin and Büyüktahtakin (24) proposed a data-driven, multi-stage, stochastic epidemic-vaccine-logistics model that can assess the growth scenario of each disease under risk metrics to optimize the distribution of treatment centers, resources, and vaccines. It is also possible to minimize the number of common infections, deaths, and close contacts of infected persons within a limited budget. Rastegar et al. (25) proposed a mixed-integer linear programming model for equitable distribution of influenza vaccine inventory locations in developing countries during a pandemic. The model divides the vaccinated population into different groups, distributing vaccines to key healthcare providers, the elderly, pregnant women, and others. In recent years, studies on vaccine allocation have been active in the epidemic context. However, due to the rapid spread of COVID-19 and limited vaccine resources, COVID-19's vaccine allocation system still needs to be further improved.

The joint response of governments, healthcare providers, and the public to COVID-19 is now a top priority. Also, the outbreak has led to extensive research by experts and academics globally on vaccine resource allocation during the pandemic. Grauer et al. (26) proposed a strategy for vaccine distribution, which sequentially prioritizes the areas with the highest number of new infections within a given time frame and compares this scheme with the standard

practice of distributing vaccines by population. Fu et al. (27) proposed an epidemiological model, which expressed the robust epidemiological optimization model of risk index minimization as a mixed-integer linear optimization problem through appropriate approximation. They applied the robust epidemiological optimization model to allocate vaccines within a given vaccination budget. Katherine Klise and Bynum (28) developed a facility location optimization model to integrate some key information to help decision-makers determine the best site to build a facility to meet expected resource needs. Tavana et al. (29) proposed a mixed-integer linear programming model for equitable distribution of COVID-19 vaccines in developing countries. Furthermore, they divided vaccines into cold, extremely cold, and ultra-cold categories, with specific refrigeration required to store and distribute different vaccines. Buhat et al. (30) used a non-linear model (NLP) to determine the optimal allocation of COVID-19 test kits in the Philippines to provide a fair opportunity for all infected persons to be tested. Medlock and Galvani (31) identified the optimal vaccine allocation using a model based on survey data and parameterized influenza pandemic mortality data.

There are arising studies that focus on the allocation of vaccine resources. However, compared with research on emergency medical supplies scheduling, in the context of large-scale epidemics, studies on the field of vaccine allocation optimization are relatively few. None of the studies concern the situation of the target population for vaccination, and directly distribute vaccines to the lower level as ordinary emergency supplies, which is easy to cause unfair distribution and waste of resources. Therefore, this paper considers the priority of the vaccination population, vaccination attitude and related policies. It combines the fairness and efficiency of COVID-19 vaccine distribution to explore the precise scheduling strategy of allocating vaccines from the concentration center to the target population when the number of vaccines is limited.

3. Problem description and model assumptions

3.1. Problem description

When COVID-19 vaccines become available, governments should prepare for new challenges (32). The scarcity of vaccine resources requires effective resource allocation strategies.

(1) Selection of priority groups for the target population: Equitable allocation does not always mean the average distribution among individuals, but rather a distribution in which "people who need more enjoy higher priority than those who need less." In some foreign countries, vaccination groups are divided according to age, and the elderly prioritize vaccination. For example, in Norway, the elderly are prioritized for protection. The attending doctor evaluates the elderly and infirm before deciding whether to be vaccinated. In China, the "high-risk" elderly population was not prioritized in the early stage of vaccine use. Those aged between 18 and 59 who need emergency vaccination will be prioritized. In practice, priority is given to target groups depending on containment and vaccine availability. However, in general, in view of the shortage of vaccine resources in the early stage of the outbreak, it is necessary to give priority to some population groups in the target population for vaccination, and the division of priority vaccination population groups is one of the considerations of the model in this study.

(2) Attitude toward the target population: In reality, some people with contraindications to COVID-19 vaccines are unsuitable for vaccination. There are also some people who are hesitant or even refuse vaccination due to the influence of vaccine factors, personal factors and cognitive factors. Therefore, in the process of vaccine distribution, people who cannot or will not be vaccinated are excluded and the vaccine is distributed to those who actually need it.

(3) Priority is given to those who have received n dose(s) of the vaccine: If the distribution of multiple doses of vaccine has been in the vaccination phase, then the society includes the vaccinated population ($n = N$) and the population to be vaccinated ($0 \leq n < N$). The target population of vaccination mentioned in this paper mainly refers to the population to be vaccinated with negative antibody, that is, the population who has not been vaccinated ($n = 0$) and the population who has been vaccinated but has not completed the whole course of vaccination ($0 < n < N$). For N doses of vaccine, people who receive n dose(s) of vaccine need to receive (N - n) dose(s) of vaccine to complete the full course of vaccination.

According to the needs of COVID-19 prevention and control, different regions have different priority vaccination policies. Take China as an example, for a period of time, the first dose of COVID-19 inactivated vaccine has been suspended in many regions of the country, and the second dose of the vaccine is guaranteed. That is, the vaccine is given priority to the population who has received one dose ($n = 1$), so as to ensure the full vaccination of the vaccine and establish the immune barrier of the population. In Canada, in addition to ensuring a second dose is given to high-risk groups, such as health care workers, the first dose of vaccines is encouraged to the general population. In Canada and some other regions, in order to ensure that more people in the unvaccinated population receive at least one dose of COVID-19 vaccine, in addition to ensuring that high-risk groups, such as health care workers, receive the second dose, the vaccine is encouraged to be prioritized to the unvaccinated population ($n = 0$). There

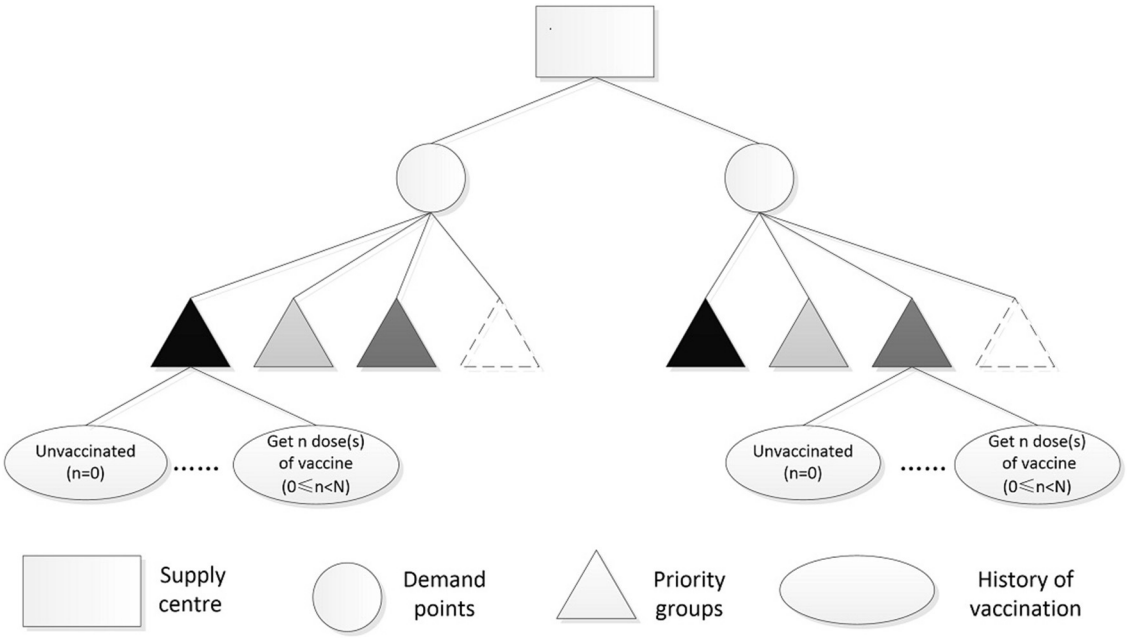

FIGURE 1
Distribution of COVID-19 vaccine.

are no universal answers to the intense debate about how best to use existing vaccines (33). Therefore, the model parameters can be set according to the relevant regional policies to ensure the priority of vaccine allocation to the population vaccinated with n injection, so that the vaccine can be more reasonably distributed in the case of limited resources, so as to achieve better immunization effect.

Under the background of limited number of vaccines in the early stage of use and herd immunity in all regions, this study develops a vaccine distribution model considering the target population based on the fairness and efficiency of COVID-19 vaccine distribution and the goal of maximizing vaccine coverage. Vaccines are distributed and scheduled under a two-level "supply-demand-point" network, such as "provincial centralized distribution center - municipal Centers for Disease Control (CDC)" "municipal centralized distribution Center - District and county CDC," and other networks. According to the quantity of vaccines purchased and supplied, decision makers can accurately and scientifically allocate vaccines and timely distribute them to all vaccination sites to fully guarantee the implementation of vaccination work. Figure 1 shows the diagram of COVID-19 vaccine distribution studied in this paper. The icon with darker colors indicates a higher priority for each priority group, and the icon with a dotted line represents people who are unable or unwilling to be vaccinated.

The mathematical model mainly considers:

- Vaccination history of the target population.
- Different levels of priority groups for vaccination.
- Some people are unable or unwilling to be vaccinated.
- Priority should be given to the population vaccinated with n dose(s) of vaccine.

3.2. Model assumptions

(1) The type of COVID-19 vaccine allocated is a multi-dose vaccine.
(2) People at all levels can be vaccinated simultaneously, and there is no such thing as vaccinating only one group.
(3) If there is a repetition between groups of the target population, they are divided into the higher priority group.
(4) The demand for vaccines is fixed for a period of time.
(5) Demand points are independent of each other, vehicles are delivered in one direction, and there is no material transfer.
(6) The number of vehicles transporting materials is sufficient, and the road condition is good. The road speed, approved load and transport cost per unit distance of the vehicles are the same.

4. Mathematical model

4.1. Symbol description

Table 1 shows the list of mathematical notations, which mainly includes the sets, parameters and variables of the model.

4.2. Optimization model for vaccine allocation for COVID-19

$$Max\ Obj = \sum_{i\in I}\sum_{j\in J}\sum_{n\in N}\frac{y_{ijn}}{p} \tag{1}$$

s.t.

$$y_{ijn} \le p_{ijn}(1\text{-}\mu_{ijn}), \forall i \in I, j \in J, n \in N \tag{2}$$

TABLE 1 List of mathematical notations.

Sets	
I	Set of demand points
J	Set of priority groups
N	The target total number of doses to be completed for the entire course of vaccination of a type of vaccine
K	Set of costs
Parameters	
i	Demand points, $i \in I$
j	Priority groups, $j \in J$
n	The dose of vaccine that has been administered to the target population ($0 \le n < N$)
k	Types of costs for vaccine distribution
P	Total population of all regions
p_{ij}	The number of the target population in group j in demand point i
p_{ijn}	The number of the target population who had received n dose(s) of the vaccine in group j in demand point i
μ_{ijn}	The proportion of the target population with n dose(s) who will not receive the vaccine in group j in demand point i
α_n	The expected proportion of people who have been vaccinated with n dose(s)
θ_j	Minimum vaccination coverage in group j
Q	The total amount of vaccines in the supply center
Q_i	Capacity of vaccine storage in warehouse of demand point i
TC_{ik}	Type k cost of a single dose of vaccine in demand point i
BG	Budget
Variables	
y_{ijn}	Integer, the number of individuals vaccinated in group j vaccinated with n dose(s) in area i
x_{ijn}	Integer, the number of vaccines allocated in group j in the area i vaccinated with n dose(s)

$$\frac{\sum_{n\in N} y_{ijn}}{p_{ij}} \ge \theta_j, \forall i \in I, j \in J \tag{3}$$

$$y_{ijn} \ge p_{ijn}(1\text{-}\mu_{ijn})\alpha_{jn}, \forall i \in I, j \in J \tag{4}$$

$$x_{ijn} = (N-n)\, y_{ijn}, \forall i \in I, j \in J, n \in N \tag{5}$$

$$\sum_{i\in I}\sum_{j\in J}\sum_{n\in N} x_{ijn} \le Q, \forall i \in I, j \in J, n \in N \tag{6}$$

$$\sum_{j\in J}\sum_{n\in N} x_{ijn} \le Q_i, \forall i \in I \tag{7}$$

$$\sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{n\in N} TC_{ik}x_{ijn} \le BG \tag{8}$$

$$y_{ijn}, x_{ijn} \in Z^+, \forall i \in I, j \in J, n \in N, k \in K \tag{9}$$

Objective function (1) maximizes the vaccination rate of COVID-19 vaccines and makes vaccination available to many people to achieve herd immunity. Constraint (2) ensures that the number of vaccinated individuals in group j in the area i vaccinated with n dose(s) should not exceed the number of target population in group j in the area i vaccinated with n injection. The actual target population is the population to be vaccinated except those who cannot or will not be vaccinated. Constraint (3) ensures that the vaccination ratio for each priority in each region is not lower than the minimum pre-set coverage rate for each level to prevent low vaccination rates at some demand points. Constraint (4) indicates that people in group j who have received n ($0 \le n < N$) injection(s) are given priority. Constraint (5) represents the relationship between the amount of vaccine allocated and the number of people vaccinated, considering vaccination history. Constraints (6) and (7) are inventory and capacity constraints, respectively. Constraint (6) is the constraint that the total allocation of vaccines in all demand points does not exceed the vaccine stock in the allocation center. Additionally, Constraint (7) is that the amounts of vaccines obtained in each region does not exceed its warehouse capacity. Constraint (8) indicates that the total cost of vaccine distribution and vaccination in each region does not exceed the local budget. The total cost, such as transportation, storage, and personnel, should be included. Constraint (9) means the decision variables are a positive integer.

5. Case study

5.1. Case background

The COVID-19 epidemic caused a public health crisis and had a significant social, political, and economic impact worldwide. The pace of development of many COVID-19 vaccine candidates is rapid that countries are beginning to approve them for mass distribution. However, there may be some difficulties, such as the insufficient supply of COVID-19 vaccines. In one distribution, the Xuzhou municipal government received 10 million doses of inactivated COVID-19 vaccine and distributed them to ten regions under its jurisdiction. Due to the

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TABLE 2 Number of priority persons in each region.

	Priority level		
	High-risk group	High-danger group	General population
Gulou district	126,717	190,076	316,793
Yunlong district	75,596	113,394	188,990
Jiawang district	103,571	155,357	258,928
Quanshan district	114,316	171,474	285,791
Tongshan district	266,632	399,948	666,581
Pizhou city	387,514	581,271	968,786
Xinyi city	225,858	338,786	564,644
Suining county	288,317	432,476	720,793
Feng county	241,945	362,918	604,864
Pei county	248,216	372,324	620,540

limited number of vaccines, it is necessary for policy makers to formulate reasonable distribution strategies with both fairness and efficiency in mind. It's worth noting that some of the model parameters are based on reasonable estimates as detailed vaccine cost and other relevant data are not published officially, and these values parameters do not affect the nature of the model.

When vaccine availability is limited, resources should be more skewed toward a subset of the population. In Table 2, According to the standards published by China's National Health Commission, the target population in China is roughly divided into three groups: high-risk population, high-danger population, and the general population. This classification scheme based on risk and impact of infection can avoid the problems of inconsistency where the division of priority vaccination population among different regions is inconsistent due to outbreak control and vaccine supply situations. High-risk groups mainly refer to epidemic prevention and medical personnel, entry-exit workers, people who need to go to high-risk countries for special reasons, and people who play an important role in fighting the epidemic. High-danger groups, mainly the elderly, young children, pregnant women, and people with a low resistance to COVID-19, have a high-risk of infection.

The priority vaccination population was divided into three groups, and the priority order was as follows: high-risk population > high-danger population > the general population. The higher the priority, the greater the risk of infection and the more severely affected by COVID-19. They are more in need of vaccination than the general population and should therefore be given priority when vaccine availability is limited. However, if the general population cannot be vaccinated, they may experience panic and jealousy. Therefore, the decision makers also need to allocate a certain amount of vaccine to the general population when making vaccine allocation. We set the corresponding minimum vaccine coverage for each group, and the group with higher priority had higher minimum coverage than the group with lower priority, as shown in Table 3.

TABLE 3 Minimum coverage for each priority.

	High-risk group	High-danger group	General population
Minimum coverage	0.95	0.7	0.5

Table 4 shows the inoculation status of each region. When vaccine availability is limited, priority is promoted for those who have received one dose of vaccine. For vaccinations have been vaccinated but not completed group and unvaccinated people, the vaccine coverage rates are 3/5 and 2/5 respectively. The purpose is to give priority to vaccinated personnel who have received one shot of vaccine, so as to achieve better immune effect. At the same time, in order to avoid panic and jealousy among unvaccinated people, a certain amount of vaccine will also be appropriately allocated to such people.

Vaccine distribution also faces vaccine hesitancy. Vaccine hesitancy is universal in all countries and COVID-19 vaccine hesitancy has been a growing concern (34). The decision makers need to consider the vaccination intention of the target population when making allocation decisions. According to the existing literature on vaccination willingness and society's current situation, the proportion of high-risk, high-danger, and the general population who are unable or unwilling to be vaccinated is set as 0.016, 0.034, and 0.020, respectively. Therefore, by calculation, the number of people to be vaccinated in each region is shown in Table 5.

Tables 6, 7 show the warehouse capacity and the cost of vaccine distribution in each region respectively. Among them, the cost types mainly include transportation cost, storage cost, and personnel cost in this case. The total budget for vaccination services and distribution is 150,000,000 yuan.

5.2. Result analysis

MATLAB and LINGO were used to calculate the results of the model. The results are shown in Tables 8, 9.

The optimal result is 71.86%, meaning that when we consider the constraint conditions of vaccine storage, budget, and minimum coverage, the maximum vaccination rate is 71.86%, with 7,468,263 vaccinated people and 9,775,979 doses of vaccine allocated. As can be seen from Table 8, the allocation of vaccines in each priority group almost covers the high-risk group, and is distributed to the high-risk group and the general population in each region according to the proportion of priority. This result validates the validity of the model. As we would expect to be able to distribute the vaccine to the vast

TABLE 4 Vaccination in each region.

	High-risk group		High-danger group		General population	
	Get a dose	Unvaccinated	Get a dose	Unvaccinated	Get a dose	Unvaccinated
Gulou district	76,030	50,687	114,045	76,030	190,076	126,717
Yunlong district	45,358	30,238	68,036	45,358	113,394	75,596
Jiawang district	62,143	41,428	93,214	62,143	155,357	103,571
Quanshan district	68,590	45,726	102,885	68,590	171,474	114,316
Tongshan district	159,979	106,653	239,969	159,979	399,948	266,632
Pizhou city	232,509	155,006	348,763	232,509	581,271	387,514
Xinyi city	135,515	90,343	203,272	135,515	338,786	225,858
Suining county	172,990	115,327	259,485	172,990	432,476	288,317
Feng county	145,167	96,778	217,751	145,167	362,918	241,945
Pei county	148,929	99,286	223,394	148,929	372,324	248,216

TABLE 5 Actual number of people to be vaccinated in each region.

	High-risk group		High-danger group		General population	
	Get a dose	Unvaccinated	Get a dose	Unvaccinated	Get a dose	Unvaccinated
Gulou district	76,030	49,876	114,045	73,445	190,076	124,183
Yunlong district	45,358	29,755	68,036	43,815	113,394	74,084
Jiawang district	62,143	40,766	93,214	60,030	155,357	101,500
Quanshan district	68,590	44,995	102,885	66,258	171,474	112,030
Tongshan district	159,979	104,946	239,969	154,540	399,948	261,300
Pizhou city	232,509	152,526	348,763	224,603	581,271	379,764
Xinyi city	135,515	88,898	203,272	130,907	338,786	221,340
Suining county	172,990	113,482	259,485	167,109	432,476	282,551
Feng county	145,167	95,230	217,751	140,232	362,918	237,106
Pei county	148,929	97,698	223,394	143,866	372,324	243,251

TABLE 6 Storage capacity of each region.

	Gulou district	Yunlong district	Jiawang district	Quanshan district	Tongshan district
Storage capacity	1,260,000	900,000	1,000,000	1,000,000	2,600,000
	Pizhou city	Xinyi city	Suining county	Feng county	Pei county
	7,600,000	5,000,000	6,000,000	5,000,000	6,000,000

majority of the high-risk population, the majority of the high-risk population, and a certain number of the general population with limited amounts of vaccine. In line with the principle of voluntary vaccination, the majority of the vaccine will be given as a priority to those who have received a single dose and a smaller proportion will be given to those who have not yet received the vaccine, in accordance with local social policies. Table 9 shows the number of vaccines allocated for each region.

5.3. Sensitivity analysis

Five scenarios were considered in the sensitivity analysis, including budget increase and decrease. The corresponding results of these five scenarios are shown in Table 10. As the budget increases, the number of vaccines to be allocated and vaccinated individuals increases. Thus, increasing vaccine coverage makes it easier to achieve herd immunity through increased budgets; conversely, as budgets decrease, the number

of vaccines available will decrease, corresponding to a decrease in the number of people vaccinated and a decrease in vaccine coverage. Therefore, policy makers need to make trade-offs between cost and vaccination coverage when allocating vaccines. When the epidemic is severe and the demand for vaccines is high, governments need to increase funding to increase vaccine coverage and establish a universal immunization barrier as much as possible. For low-risk areas with a low budget and a small number of vaccines, the government can temporarily vaccinate high-risk groups and high-risk groups, and then gradually move to the general population.

6. Discussion

The vaccine distribution model constructed in this study mainly includes the following parts: (i) multi-dose vaccine distribution. For the multi-dose COVID-19 vaccine type, there are unvaccinated individuals and those who have not completed the full vaccination in the society during a certain period, so the vaccination history of the vaccinated individuals should be considered when allocating the vaccine. (ii) The vaccination population can be divided into different priority levels to distribute more vaccines to the higher priority groups. (iii) Additionally, there are still individuals who are unable or unwilling to be vaccinated. Following the policy and principle of voluntary vaccination, vaccine distribution should exclude such groups to avoid wasting resources and allocate vaccine resources to those who are able and willing to be vaccinated. (iv) In accordance with regional policies, priority should be given to the population vaccinated with n dose(s) of vaccine. (v) A vaccine distribution model was developed to account for the vaccinated population under COVID-19 considering equity and efficiency. This paper takes into account fairness and efficiency, and establishes a vaccine distribution model considering the target population of vaccination under COVID-19, which has certain practical significance. First, the goal of the model is to maximize the vaccination rate. Herd immunity is easier to achieve when the number of people vaccinated is larger. Some people with contraindications or who are not in the age range for vaccination are not suitable for vaccination, which requires that those who are suitable for vaccination should be covered. At the same time, the willingness to vaccinate is one of the factors affecting the vaccination rate. The government should take such measures as opening lectures and publicity to enhance the public's vaccination awareness, so as to improve the vaccination rate. In addition, the division of vaccine priority groups, the implementation of vaccination-related policies, and the appropriate "skewering" of vaccine allocation to groups with greater need can ensure the fairness of distribution. High-risk groups are the backbone of the epidemic prevention work and the maintenance of social order. High-danger groups are vulnerable groups that need to be paid close attention

TABLE 7 Transportation cost, storage cost, and personnel cost in each region.

	Transportation cost	Storage cost	Personnel cost
Gulou district	2.2	5	4
Yunlong district	2.3	4.5	4
Jiawang district	2.8	3.5	4
Quanshan district	2.9	3.5	4
Tongshan district	3	7.5	4
Pizhou city	6	10	3
Xinyi city	7.5	6.5	3
Suining county	7.2	7.5	3
Feng county	6.5	7	3
Pei county	6.7	7	3

TABLE 8 Number of vaccinated individuals in each region.

	High-risk group		High-danger group		General population	
	Get a dose	Unvaccinated	Get a dose	Unvaccinated	Get a dose	Unvaccinated
Gulou district	76,030	49,876	114,045	73,445	190,076	124,183
Yunlong district	45,358	29,755	68,036	43,815	113,394	74,084
Jiawang district	62,143	40,766	93,214	60,030	155,357	40,600
Quanshan district	68,590	44,995	102,885	66,258	171,474	44,812
Tongshan district	159,979	93,322	239,969	61,816	239,970	104,520
Pizhou city	232,509	135,629	317,049	89,841	348,763	151,906
Xinyi city	135,515	79,050	184,787	52,363	203,272	88,536
Suining county	172,990	100,911	235,890	66,843	259,485	113,020
Feng county	145,167	84,681	217,751	56,093	217,751	94,843
Pei county	148,929	86,876	216,775	57,546	223,394	97,301

TABLE 9 Distribution of vaccines by region.

	High-risk group		High-danger group		General population	
	Get a dose	Unvaccinated	Get a dose	Unvaccinated	Get a dose	Unvaccinated
Gulou district	76,030	99,752	114,045	146,890	190,076	248,366
Yunlong district	45,358	59,510	68,036	87,630	113,394	148,168
Jiawang district	62,143	81,532	93,214	120,060	155,357	81,200
Quanshan district	68,590	89,990	102,885	132,516	171,474	89,624
Tongshan district	159,979	186,644	239,969	123,632	239,970	209,040
Pizhou city	232,509	271,258	317,049	179,682	348,763	303,812
Xinyi city	135,515	158,100	184,787	104,726	203,272	177,072
Suining county	172,990	201,822	235,890	133,686	259,485	226,040
Feng county	145,167	169,362	217,751	112,186	217,751	189,686
Pei county	148,929	173,752	216,775	115,092	223,394	194,602

TABLE 10 Sensitivity analysis of budget changes.

Scenario	Budget	Coverage	The number of vaccination	Number of vaccines allocated
S1	145,000,000	68.93	7,164,318	9,357,274
S2	147,500,000	70.63	7,340,562	9,585,076
S3	150,000,000	71.86	7,468,263	9,775,979
S4	152,500,000	72.67	7,552,669	9,888,246
S5	155,000,000	74.25	7,716,854	10,000,000

to, and their protection is of great significance. This paper also considers the efficiency of general material distribution, such as warehouse capacity, material reserves, cost, etc. should be completed under the constraints of total inventory, total budget and other conditions. The optimal model of vaccine distribution established in this paper can provide a flexible vaccine distribution scheme and provide a reference for decision makers to formulate effective vaccine distribution strategies.

According to the technical guidelines for new coronavirus vaccination, vaccine types mainly include adenovirus vector vaccine, inactivated vaccine and recombinant protein vaccine. One injection ($N = 1$), two injections ($N = 2$) and three injections ($N = 3$) are required to complete the whole vaccination process. The distribution of single dose vaccine is relatively simple, while the distribution of multi-dose vaccine in this study not only takes into account the willingness to vaccinate and priority vaccination population, but also involves considering vaccination history and prioritizing the distribution of vaccine to the population that has been vaccinated with n dose(s) according to relevant policies. While the allocation optimization model of multi-dose vaccine can also be applied to the allocation of single-dose vaccine, in which case, constraints (4) and (5) are unnecessary and can be omitted. Because when the allocated resources are single-dose vaccines ($N = 1$), there is only one group of target vaccinated people, that is, the unvaccinated population ($n = 0$). In this case, there is no situation in the society that has been vaccinated but has not completed the whole process of vaccination, which means that there is no need to give priority to those who have received n-dose of vaccine, and there is no situation that people who have been vaccinated but have not completed the whole process of vaccination still need to be vaccinated (N - n) dose(s).

7. Conclusions

In this study, based on the current situation of the epidemic and from the perspective of vaccination history, priority vaccination groups, and the voluntary nature of vaccination, a vaccine distribution model considering vaccination groups was constructed, which was realistic and appropriate, and combined with the different characteristics of vaccination groups, providing decision-makers with a more flexible decision-making tool. The results showed that our model could exclude some people who are unable or unwilling to refuse vaccination and prioritize those with higher priority and those who have been vaccinated but have not completed the full vaccination. Furthermore, the integer programming model was validated with real world data. Through numerical experiments, we also found that increasing the budget can improve the

vaccination rate, enable more people to get vaccinated, and achieve herd immunity with a given number of vaccines.

The optimization of vaccine allocation studied in this paper pays more attention to the target population of vaccination. However, vaccine allocation and vaccination process need to be completed over a long period of time, which is a dynamic and multi-cycle distribution process. The static model established in this paper has certain limitations. To further improve the applicability and generality of the model, the future research directions of this paper are as follows: (i) Constructing a multi-cycle vaccine distribution model. The single-cycle model has some limitations in the case of limited vaccine, and the next phase of vaccine allocation according to the previous phase of vaccine use and vaccination is the focus of the following research. (ii) Based on the infectivity of the epidemic, the vaccine distribution model under the situation of uncertain demand was developed to dynamically analyze the vaccine demand to conduct precise scheduling of vaccines more accurately. (iii) Presently, vaccine distribution in many countries is still unfair. Therefore, a model for national and even international large-scale vaccine distribution could be developed in the future.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

Conceptualization and supervision: BH and ZW. Methodology and visualization: TY. Investigation: WC and GJ. Writing—original draft preparation: BH and TY. Writing—review and editing: ZW, TY, WC, GJ, and BH. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Clinical characteristics and clinical outcome of community clusters with SARS-CoV-2 infection

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Background: Community clustering is one of the main features of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). However, few studies have been conducted on the clinical characteristics and clinical outcome of clustered cases and sporadic cases with COVID-19.

Methods: We recruited 41 community clusters confirmed with SARS-CoV-2 infection compared with 49 sporadic cases in Zhejiang Province from 19 January 2020 to 9 June 2020. Clinical data were collected to evaluate the clinical outcome and characteristics of community clusters.

Results: Compared to sporadic cases, clustered cases had significantly lower Acute Physiology and Chronic Health Evaluation II (APACHE II) score {5.0 [interquartile range (IQR), 2.0–7.5] vs. 7.0 [IQR, 4.0–12.5]; $P = 0.005$}, less members in intensive care unit (ICU) (6 [14.6%] vs. 18 [36.7%]; $P = 0.018$), and shorter time of viral shedding in fecal samples (18.5 [IQR, 17.0–28.3] vs. 32.0 [IQR, 24.3–35.5]; $P = 0.002$). Univariable logistic regression revealed that older age (odds ratios 1.078, 95% confidence intervals 1.007–1.154, per year increase; $p = 0.032$), high APACHE II score (3.171, 1.147–8.76; $P = 0.026$), elevated interleukin-2 levels (3.078, 1.145–8.279; $P = 0.026$) were associated with ICU admission of clustered cases.

Conclusions: Compared to sporadic cases, clustered cases exhibited milder disease severity and a better clinical outcome, which may be closely related to the management of early detection, early diagnosis, early treatment and early isolation of COVID-19.

KEYWORDS

COVID-19, SARS-CoV-2, clustering epidemic, clustered cases, sporadic cases

Introduction

There was an outbreak of an unexplained pneumonia in Wuhan, Hubei Province, China in December 2019 (1, 2). The virus has been isolated from infected patients and was named severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2; previously known as 2019-nCoV) by 7 January 2020 (3). The disease was officially named coronavirus disease 2019 (COVID-19) by the WHO in February 2020 (3). Numerous clinical studies on COVID-19 have been published, including epidemiology, clinical features, laboratory findings, imaging features, risk factors, and clinical outcome (3–6). Chan et al. were the first to publish a study of a family cluster, noting the existence of person-to-person transmission of SARS-CoV-2 and that family clustering was the main characteristic of COVID-19 (7). A retrospective study of clustered cases and sporadic cases in Wuhan showed that the incidence of COVID-19 was significantly increased in cluster-onset families compared with solitary-onset families (8). In addition, older age and an elevated neutrophil/lymphocyte ratio are the main risk factors for death in infected patients in cluster-onset families (8). However, there are still few comparative studies assessing clustered cases and sporadic cases.

Hence, we conducted a study on 90 hospitalized patients with confirmed SARS-CoV-2 infection in Zhejiang Province. We compared the clinical characteristics between clustered cases and sporadic cases during hospitalization to evaluate the differences in the impacts of different clinical characteristics between these two case types.

Methods

Data sources

We conducted a retrospective study to investigate 90 patients confirmed with COVID-19 infection admitted to the First Affiliated Hospital, Zhejiang University School of Medicine, Zhejiang Province, China.

The entry criteria included the following: (1) patients with COVID-19 infection were confirmed once admitted, based on real-time reverse transcription-polymerase chain reaction (RT-PCR) assay of nasopharyngeal swab specimens by the laboratory of the First Affiliated Hospital, Zhejiang University School of Medicine, Zhejiang Province, China; (2) patients were discharged by June 30, 2020.

The exclusion criteria included: (1) missing case information; (2) missing laboratory test results.

Information on all patients was collected, including demographic data, body mass index, comorbidities, clinical symptoms, exposure history, laboratory findings, treatment, and clinical outcomes. Comorbidities included hypertension, diabetes mellitus, and fatty liver disease. Laboratory findings included complete blood count, coagulation profile, liver and renal function, creatine kinase, lactate dehydrogenase, electrolytes, myocardial enzymes, C-reactive protein (CRP), inflammatory factors, complements, and immunoglobulins. Chest computed tomography (CT) scans were performed. Treatment included antiviral therapy, hormonal therapy, antibiotics, mechanical ventilation, extracorporeal membrane oxygenation (ECMO), artificial liver support system (ALSS), and continuous renal replacement therapy (CRRT).

Definition

Patients were divided into moderate, severe, or critical types according to the *Diagnosis and Treatment Protocol for Novel Coronavirus Pneumonia (Trial Version 9)* (9). Moderate cases were defined as having fever and respiratory symptoms and radiological findings of pneumonia. Severe adult cases were defined as having dyspnea (respiratory rate $\geq$ 30 breaths/min), resting oxygen saturation $\leq$ 93%, arterial oxygen partial pressure/fraction of inspired oxygen $\leq$ 300 mmHg (1 mmHg = 0.133 kPa), or cases with chest imaging showing obvious lesion progression within 24–48 h >50%. Critical cases were defined based on respiratory failure and the requirement of mechanical ventilation, shock, or other organ failure and the requirement for intensive care unit (ICU) care.

According to the *Protocol on Prevention and Control of Novel Coronavirus Pneumonia (Edition 9)*, exposure history referred to close contact with a COVID-19-infected individual (with positive results based on the nucleic acid test) within 2 weeks prior to the onset of disease. Clustered cases were defined as two or more cases with fever and/or respiratory symptoms in a small area, such as families, offices, and schools within 2 weeks, including index cases and secondary cases. Sporadic cases were defined as only one case with fever and/or symptoms in the small area.

Fever was defined as an axillary temperature of 37.4°C or greater. Fever duration was defined as the time from the onset of fever to the return of normal temperature. Time of viral shedding was the duration of positive RT-PCR result of specimens. The Acute Physiology and Chronic Health Evaluation (APACHE) II scores were calculated as described in the published literatures (10). Clinical outcomes were defined as the comprehensive assessment of clinical features, including clinical grades, laboratory findings, ICU care and so on.

Statistical analysis

Data were statistically analyzed and plotted using Excel (Microsoft Corporation, Redmond, Washington, USA), SPSS 26.0 software (IBM, Armonk, New York, USA) and GraphPad Prism 8.0 software (GraphPad Software, San Diego,

California, USA). Data were analyzed for normal distribution and homogeneity of variance before statistical analysis. Normally distributed continuous variables were expressed as the mean with standard deviation (mean ± sd). Non-normally distributed continuous variables were expressed as median with interquartile range (IQR). Categorical variables were expressed as numbers and percentages. Comparisons between groups of normally distributed continuous variables used parametric *t*-tests. Comparisons between groups of non-normally distributed measures used non-parametric Mann-Whitney *U*-tests. Comparisons between groups of categorical variables used χ^2 test. Univariable logistic regression analysis was used to investigate the risk factors for ICU admission in clustered cases, and odds ratios with 95% confidence intervals were calculated. *P*-value < 0.05 (two-tailed) suggested that the difference was statistically significant.

Ethical approval

This study was approved by the Ethics Committee of the First Affiliated Hospital, Zhejiang University School of Medicine.

Results

Patients' characteristics

From 19 January 2020 to 9 June 2020, 90 admitted hospital patients were confirmed with SARS-CoV-2 infection in The First Affiliated Hospital, Zhejiang University School of Medicine. In total, 41 were clustered cases, and 49 were sporadic cases. The average age of all patients was 52.6 ± 15.9 years. In total, 55 (61.1%) of the infected patients were male.

In total, 66 (73.3%) patients had exposure history. The proportion of definite exposure history was increased in clustered cases compared with sporadic cases (38 [92.7%] vs. 28 [57.1%]; $P < 0.001$).

In total, 53 (58.9%) of the infected patients had underlying diseases. Compared with sporadic cases, clustered cases had less percentage of comorbidities (19 [46.3%] vs. 34 [69.4%]; $P = 0.027$), such as hypertension (8 [19.5%] vs. 22 [44.9%]; $P = 0.011$).

The most common symptoms at onset of illness were fever (75 [83.4%]), cough (74 [82.2%]), and expectoration (43 [47.8%]). In clustered cases, patients were less likely to have headache (1 [2.4%] vs. 7 [14.3%]; $P = 0.049$) and myalgia (7 [17.1%] vs. 13 [26.5%]; $P = 0.048$). However, no difference in symptoms were noted between two groups of patients with the exception of headache and myalgia (see in Table 1; Supplementary Table 1).

Laboratory findings

The trend in laboratory findings at admission was approximately the same in sporadic and clustered cases. Only some differences in laboratory findings were noted between clustered cases and sporadic cases. The mean glomerular filtration rate (GFR) was significantly increased in clustered cases than sporadic cases (96.4 [IQR 77.2–110.7] vs. 89.1 [IQR 66.1–100.7]; $P = 0.028$). Lactate dehydrogenase levels were significantly reduced in clustered cases compared with sporadic cases (223.0 [IQR, 194.0–306.5] vs. 274.0 [IQR, 219.0–356.0]; $P = 0.037$).

In terms of inflammatory cytokines, the levels of interleukin-4 (IL-4) (1.4 [IQR 1.0–1.8] vs. 1.8 [IQR 1.4–1.8]; $P = 0.011$) and Tumor Necrosis Factor-α (11.2 [IQR 6.5–44.6] vs. 22.1 [IQR 12.2–65.0]; $P = 0.023$) were significantly reduced in clustered cases compared with sporadic cases (see Table 1; Supplementary Table 2).

Clinical treatments

Eighty-nine (98.9%) patients received antiviral therapy, and 70 (77.8%) patients received corticosteroids. Time from illness onset to the initiation of antiviral therapy was shorter in clustered cases compared with sporadic cases (5.0 [IQR, 2.0–7.0] vs. 7.0 [IQR, 4.3–10.0]; $P = 0.002$). Antiviral therapy included single or combined use of abidol, lopinavir/ritonavir, and alpha-interferon. In addition, time from illness onset to the use of corticosteroids and to the end of intravenous corticosteroids use in clustered cases were both shorter compared with sporadic cases (7.0 [IQR, 4.5–8.0] vs. 8.0 [IQR, 7.0–11.0], $P = 0.003$; 17.5 [IQR, 13.8–21.3] vs. 21.0 [IQR, 18.0–24.0], $P = 0.010$, respectively).

A lower number of patients in clustered cases received treatments, such as antibiotics, mechanical ventilation, and ALSS, compared with sporadic cases (14 [34.1%] vs. 29 [59.2%], $P = 0.018$; 0 [0.0%] vs. 8 [16.3%], $P = 0.019$; 0 [0.0%] vs. 10 [20.4%], $P = 0.006$, respectively) (see Table 2).

Clinical outcomes

The median time from illness onset to confirmed diagnosis was shorter in clustered cases than sporadic cases (4.0 [IQR, 1.0–6.0] vs. 6.0 [IQR, 4.0–7.0]; $P = 0.032$). The length of stay of all patients was 16.5 (IQR, 13.0–24.0) days. Compared to sporadic cases, clustered cases had significantly lower APACHE II score (5.0 [IQR, 2.0–7.5] vs. 7.0 [IQR, 4.0–12.5]; $P = 0.005$) on the day of hospital admission. The proportion of critical illness (7 [17.1%] vs. 18 [36.7%]; $P = 0.038$) and ICU care (6 [14.6%] vs. 18 [36.7%]; $P = 0.018$) was reduced in clustered cases compared with sporadic cases.

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TABLE 1 Clinical characteristics and laboratory findings of 90 patients with laboratory confirmed coronavirus disease 2019 infection.

	All patients ($n = 90$)	Clustered cases ($n = 41$)	Sporadic cases ($n = 49$)	*P*-value
Clinical characteristics				
Age, years	52.6 ± 15.9	50.0 ± 17.7	54.8 ± 14.1	0.153
Gender				0.372
Male	55, 61.1%	23, 56.1%	32, 65.3%	
Female	35, 38.9%	18, 43.9%	17, 34.7%	
Exposure history	66, 73.3%	38, 92.7%	28, 57.1%	<0.001***
Any coexisting disorder	53, 58.9%	19, 46.3%	34, 69.4%	0.027*
Hypertension	30, 33.3%	8, 19.5%	22, 44.9%	0.011*
Signs and symptoms				
Headache	8, 8.9%	1, 2.4%	7, 14.3%	0.049*
Myalgia	20, 22.2%	7, 17.1%	13, 26.5%	0.048*
Laboratory findings				
Prothrombin time (s)	11.8 (11.3–12.3)	11.6 (11.3–12.1)	11.9 (11.4–12.6)	0.045*
Glomerular filtration rate (mL/min)	94.0 (72.6–104.9)	96.4 (77.2–110.7)	89.1 (66.1–100.7)	0.028*
Lactate dehydrogenase (U/L)	245.5 (196.0–336.3)	223.0 (194.0–306.5)	274.0 (219.0–356.0)	0.037*
Interleukin-4 (pg/mL)	1.8 (1.4–1.8)	1.4 (1.0–1.8)	1.8 (1.4–1.8)	0.011*
Tumor necrosis factor-α (pg/mL)	16.5 (6.7–50.4)	11.2 (6.5–44.6)	22.1 (12.2–65.0)	0.023*

*$0.01 < P < 0.05$; ***$P \leq 0.001$.

We detected acute respiratory distress syndrome (ARDS), bacterial infection, intestinal flora disorders and fecal RNA positivity in 10 (11.1%), 16 (17.8%), 9 (10.0%), and 30 (35.5%) patients, respectively. Compared with sporadic cases, clustered cases were less likely to develop ARDS (0 [0%] vs. 10 [20.4%]; $P = 0.006$) and bacterial infection (3 [7.3%] vs. 13 [26.5%]; $P = 0.036$). Fever persisted for a shorter time in clustered cases compared with sporadic cases (10.0 [IQR, 6.0–12.8] vs. 13.0 [IQR, 9.0–27.0]; $P = 0.020$). Shortened viral shedding in fecal samples was observed in clustered cases compared with sporadic cases (18.5 [IQR, 17.0–28.3] vs. 32.0 [IQR, 24.3–35.5]; $P = 0.002$) (see Table 3; Figure 1).

Difference in clustered cases admitted or not admitted to ICU

Of the clustered cases, 6 (14.6%) were admitted to the ICU. Patients with ICU care were older than those with non-ICU care (66.5 ± 18.2 vs. 47.2 ± 16.2; $P = 0.012$). Compared with non-ICU patients, ICU patients were more likely to have comorbidities (5 [83.3%] vs. 14 [40.0%]; $P = 0.049$), to exhibit an increased APACHE II score (12.5 [IQR, 9.8–14.3] vs. 3.0 [IQR, 2.0–6.0]; $P < 0.001$) at admission, to develop bacterial infection (2 [33.3%] vs. 1 [2.9%]; $P = 0.008$), and to be treated with antibiotics (6 [100.0%] vs. 8 [22.9%]; $P < 0.001$).

White blood cell (WBCs) count, and neutrophil count at admission were increased, while GFR at admission were reduced in ICU cases (10.1 [IQR, 8.4–18.5] vs. 5.2 [IQR, 3.9–7.8], $P = 0.007$; 9.1 [IQR, 7.6–16.6] vs. 3.7 [IQR, 2.3–6.7], $P = 0.005$; 80.5 [IQR, 60.8–94.3] vs. 99.7 [IQR, 83.2–112.5], $P = 0.015$, respectively). Blood glucose, troponin I (TNI), IL-2, and immunoglobulin G (IgG) levels were increased substantially in ICU patients compared with non-ICU patients (8.1 [IQR, 7.5–12.9] vs. 6.3 [IQR, 4.7–7.9], $P = 0.022$; 0.016 [IQR, 0.007–0.020] vs. 0.003 [IQR, 0.002–0.006], $P = 0.012$; 2.0 [IQR, 1.0–3.2] vs. 1.0 [IQR, 0.5–1.2], $P = 0.029$; 2,192.5 [IQR, 1,645.3–2,897.3] vs. 1,233.0 [IQR, 1,015.0–1,805.5], $P = 0.004$, respectively).

The improvement in chest CT scans occurred much later in ICU patients compared with non-ICU patients (23.0 [IQR, 20.0–28.5] vs. 13.0 [IQR, 11.0–17.0]; $P = 0.001$) (see Table 4).

Difference in sporadic cases admitted or not admitted to ICU

We compared the differences in sporadic cases admitted or not admitted to ICU (see Table 5) to figure out the risk factors of ICU admission between the two groups. Many

TABLE 2 Clinical treatments of 90 patients with laboratory confirmed coronavirus disease 2019 infection.

Treatments	All patients ($n = 90$)	Clustered cases ($n = 41$)	Sporadic cases ($n = 49$)	*P*-value
Antiviral therapy	89, 98.9%	41, 100.0%	48, 98.0%	0.358
Time from illness onset to the initiation of antiviral therapy, days	5.0 (4.0–8.0)	5.0 (2.0–7.0)	7.0 (4.3–10.0)	0.002**
Time from illness onset to the end of antiviral therapy, days	21.0 (117.5–27.5)	20.0 (17.0–25.0)	23.0 (18.0–30.8)	0.111
Use of corticosteroids	70, 77.8%	31, 75.6%	39, 79.6%	0.651
Time from illness onset to the use of corticosteroids, days	8.0 (6.0–9.0)	7.0 (4.5–8.0)	8.0 (7.0–11.0)	0.003**
Time from illness onset to the end of intravenous corticosteroids use, days	19.5 (16.8–24.0)	17.5 (13.8–21.3)	21.0 (18.0–24.0)	0.010**
Ambroxol	56, 62.2%	21, 51.2%	35, 71.4%	0.049*
Antibiotic therapy	43, 47.8%	14, 34.1%	29, 59.2%	0.018*
Use of gamma globulin	36, 40.0%	14, 34.1%	29, 59.2%	0.863
Use of probiotics	9, 10.0%	5, 12.2%	4, 8.2%	0.778
Use of vasopressors	2, 2.2%	0, 0.0%	2, 4.1%	0.555
Mechanical ventilation	8, 8.9%	0, 0.0%	8, 16.3%	0.019*
ECMO	6, 6.7%	0, 0.0%	6, 12.2%	0.058
ALSS	10, 11.1%	0, 0.0%	10, 20.4%	0.006**
CRRT	5, 5.6%	0, 0.0%	5, 10.2%	0.100

ECMO, extracorporeal membrane oxygenation; ALSS, artificial liver support system; CRRT, continuous renal replacement therapy. *$0.01 < P < 0.05$; **$0.001 < P \leq 0.01$.

indicators were significantly different between patients admitted or not admitted to ICU in both sporadic cases and clustered cases, such as age, APACHE II score, WBCs count, neutrophil count, GFR, TNI, and IgG. There were some indicators that differed significantly only in sporadic cases, such as Albumin, Hydroxybutyrate dehydrogenase, CRP, Procalcitonin, IL-6, and IL-10.

Discussion

Despite the fact that the epidemic has been going on for half a year, our knowledge of this disease remains incomplete. The recurrence of the epidemic proves that we still need to pay more attention to the prevention and control of this disease.

This study reported 90 patients with confirmed COVID-19, of which 41 were clustered cases and 49 were sporadic cases. We found that patients in different groups showed no significant differences in demographics, clinical symptoms, and most laboratory findings, which was similar to the findings of Chen et al. (11). The most common symptoms were fever, cough, and expectoration, which is consistent with other studies (8, 12).

According to our findings, clustered cases had lower APACHE II scores on admission, fewer critical patients, and fewer patients receiving ICU care, mechanical ventilation, ECMO, ALSS, and CRRT compared with sporadic cases. The APACHE II score was widely used in the ICU to assess disease severity and mortality and was significantly higher in the severe group compared with the non-severe group (13). The fever duration and viral shedding in fecal specimens were shorter in clustered cases compared with sporadic cases. Viral shedding could be sustained until the patients' death (3). Delayed hospital admission could prolong the viral RNA shedding in the upper respiratory tract, and prolonged viral shedding could lead to worse clinical outcomes (14). Compared to sporadic cases, the time from illness onset to the end of intravenous corticosteroids use was shorter, and the possibility to develop ARDS and bacterial infections was reduced in clustered cases. For patients with progressive deterioration of oxygenation indicators, rapid progress in imaging and excessive activation of the body's inflammatory response, glucocorticoids would be used. Once the patients' laboratory findings got better, glucocorticoids would be gradually reduced and then stopped. The dosage of methylprednisolone changes from 20 to 80 mg/day according to each patient's condition. In a study of COVID-19, nine of 41 patients received corticosteroids, which could reduce the host lung inflammatory responses to avoid acute lung injury and ARDS (15). WHO highly recommended corticosteroids in patients with severe COVID-19 (16). However, it may also lead to delayed viral clearance and increased risk of secondary infection (17). ARDS is associated

TABLE 3 Clinical outcomes of 90 patients with laboratory confirmed coronavirus disease 2019 infection.

Outcomes	All patients ($n = 90$)	Clustered cases ($n = 41$)	Sporadic cases ($n = 49$)	*P*-value
LOS	16.5 (13.0–24.0)	16.0 (12.5–20.0)	19.0 (13.5–27.5)	0.087
APACHE II	6.0 (3.0–11.0)	5.0 (2.0–7.5)	7.0 (4.0–12.5)	0.005**
Time from illness onset to disease diagnosis, days	5.0 (2.0–7.0)	4.0 (1.0–6.0)	6.0 (4.0–7.0)	0.032*
Fever duration, days	11.0 (8.0–18.0)	10.0 (6.0–12.8)	13.0 (9.0–27.0)	0.020*
Duration of viral shedding in fecal samples, days	23.5 (18.0–32.3)	18.5 (17.0–28.3)	32.0 (24.3–35.5)	0.002**
Duration of viral shedding in the sputum sample, days	17.0 (13.0–24.3)	17.0 (13.0–21.5)	17.0 (13.0–28.5)	0.336
Complications				
ARDS	10, 11.1%	0, 0%	10, 20.4%	0.006**
Bacterial infection	16, 17.8%	3, 7.3%	13, 26.5%	0.036*
Intestinal flora disorders	9, 10.0%	5, 12.2%	4, 8.2%	0.778
Fecal RNA positivity	30, 35.3%	18, 47.4%	12, 25.5%	0.054
Clinical grade				0.038*
Moderate and severe	65, 72.2%	34, 82.9%	31, 63.3%	
Critical	25, 27.8%	7, 17.1%	18, 36.7%	
ICU care	24, 26.7%	6, 14.6%	18, 36.7%	0.018*
Time from illness onset to the improvement in chest CT scans manifestations, days	14.0 (12.0–19.0)	14.0 (11.8–18.0)	14.5 (12.0–20.0)	0.434

LOS, length of stay; APACHE II, acute physiology and chronic health evaluation II; ARDS, acute respiratory distress syndrome; ICU, intensive care unit; CT, computed tomography. *$0.01 < P < 0.05$; **$0.001 < P \leq 0.01$.

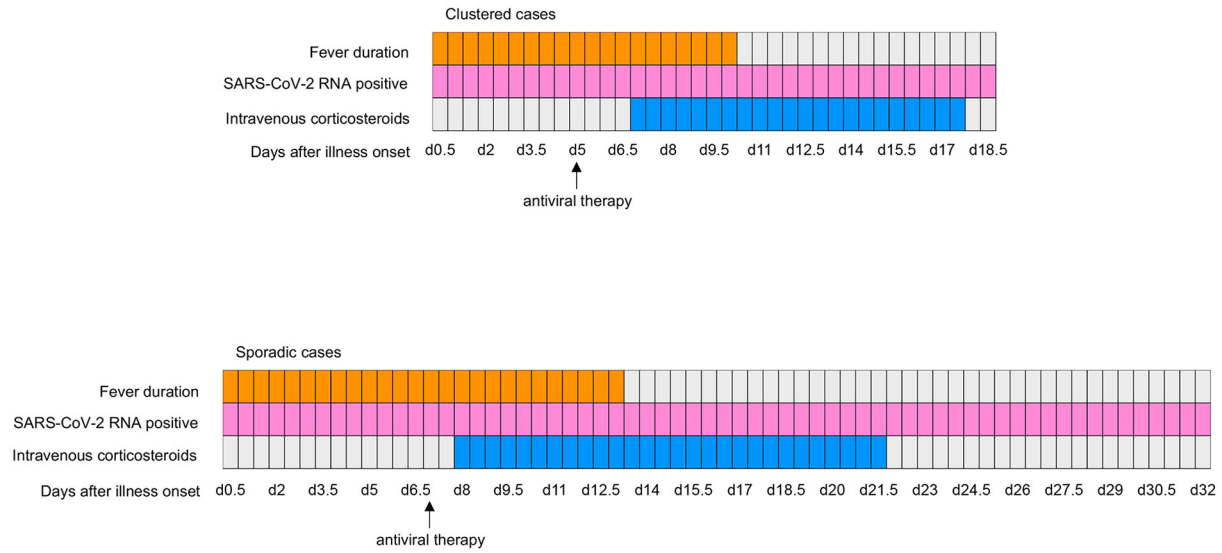

FIGURE 1
Clinical courses of major symptom and treatments and duration of viral shedding from illness onset in patients hospitalized with COVID-19. SARS-CoV-2, severe acute respiratory syndrome coronavirus 2; COVID-19, coronavirus disease 2019.

with pulmonary vascular permeability, increased lung weight, and loss of aerated lung tissue, and its 28-day mortality rate is up to 50% (18).

Above findings might suggest that patients with familial clustering had a milder disease and a better clinical outcome than sporadic cases, which is inconsistent with the findings

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TABLE 4 Difference in clustered cases admitted or not admitted to ICU.

	Admitted to ICU	Not admitted to ICU	*P*-value
Age	66.5 ± 18.2	47.2 ± 16.2	0.012*
Any coexisting disorder	5, 83.3%	14, 40.0%	0.049*
Disease severity status			<0.001***
Moderate and severe	0, 0.0%	34, 97.1%	
Critical	6, 100.0%	1, 2.9%	
APACHE II	12.5 (9.8–14.3)	3.0 (2.0–6.0)	<0.001***
Bacterial infection	2, 33.3%	1, 2.9%	0.008**
Antibiotics	6, 100.0%	8, 22.9%	<0.001***
Time from illness onset to the improvement in chest CT scans manifestations, days	23.0 (20.0–28.5)	13.0 (11.0–17.0)	0.001***
White blood cell count ($\times 10^9$/L)	10.1 (8.4–18.5)	5.2 (3.9–7.8)	0.007**
Neutrophil count ($\times 10^9$/L)	9.1 (7.6–16.6)	3.7 (2.3–6.7)	0.005**
Glomerular filtration rate (mL/min)	80.5 (60.8–94.3)	99.7 (83.2–112.5)	0.015*
Blood glucose (mmol/L)	8.1 (7.5–12.9)	6.3 (4.7–7.9)	0.022*
Troponin I (ng/mL)	0.016 (0.007–0.020)	0.003 (0.002–0.006)	0.012*
Interleukin-2 (pg/mL)	2.0 (1.0–3.2)	1.0 (0.5–1.2)	0.029*
Immunoglobulin G (mg/dL)	2,192.5 (16,45.3–2,897.3)	1,233.0 (1,015.0–1,805.5)	0.004**

ICU, intensive care unit; APACHE II, acute physiology and chronic health evaluation II; CT, computed tomography. *$0.01 < P < 0.05$; **$0.001 < P \leq 0.01$; ***$P \leq 0.001$.

of previous reports (8). This conclusion might be attributed to the fact that clustered cases had a more specific exposure history, shorter time from onset to diagnosis, and shorter time from onset to initiation of antiviral medication compared with sporadic cases. According to the Interim WHO Solidarity Trial Results, all four treatments evaluated (remdesivir, hydroxychloroquine, lopinavir, and interferon) had little or no effect on overall mortality, initiation of ventilation and duration of hospital stay in hospitalized patients (19). The 9th protocol published by National Health Commission of the People's Republic of China recommended that Paxlovid (300 mg PF-07321332 and 100 mg Ritonavir) or neutralizing monoclonal antibody therapy (1,000 mg BRII-196 plus 1,000 mg BRII-198) should be used to adults and adolescents with high-risk factors for progression from moderate to severe symptoms. Although, the result of a multinational clinical trial demonstrated that BRII-196 plus BRII-198 was safe, but not more effective than the placebo (20). Paxlovid did show efficacy in reducing the mortality and hospitalization rates in patients with COVID-19 without increasing the occurrence of adverse events (21). Like the previous report (22), our findings prove that the sooner we detect, diagnose, isolate and treat patients infected with SARS-CoV-2, the better clinical outcome patients have.

Epidemiological studies indicated that current social restriction measures for COVID-19 were effective in controlling the spread of the virus within large clusters, but might not be effective in small clusters and sporadic cases (23, 24). Enhanced management of contacts of COVID-19 cases and asymptomatic infected individuals is effective in reducing the potential of extensive dissemination of the virus within clusters (25). The results of these studies also confirm the need to enhance the early management of potential patients.

Although most of the clustered patients in this study had mild disease, some of them were still submitted to the ICU. To find out the difference in risk factors of ICU admission between clustered or non-clustered cases, we thoroughly compared the patients submitted to ICU and not submitted to ICU in two groups. We found that many of the same indicators differed between groups. We hypothesized that these indicators might be risk factors for patients admitted to the ICU, independent of whether they were clustered or not. IL-2 differed significantly between clustered cases admitted and not admitted to ICU. We indicated that IL-2 might be a specific indicator to identify the tendency of clustered cases to become critically ill. However, due to the small number of cases in this study, it might be incidental to draw conclusions. It needs large sample size to verify the hypothesis. There were some indicators that differed significantly only in sporadic cases, which might be related to the larger number of cases admitted to the ICU in it. If the number of cases was expanded, these indicators might also differ within clustered cases.

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TABLE 5 Difference in sporadic cases admitted or not admitted to ICU.

	Admitted to ICU	Not admitted to ICU	*P*-value
Age	63.2 ± 14.8	50.0 ± 11.3	0.003**
Disease severity status			<0.001***
Moderate and severe	0, 0.0%	31, 100.0%	
Critical	18, 100.0%	0, 0.0%	
LOS	27.5 (15.0–42.3)	15.0 (11.0–23.0)	0.003**
APACHE II	13.0 (12.0–16.5)	5.0 (2.0–7.0)	<0.001***
Antibiotics	15, 83.3%	14, 45.2%	0.009**
Use of gamma globulin	13, 72.2%	7, 22.6%	0.001***
Fever duration, days	32.5 (13.0–46.0)	10.0 (7.0–13.0)	<0.001***
Time from illness onset to the improvement in chest CT scans manifestations, days	19.0 (15.0–57.0)	13.0 (11.5–16.5)	0.001***
Time from illness onset to the end of antiviral therapy, days	28.0 (23.5–34.0)	19.0 (16.0–29.0)	0.004**
Time from illness onset to the end of intravenous corticosteroids use, days	23.0 (20.5–38.0)	18.0 (17.0–22.0)	0.002**
PO_2/FIO_2	167.4 (91.8–276.3)	321.9 (250.5–403.5)	0.011*
White blood cell count ($\times 10^9$/L)	7.9 (4.5–13.2)	5.1 (3.0–8.0)	0.032*
Neutrophil count ($\times 10^9$/L)	7.0 (3.5–12.0)	3.5 (1.7–6.6)	0.003**
Albumin (g/L)	33.6 (31.0–36.9)	41.5 (35.6–44.2)	<0.001***
Glomerular filtration rate (mL/min)	66.1 (53.2–100.4)	91.4 (79.9–102.4)	0.031*
Hydroxybutyrate dehydrogenase (U/L)	335.5 (296.8–420.0)	228.0 (187.0–283.0)	0.001***
Troponin I (ng/mL)	0.006 (0.002–0.028)	0.003 (0.001–0.006)	0.036*
C-reactive protein (mg/L)	50.6 (26.2–96.1)	16.2 (4.6–35.3)	<0.001***
Procalcitonin (ng/mL)	0.11 (0.07–0.32)	0.05 (0.03–0.07)	<0.001***
Interleukin-6 (pg/mL)	57.1 (24.1–148.6)	13.6 (7.4–51.2)	0.005**
Interleukin-10 (pg/mL)	6.7 (5.4–9.0)	3.5 (2.9–6.4)	0.009**
Immunoglobulin G (mg/dL)	1,488.0 (1,138.5–2,189.0)	1,231.0 (983.8–1,401.8)	0.031*

ICU, intensive care unit; LOS, length of stay; APACHE II, acute physiology and chronic health evaluation II; PO_2, partial pressure of oxygen; FIO_2, fraction of inspired oxygen; CT, computed tomography. *$0.01 < P < 0.05$; **$0.001 < P \leq 0.01$; ***$P \leq 0.001$.

The study still has some limitations. First, the number of patients included in this study is relatively small, and the disease severity is relatively mild, which might have a selection bias and not fully reflect the characteristics of familial clustering. Second, patients may have memory bias when reviewing their exposure history, resulting in a reduced inclusion of clustered cases than those that actually occurred. Third, since the patients included in this study were all hospitalized in Zhejiang Province, regional bias may exist. Fourth, given that fewer patients received ICU care among the clustered cases, it may not allow a comprehensive exploration of risk factors for ICU admission among patients of a familial cluster. We would like to conduct new research about the clinical characteristics of a large cohort of clustered cases from each center of China.

In conclusion, compared with sporadic cases, clustered cases have milder disease severity, which may be closely related to the management of early detection, early diagnosis, early treatment and early isolation of COVID-19. Although the epidemic is relatively stable at present, another outbreak may occur. Therefore, it is recommended to strengthen the early detection, early diagnosis, early treatment and early isolation of the disease to prevent the epidemic from worsening again.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by Ethics Committee of The First Affiliated Hospital, Zhejiang University School of Medicine. The patients/participants provided their written informed consent to participate in this study.

Author contributions

Material preparation, data collection, and analysis were performed by WW, TD, DF, and JW. The first draft of the manuscript was written by XZ, WW, and DS. The revised manuscript was written by XZ and JN. All authors commented on previous versions of the manuscript, contributed to the study conception and design, read, and approved the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.1010099/full#supplementary-material

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Arizona Surge Line: An emergent statewide COVID-19 transfer service with equity as an outcome

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Introduction: The Arizona Surge Line was an emergent initiative during the COVID-19 pandemic to facilitate COVID-19 patient transfers and load-level hospitals on a statewide level. It was designed and implemented by the Arizona Department of Health Services in preparation for the first hospital surge due to COVID-19, recognizing the disproportionate impact that hospital surge would have on rural and tribal populations.

Methods: We analyzed the Arizona Surge Line transfer data for the state's first two COVID-19 surges (4/16/2020–3/6/2021). Transfer data included transfer request characteristics, patient demographics and participating hospital characteristics. When applicable, we compared this data with Arizona census data, COVID-19 case data, and the CDC/ATSDR Social Vulnerability Index. The primary outcomes studied were the proportion of COVID-19 patient requests being successfully transferred, the median transfer time, and the proportion of vulnerable populations impacted.

Results: During the period of study, 160 hospitals in Arizona made 6,732 requests for transfer of COVID-19 patients. The majority of these patients (84%, 95% CI: 83–85%) were placed successfully with a median transfer time of 59 min (inter-quartile range 33–116). Of all transfer requests, 58% originated from rural hospitals, 53% were for patients of American Indian/Alaska Native ethnicity, and 73% of patients originated from highly vulnerable areas. The majority (98%) of receiving facilities were in urban areas. The Arizona Surge Line matched the number of transfers with licensed market shares during the period of study.

Conclusions: The Arizona Surge Line is an equity-enhancing initiative that disproportionately benefited vulnerable populations. This statewide transfer infrastructure could become a standard public health mechanism to manage hospital surges and enhance access to care during a health emergency.

KEYWORDS

surge, COVID, load-leveling, transfer center, equity, access to care

1. Introduction

In the spring of 2020, public health officials across the country watched with concern as New York hospitals experienced the first COVID-19 surge in the United States. At that time, New York had no centralized infrastructure to coordinate and balance patient transfers between hospital systems. As a result, healthcare workers reported "apocalyptic" conditions in safety-net hospitals while private hospitals nearby had open beds. In the words of one observer, this was "a hospital system that was less than the sum of its mighty parts" (1, 2).

1.1. Background and rationale

Public health officials at the Arizona Department of Health Services (ADHS) feared emergency department crowding and imbalanced ICU patient flow in Arizona would similarly burden the hospital system and increase adverse outcomes, including patient mortality (3, 4). At that time, Arizona's system of hospitals, which includes private for-profit hospitals, public non-profit and public for-profit hospitals, critical access facilities, as well as the Indian Health Service and tribally operated P.L. 93–638 hospitals, had no existing centralized transfer infrastructure. Furthermore, Arizona health officials knew of no statewide precedent for such infrastructure.

There was a particular concern for the impact on rural and tribal populations in Arizona. Marginalized communities were already vulnerable to external health stressors and would soon face disproportionately higher rates of infection and mortality from COVID-19 (5). The bulk of the tertiary care system in Arizona lies within the urban centers and Phoenix and Tucson. If urban centers declined rural transfers due to overwhelmed capacity, a patient surge would likely worsen historical and ongoing health disparities in the state of Arizona.

1.2. Description of case

ADHS assembled the state's major hospital systems to implement a centralized statewide transfer infrastructure, the Arizona Surge Line (ASL), before the state's first COVID-19 surge. The ASL's mission was to protect hospitals and patients from unbalanced hospital surges by (a) load-leveling hospitals across the state, (b) expediting transfers of COVID-19 patients (c) ensuring equitable access to care, and (d) relieving clinicians of the operational burden of transfer to allow more time for patient care.

ADHS funded and administered the ASL. Hospital leaders contributed medical and transfer expertise to protocolize the ASL, focusing on bringing patients to a higher level of care (i.e., ICU). Patient transfers were directed to selected hospital systems based on a statewide bed availability dashboard and an alignment of transfer proportions with hospital systems' market share. Hospitals were not required to accept patients; final decisions on transfer and placement were made in real-time between physicians at the sending and receiving facilities. Large healthcare systems managed patient transfers within their system.

The ASL went live on April 16, 2020. In May 2020, the Arizona Governor issued an Executive Order that required hospitals to use the ASL for COVID-19 transfers and complete bed assignments within 30 min. It also required insurers regulated by the state to cover COVID-19 transfer and treatment at in-network rates if the ASL facilitated the transfer (6).

The rapid implementation and cost of the ASL are detailed in a prior publication (7). This manuscript details the outcomes from transfer requests for a higher level of care during the first two surges of COVID-19 in Arizona. When utilized in the ASL analysis, statewide census and COVID-19 data comes from the Arizona Census 2020 (8) and the ADHS COVID-19 dashboard, respectively (9). Data on social vulnerability comes from CDC/ATSDR's Social Vulnerability Index (SVI) (10).

2. Methods

2.1. Study design

The study is an evaluation of a public health initiative, and the Arizona Surge Line was not designed as a research project. This analysis could be classified as a retrospective cohort study.

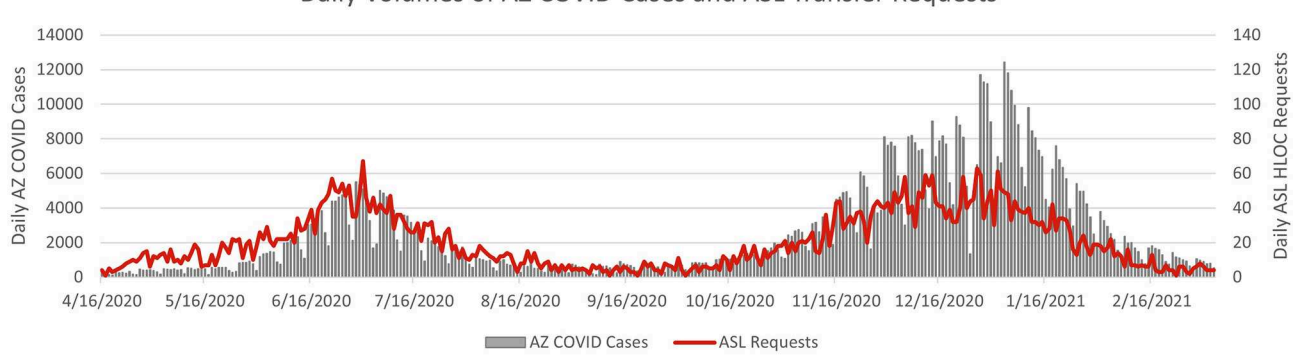

FIGURE 1
Daily counts of Arizona COVID-19 cases and ASL transfer requests to a higher level of care. In this graph, the daily volumes of ASL transfers (ASL data) are compared on top of the AZ COVID cases (state data) over the course of the first two COVID-19 surges in Arizona. Transfer requests generally followed the state's COVID-19 case counts, peaking at 67 requests/day surge Surge 1 and 63 requests/day during Surge 2.

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TABLE 1 Characteristics and outcomes of Arizona Surge Line transfer requests: 4/16/2020–3/6/2021.

All requested transfers				
Number of transfer requests		All *N* = 6,732	Surge 1 *N* = 2,880	Surge 2 *N* = 3,852
Referring facility	Rural	3,904 (58%)	1,648 (57.2%)	2,256 (58.6%)
	Urban	2,676 (39.8%)	1,208 (41.9%)	1,468 (38.1%)
	Out of state	152 (2.3%)	24 (0.8%)	128 (3.3%)
Final case status	Canceled	942 (14%)	301 (10.5%)	641 (16.6%)
	Declined	154 (2.3%)	74 (2.6%)	80 (2.1%)
	Transferred	5,636 (83.7%)	2,505 (87%)	3,131 (81.3%)
Requested level of care*	ICU	2,114 (38.5%)	688 (37.1%)	1,426 (39.2%)
	ICU ECMO	87 (1.6%)	19 (1%)	68 (1.9%)
	Medical/surgical	1,298 (23.6%)	433 (23.4%)	865 (23.8%)
	Telemetry	1,991 (36.3%)	714 (38.5%)	1,277 (35.1%)
Patient race#	American Indian/Alaska Native	2,853 (49.5%)	1,353 (53.6%)	1,500 (46.3%)
	Asian	15 (0.3%)	8 (0.3%)	7 (0.2%)
	Black/African American	87 (1.5%)	54 (2.1%)	33 (1%)
	Hispanic	1,383 (24%)	628 (24.9%)	755 (23.3%)
	Native Hawaiian/Pacific Islander	9 (0.2%)	6 (0.2%)	3 (0.1%)
	White/Caucasian	1,420 (24.6%)	477 (18.9%)	943 (29.1%)
Patient gender&	Female	2,934 (43.7%)	1,295 (45%)	1,639 (42.6%)
	Male	3,787 (56.3%)	1,580 (55%)	2,207 (57.4%)
Patient age		61 (48, 72)	58 (44, 70)	63 (51, 73.8)
All completed transfers				
Number of completed transfers		All *N* = 5,636	Surge 1 *N* = 2,505	Surge 2 *N* = 3,131
Referring facility	Rural	3,486 (61.9%)	1,500 (59.9%)	1,986 (63.4%)
	Urban	2,056 (36.5%)	987 (39.4%)	1,069 (34.1%)
	Out of State	94 (1.7%)	18 (0.7%)	76 (2.4%)
Accepting facility	Rural	101 (1.8%)	33 (1.3%)	68 (2.2%)
	Urban	5,534 (98.2%)	2,471 (98.6%)	3,063 (97.8%)
	Out of state	1 (0%)	1 (0%)	0 (0%)
Time to place (minute)		59 (33, 116)	53 (29, 102.8)	64 (35, 126)
Requested level of care*	ICU	1,723 (37.1%)	565 (35.2%)	1,158 (38.1%)
	ICU ECMO	30 (0.6%)	12 (0.7%)	18 (0.6%)
	Medical/surgical	1,120 (24.1%)	373 (23.2%)	747 (24.6%)
	Telemetry	1,770 (38.1%)	657 (40.9%)	1,113 (36.7%)
Patient race#	American Indian/Alaska Native	2,578 (52.8%)	1,253 (56.3%)	1,325 (49.9%)
	Asian	11 (0.2%)	5 (0.2%)	6 (0.2%)
	Black/African American	65 (1.3%)	37 (1.7%)	28 (1.1%)
	Hispanic	1,131 (23.2%)	536 (24.1%)	595 (22.4%)
	Native Hawaiian/Pacific Islander	9 (0.2%)	6 (0.3%)	3 (0.1%)
	White/Caucasian	1,087 (22.3%)	388 (17.4%)	699 (26.3%)

(Continued)

TABLE 1 (Continued)

All completed transfers				
Number of completed transfers		All $N = 5,636$	Surge 1 $N = 2,505$	Surge 2 $N = 3,131$
Patient gender[&]	Female	2,501 (44.4%)	1,134 (45.3%)	1,367 (43.7%)
	Male	3,134 (55.6%)	1,370 (54.7%)	1,764 (56.3%)
Patient age		61 (47, 72)	58 (44, 70)	63 (51, 73)

The following table lists the characteristics and outcomes from the requested and completed patient transfers through the Arizona Surge Line from 4/16/2020 to 3/6/2021. This reflects the first two hospital surges due to COVID-19 in Arizona.
Surge 1: 4/16/2020–9/19/2020; Surge 2: 9/20/2020–3/6/2021.
Median (IQR) for continuous variables and count (percentage) for categorical variables.
*Requests without requested level of care captured (1,242 transfer requests including 993 completed transfers) were not included in the total count for proportion estimation; the initial ASL protocols did not capture this information.
[#]Requests without patient race (965 transfer requests including 755 completed transfers) were not included in the total count for proportion estimation.
[&]Requests without gender information (11 transfer requests including 1 completed transfers) were not included in the total count for proportion estimation.

2.2. Setting

Arizona is a large state (113,635 square miles) with distinct urban and rural regions. Within the state are a variety of private for-profit hospitals, public non-profit hospitals, public for-profit hospitals, Critical Access Hospitals, Indian Health Service and Tribally operated P.L. 93–638 Hospitals, and Veterans Affairs Medical Centers (VAMCs). Most hospital systems reside in Phoenix or Tucson. There is not a single hospital association that represents all hospitals.

The Arizona Department of Health Services (ADHS) is the state public health department, with a vision of "Health and Wellness for all Arizonans." The Arizona Surge Line was a novel public health initiative for ADHS, as it centralized the transfer of COVID-19 patients and balanced patients across the state's varying hospital locations, systems, and types.

2.3. Study population

The study analyzed the data from all patient transfer requests through the Arizona Surge Line. This included patient and hospital demographics, along with the transfer outcomes.

2.4. Data variables and sources

Upon receiving a patient transfer request, the Arizona Surge Line captured minimal clinical information of the patient, which included patient demographics on transfer requests: patient name, date of birth, sex, home zip code, race/ethnicity, and COVID-19 status (positive or presumed positive); as well as the name of the sending facility and the level of care requested. ASL agents completed follow-up calls nightly between midnight to 4:00 a.m. to confirm the timing and outcome of patient placement.

2.5. Analysis

The analysis of the data was completed and validated by two independent investigators (E.T. and C.H.) to enhance validity and statistical rigor.

For the statistical analysis: count and percentage were used to summarize categorical variables, and median and inter-quartile range (IQR) used for continuous variables. Characteristics and outcomes were summarized for all transfer requests for the subgroup of completed transfers. Confidence interval (CI) for any proportion was obtained by the Clopper-Pearson method, and CI for any median by the exact method based on sign test. The unit of analysis was transfer request/patient. The score CI was used for difference of proportions.

3. Results

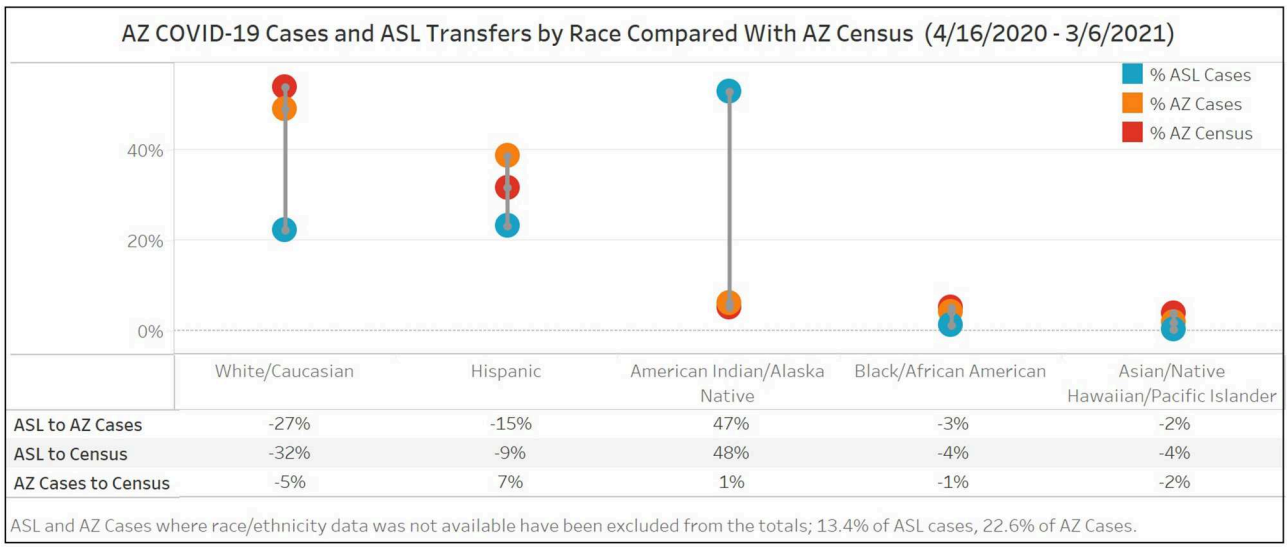
The data below reflect the following variables over Surges 1 (April 16, 2020 to September 19, 2020) and 2 (September 20, 2020 to March 6, 2021): (1) characteristics of the transfers requested and completed by the Arizona Surge Line, (2) demographics of the patients transferred through the Arizona Surge Line, and (3) characteristics of the Arizona hospitals transferring and receiving patients through the ASL.

3.1. Transfer characteristics

During Surge 1 and Surge 2, hospitals across Arizona made 6,732 requests for transfer to a higher level of care. Hospitals without a parent system made up 73% of these requests. Transfer requests generally followed the state's COVID-19 case counts, peaking at 67 requests/day during Surge 1 and 63 requests/day during Surge 2 (Figure 1).

Most transfer requests were for ICU/ICU ECMO (40%; 95% CI: 39–41%) or Telemetry (36%; 95% CI: 35–38%) levels of care, with only 24% requesting Medical-Surgical placement (95% CI: 23–25%). Initial ASL protocols did not capture the requested level of care, yielding an 18% unknown result which was excluded from the proportion estimation for this characteristic. Known requested levels of care changed minimally between Surge 1 and Surge 2 with ICU/ICU ECMO requests increasing by 3% and Telemetry decreasing by 3.5% (Table 1).

The majority of requests resulted in successful placement in an acute care hospital. Accepted patient transfers made up 84% of request outcomes (95% CI: 83–85%) during Surge 1 and Surge 2. Cancellations represent 14% of request outcomes (95% CI: 13–15%)



	White/Caucasian	Hispanic	American Indian/Alaska Native	Black/African American	Asian/Native Hawaiian/Pacific Islander
ASL to AZ Cases	-27%	-15%	47%	-3%	-2%
ASL to Census	-32%	-9%	48%	-4%	-4%
AZ Cases to Census	-5%	7%	1%	-1%	-2%

ASL and AZ Cases where race/ethnicity data was not available have been excluded from the totals; 13.4% of ASL cases, 22.6% of AZ Cases.

FIGURE 2
Race/ethnicity of Arizona COVID-19 cases and ASL completed transfers for Surge 1 and Surge 2 (4/16/20-3/6/21) compared to Arizona's 2020 Census. Race/ethnicity from Arizona's 2020 census is compared with Arizona's reported COVID-19 cases and ASL completed transfers during Surge 1 and Surge 2. The highest discrepancy between race proportions in ASL completed transfers and census was seen for AI/AN and White/Caucasian.

and occurred when placement was found within the referring system, at an out-of-state hospital, or was no longer required. There were 2% of requests declined due to available capacity or the availability of scarce resources such as ECMO and hemodialysis (Table 1).

The median of transfer time, defined as the interval between the first call to the ASL and ultimate bed assignment at a receiving facility, was 59 min (95% CI: 57–61) during the period of study; it increased from 53 min during Surge 1 (95% CI: 51–56) to 64 min in Surge 2 (95% CI: 61–67), as the capacity and resources of Arizona hospital systems became strained. At each surge peak, multiple facilities had to be contacted before the patient's placement was secured. During Surge 1 (excluding the initial week of the ASL program), the median transfer time over any 7-day period reached the highest level of 75.5 min during the 7-day period starting 7/3/2020, coinciding with the peak of COVID-19 cases in this surge; during Surge 2 the 7-day median reached the highest level of 118.5 min during the 7-day period starting 12/26/20, coinciding with the peak of Surge 2.

3.2. Patient demographics

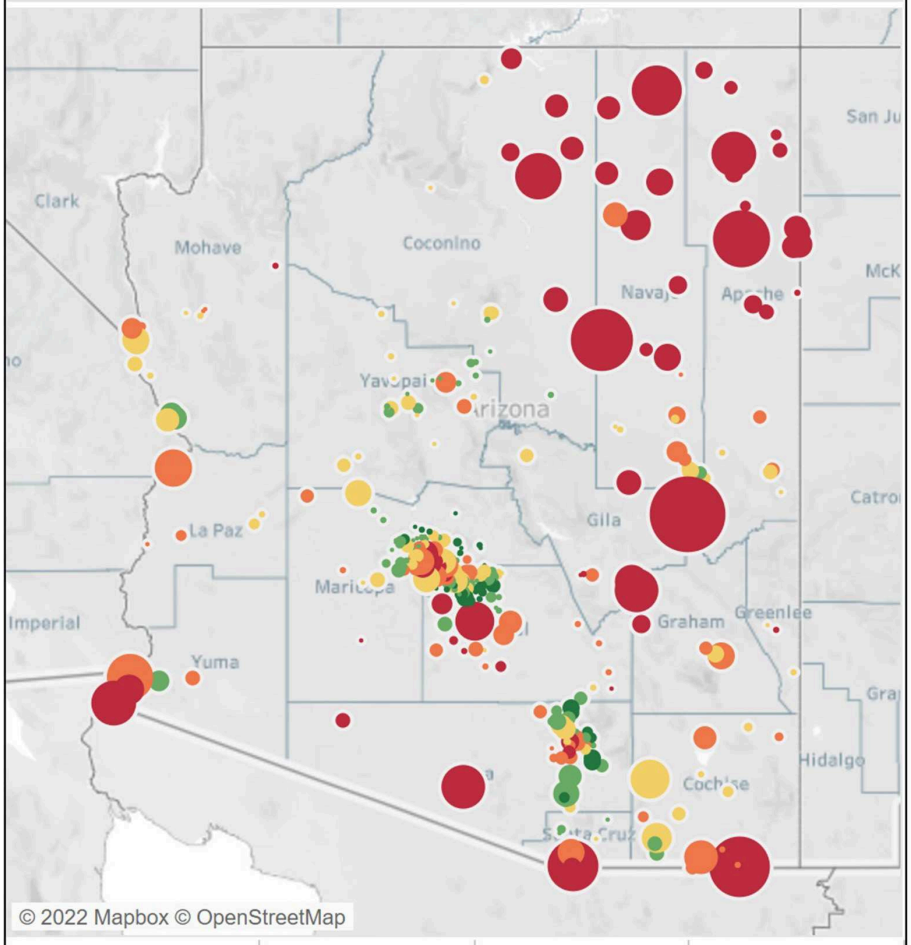
The ASL captured the age of every transferred patient. During Surge 1 the median age for patients transferred was 58 years and comprised 55% male and 45% female. During Surge 2 the median age increased to 63 years with males comprising 56% of transfers and females 44%. These demographics align with data captured on Arizona's COVID-19 hospitalizations through Surge 1 and Surge 2 where hospitalizations by gender showed 53% male, 47% female, and an increasing percentage of patients 65 and older (Surge 1: 37%, Surge 2: 50%).

Race/ethnicity information for transferred patients was captured for 87% of completed transfers. Race/ethnicity is not a demographic that is typically collected during the hospital transfer process, but ASL data quality improved as sending facilities became more familiar with its process. After excluding the transfers which did not include race data, 53% were American Indian/Alaska Native (AI/AN), 23% Hispanic, 22% White/Caucasian, and 2% Black/African American, Asian, or Native Hawaiian/Pacific Islander. There was a 6-percentage point decrease (95% CI: 4–9%) in AI/AN representation from Surge 1 (56%) to Surge 2 (50%), with White/Caucasian increasing by 9% (95% CI: 7–11%) from Surge 1 (17%) to Surge 2 (26%).

Race/ethnicity from Arizona's 2020 census is compared below (Figure 2) with Arizona's reported COVID-19 cases and ASL completed transfers during Surge 1 and Surge 2 (April 16, 2020 to March 6, 2021). The highest discrepancy between race proportions in ASL completed transfers and census was seen for AI/AN and White/Caucasian. AI/AN make up 5% of Arizona's population and 6% of AZ COVID cases yet disproportionately accounted for 53% (95% CI 51–54%) of the patients transferred through the ASL. An inverse relationship was seen for White/Caucasians who account for 55% of the state's population and 54% of AZ COVID-19 cases, but 22% of ASL transfers (95% CI 21–23%). Of note, 77% of Arizona COVID-19 case data included race/ethnicity data.

Patient home zip codes were collected from 92% of the ASL transfers with zip codes located outside the state of Arizona excluded from the analysis. Of these, 25% were P.O. Box zip codes, of which 79% were in reservation areas. Transfers that listed a P.O. Box zip code for patient origin treated the referring hospitals as a proxy for the home zip code. Zip codes with the highest vulnerabilities

Top: Arizona map of home zip codes for patients transferred through the Arizona Surge Line, color coded by CDC/ATSDR's Social Vulnerability index; Bottom: SVI of transferred patients home zip codes, 4/19/20 - 3/16/21.



Overall SVI	Grand Total	Surge 1	Surge 2
.8 - 1	**51.8%**	55.8%	48.7%
.6 - .79	**21.0%**	21.5%	20.5%
.4 - .59	**16.6%**	15.0%	17.9%
.2 - .39	**7.7%**	5.5%	9.5%
0 - .19	**2.9%**	2.3%	3.4%

FIGURE 3
Map of home zip codes for transferred patients through the Arizona Surge Line (4/19/20–3/16/21), color-coded by CDC/ATSDR's Social Vulnerability Index. On this map of Arizona, the colors reflect the levels of the CDC/ATSDR social vulnerability index, with red and orange indicating the top two quintiles indicating greater vulnerability. The circles represent an ASL transferred patient's home zip code, and the larger the circle, the larger the transfer volume from that particular zip code. Zip codes with the highest vulnerabilities were the points of origin for 73% of ASL's transferred patients.

as measured on the CDC/ATSDR Social Vulnerability Index, which tracks factors that weaken a community's ability to prevent suffering and loss in a disaster, were the points of origin for 73% of the ASL patients' transfers (Figure 3).

Per the Executive Order, insurance coverage of COVID-19 patient transfer and care would be covered at in-network rates. The ASL did not collect information on insurance.

3.3. Hospital characteristics

In total, over 160 acute care hospitals within Arizona participated in the ASL, including 53 non-profits, 39 for-profits, 3 Veterans Affairs, 11 Indian Health Service, 10 tribally-operated facilities under Public Law 93–638 (P.L. 93–638), and 14 critical access hospitals. These spanned all 15 Arizona counties. An additional 31 clinics and

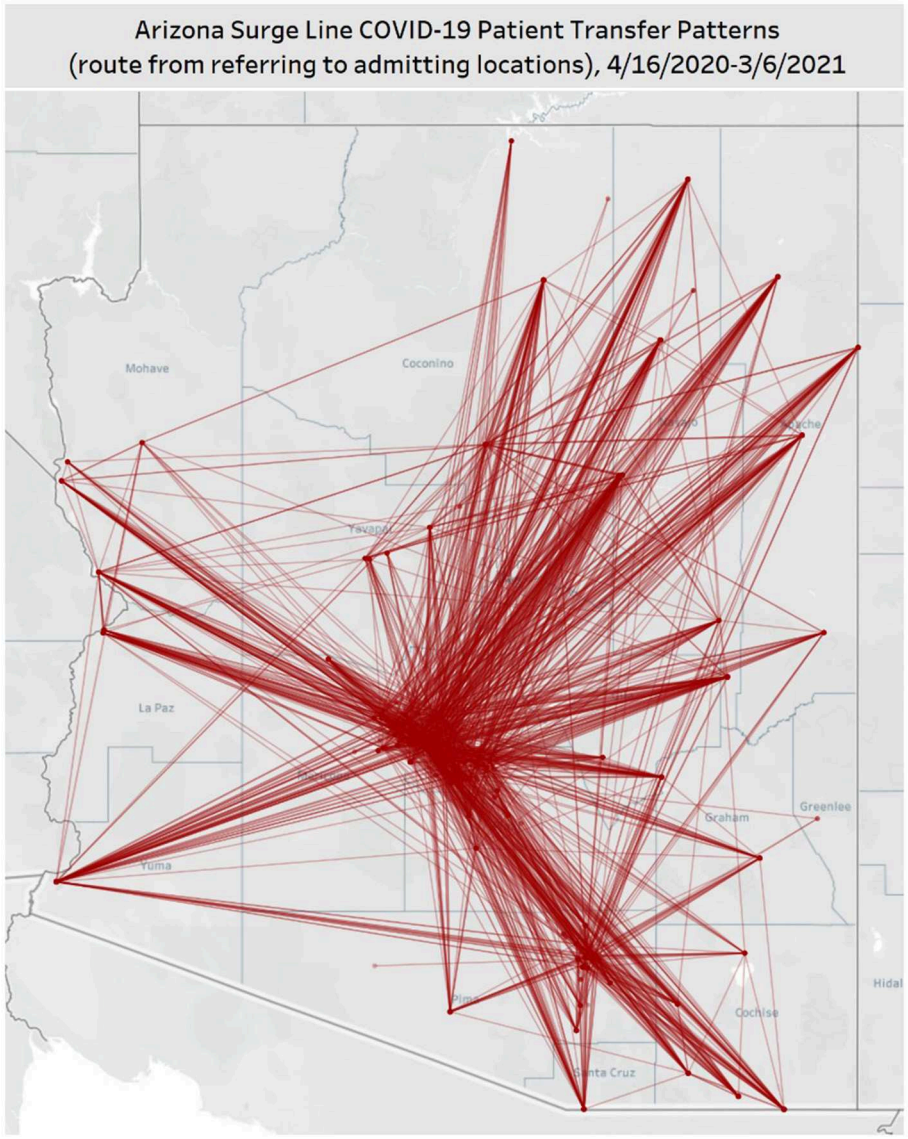


FIGURE 4
Map of hospital-to-hospital transfers completed through the ASL for Surge 1 (4/16/20–9/19/20) and Surge 2 (9/20/20–3/6/21). In this map of Arizona, each line represents a route patients took between sending and receiving facilities, as facilitated by the Arizona Surge Line. The time frame represents the first two COVID-19 surges in Arizona. 61% of transfers went from rural to urban facilities.

post-acute care facilities also sought direct admission into Arizona hospitals during this time period.

The majority (58%) of transfer requests were sent from Arizona's rural hospitals [classified the Health Resources & Services Administration definition (11)], with 30% coming from an Indian Health Service location, 31% from a critical access hospital, 29% from a tribally-operated P.L. 93–638, and 10% from a profit/non-profit/clinic. The majority (98%) of receiving facilities were in urban areas. Figure 4 shows the movement of patients during Surge 1 and 2, with 61% of transfers going from rural to urban facilities. Only 2% of transfers were rural to rural, an abnormal transfer pattern that occurred during peak surges when urban facilities had no more available resources.

Transfer requests from out-of-state hospitals comprised a small percentage of the total ASL requests. The ASL did not facilitate these transfers when Arizona hospital capacity was <10%. Out-of-state transfer requests increased from Surge 1 (0.8%) to Surge 2 (3.3%).

The algorithms for patient placement for the ASL included consideration for hospital system licensed market share. During Surge 1 and Surge 2, the Arizona Surge Line successfully aligned the percentage of transferred patients to within 5% of the licensed market share for all systems.

Throughout Surges 1 and 2, no Arizona hospitals reported through state-required reporting to be functioning under crisis standards of care (internal ADHS data).

4. Discussion

4.1. Summary of findings

During Surges 1 and 2, the ASL wove a patchwork of private and public hospital systems with varying capacities and resources into a support network that exceeded the sum of its parts. To our knowledge, the ASL is the only statewide load-leveling transfer line in the country that has documented this level of systematic equity enhancement, patient placement, and hospital load leveling.

During the period of study, rural facilities initiated the majority of transfer requests. The predominance of rural requests bears witness to the uneven distribution of healthcare infrastructure such as ICU/ICU ECMO and telemetry beds in the state and specialty services such as pulmonology or nephrology. The increase in out-of-state transfer requests is likely due to the increased lack of hospital capacity in the surrounding states, and suggests a regional approach to load-leveling may be indicated.

The patients transferred were predominantly American Indian/Alaskan Native (AI/AN), with a downward trend between Surges 1 and 2 likely attributable to the resourceful approaches to vaccination campaigns conducted in and by those populations in Arizona (12). The disproportionate transfers from AI/AN communities and socially vulnerable zip codes speak to the movement of patients who lack a larger parent healthcare system.

Except in the direst circumstances, urban facilities received these patients. Although transfers never consistently met the target of 30-min bed placement, most requests were fulfilled, and ASL transfers were anecdotally reported to be faster than non-COVID-19 placement. The ASL transfers successfully matched the market share benchmarks for participating organizations, relieving concerns of some hospital systems that transfer through the ASL may negatively impact market value.

4.2. Prior research

During the pandemic, a growing body of studies, guidelines, and recommendations on hospital surge management have emphasized load-balancing to enhance equity, improve patient outcomes, and postpone or mitigate crisis standards of care (13–16). Three regional transfer lines, including Arizona's, jointly recommended the implementation of regional, centralized transfer centers as a fundamental component of a surge response (17). To our knowledge, this is the first published set of outcomes from a statewide load-leveling and transfer center in this country.

4.3. Lessons learned

The ASL, a statewide load-leveling and transfer center, is an equity-enhancing initiative. It removed insurance as a barrier, expedited transfers for patients from vulnerable zip codes and from populations disproportionately impacted by COVID-19, and supported rural facilities and providers. Further, while no causation can be inferred, there was no widespread hospital activation of crisis standards of care or triage during the period of study. We anticipate critical medical review of this initiative will show that the Arizona Surge Line saved lives, especially among the marginalized populations with disparities in excess mortality associated with COVID-19.

Based on the successful outcomes in Arizona during Surges 1 and 2, transfer infrastructure should be a standard public health mechanism to anticipate and diffuse potential hospital surges in future health crises.

4.4. Limitations/acknowledgment of methodological or conceptual constraints

This analysis was limited to the patients that were transferred between Arizona hospital systems through the Arizona Surge Line, and thus does not include out-of-state transfers, non-COVID transfers or COVID transfers that occurred within a hospital system.

Additionally, this analysis was limited to the first two COVID-19 hospital surges in Arizona. The Arizona Surge Line functioned differently in the third surge and should be addressed separately.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants' legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

LV wrote the first draft. ET and CH completed the analysis. LS, DW, JR, and MG wrote and adjusted sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Dynamic analysis of NGO emergency relief goods supply: 2020 Hubei COVID-19 as a case

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Intention: Global emergencies cause significant damage to lives, assets, and the economy. Therefore, the supply of relief goods is essential in emergency relief contexts, which is generally the function of non-government organizations (NGOs) as they have unique relief goods supply advantages. However, few studies have explored the influencing factors on NGO relief goods supply efficiency. To systematically explore the factors affecting supply efficiency, we aim to develop a supply chain model for simulating and providing policy suggestions.

Method: Taking the 2020 Hubei COVID-19 as case study, this research developed a system dynamic (SD) model for the NGO relief supply system to evaluate and quantify the impact of factor changes on relief supplies.

Conclusion: It was found that transportation and information delays aggravated the NGO emergency supply chain bullwhip effect and caused large supply fluctuations. The initial relief goods inventory was found to be a decisive factor in reducing shortages in disaster areas; however, government support was found to play only a limited role in reducing information and transportation delays.

Value: This study enriches NGO emergency supply chain literature and provides suggestions for guiding NGO relief goods supplies in the future.

KEYWORDS

COVID-19, relief goods supply, NGO (non-governmental organization), system dynamic (SD) model, emergency relief

1. Introduction

The frequency and scale of humanitarian emergencies from natural disasters, war, and disastrous emergencies such as COVID-19 or terrorism have increased in recent years, with research suggesting that there may be more of such emergencies in the near future (1, 2). These emergencies have highlighted the significant gap in relief goods. For example, relief goods were in short supply during the 2004 Indian Ocean tsunami disaster (3), the 2010 Haiti earthquake (4), and the 2015 Nepalese earthquake (5). During COVID-19, the demand for medical and daily living supplies has also increased significantly (6). Immediately after the occurrence of an emergency in the response phase, it is vital that relief goods are delivered as quickly as possible to the victims in the affected regions (7) as shortages or delivery delays can result in serious losses (8, 9). Therefore, to save the lives of the people in the affected regions (10), relief goods supply is a vital part of emergency relief operations.

Providing relief goods and distributing them to affected areas are important emergency relief operation functions. While there are many relief goods providers, the primary contributors have generally been national government organizations (GO), such as the Federal Emergency Management Agency (FEMA) in the USA, NGOs (the Red Cross, community rescue teams, etc.), and private donors. These three entities have different purposes when providing relief goods to the affected areas and use different distribution channels (11). Of these providers, NGOs have been playing vital roles (12). For example, after the 2005 Hurricane Katrina, the

2008 Wenchuan earthquake, and the 2013 Haiyan typhoon, many NGOs provided emergency relief goods to the affected areas as part of the post-disaster relief and reconstruction (13–15). Compared with the GOs, NGOs are often more flexible in their disaster responses (16–18). For example, when a magnitude 9.0 earthquake struck East Japan on March 11, 2011, the Japanese Council of Social Welfare was supposed to immediately open and manage a disaster volunteer center; however, this was delayed by 1 month. Conversely, the NGOs took between 1 day and 1 week to establish emergency relief centers that provided food and trained rescue teams (19). Another example is the Bhuj earthquake in Turkey when the public rescue team could not access the distant village. However, NGOs managed to successfully reach the community and provide food and medical services (20). In 2004, one of the deadliest tsunamis hit the Indian Ocean and resulted in 227,898 missing persons (21). The Red Cross, Crescent Societies, and hundreds of NGOs responded rapidly using communication technology and modern transportation to rescue people and transport relief goods, which was in contrast to the slow bureaucratic and inefficient decision-making processes of the government (21).

Because of the increased frequency of emergency events, there has been a renewed research focus on emergency supply chains (22). After an emergency, relief goods need to be efficiently transported to the disaster area to reduce casualties. Najafi et al. (23) developed a dynamic earthquake dispatch and vehicle routing to assist disaster managers to plan their logistical activities in the earthquake response phase. Cao et al. (24) designed relief strategies based on a sustainability beneficiary perspective, for which a multi-objective mixed-integer nonlinear programming model was formulated, which was solved using a proposed genetic algorithm. Singh et al. (25) identified and analyzed relief supply chain resilience factors to ensure post-disaster supply capacities. Most previous relief goods supply research has tended to focus on emergency logistics, routing planning, and relief goods allocation. However, systematic research on the influences of the various supply effect factors is equally important.

NGOs and humanitarian supply chains build a "fairness" concept into their supply models (26). Therefore, most humanitarian supply chain research has focused on the last-mile distribution problem. For example, Rabta et al. (27) examined the use of drones for last-mile humanitarian logistics distribution, for which an optimization model was developed for the drone delivery of multiple lightweight relief item packages to remote locations within the disaster-prone area. Chen and Zhao (12) examined NGO capacity limitations and the relationships between GOs and NGOs, for which they modeled the relationships between received and donated relief goods quantities and developed a conditional earmarking donation strategy. Tatham and Blecken (28) empirical survey found that most NGOs did not adequately assess their supply chain performances and the associated logistics activities because they did not have the necessary capabilities. Therefore, to systematically resolve these practical NGO relief goods supply problems, as a case example, this paper employed system dynamics (SD) to study the NGO relief goods supply chains during the 2020 Hubei COVID-19 crisis.

SD is a pseudo-continuous modeling and simulation approach that has been widely used to holistically analyze complex, interdependent, and non-linear systems (29). SD can solve simultaneity (mutual causation) problems by updating all variables in small time increments, providing positive and negative feedback and time delays, and structuring the interactions and control. As the strength of the SD modeling approach is its ability to forecast system behavior beyond the problem symptoms, it has previously been employed to model supply chain systems and evaluate the policy effects on systems (30). Olivares-Aguila and ElMaraghy (31) used an SD framework to observe supply chain behavior and evaluate the disruption impacts, and Xu et al. (32) developed an SD model to assist in the post-seismic relief supply allocations in the Longmen Shan fault area where many destructive earthquakes have occurred. Because SD methods are able to simulate and analyze specific human and environmental characteristics and their relationships during emergency events, it was deemed suitable for an analysis of the complex relief goods supply chain system (33).

In July 2020, the research team was invited to review the joint NGO relief goods supply activities in Hubei, which provided us with a rare opportunity to examine the NGO emergency supply chain system and obtain primary data for the SD model. This study was focused on three key problems: (1) what impact do emergency uncertainties have on NGO relief goods supplies; (2) how do the various factors affect the NGO emergency supply chain; and (3) how can the impact of these adverse factors be mitigated.

Using SD Simulation, this study explored the key elements of the NGO relief goods supply system and the influence of different behaviors on system performance. The preliminary investigation highlighted many of the practical NGO relief goods supply problems; therefore, it is hoped that the developed model and our conclusions can assist in resolving these problems.

2. NGO relief goods supply in Hubei during the COVID-19 crisis

The new coronavirus (COVID-19) that appeared in Hubei, China, at the end of 2019 had infected more than 10,000 Chinese people by February 1, 2020 (34). To mitigate the COVID-19 outbreak, a closure strategy was implemented on January 23, 2020, in Hubei, with other parts of China imposing travel restrictions (35). These policies effectively reduced the increase in infected people but also resulted in severe goods supply problems in Hubei (36). The government allocated more than 66 billion CNY to contain the outbreak and delivered 20 tons of medical supplies per hour across the country to support the relief effort. At the same time, the NGOs were fundraising for an epidemic prevention and control (EPC) program (12), for which the government established a coordination center. Specifically, the charitable foundations collected and donated funding to support the NGOs, and some emergency management NGOs and public health NGOs assisted state agencies, medical institutions, and foundations by delivering materials and services and assisting in the EPC program. Community-based NGOs assisted the local government responses (37), and community volunteers provided material assistance and emotional social support (38), which specifically included materials collection, distribution, transportation, and community services such as purchasing, sterilization, and psychological counseling (39).

While these actions and relief goods greatly assisted the EPC program, there were many problems in the actual goods supply process. For example, the purchase of materials over the internet meant that some elderly groups were unable to source enough materials (40). Because of the insufficient emergency materials

reserves, hospitals across the country, and especially those in Hubei where the situation was the most severe, were short of needed medical supplies, especially personal protective supplies such as medical protective clothing and N95 masks (41).

In July 2020, the research team went to Hubei to investigate the NGO relief goods supply process during COVID-19. Supported by the Hubei United Disaster Relief Welfare Network (HUDRWN), 50 HUDRWN NGO members were selected for interviews and questionnaires using stratified sampling, and descriptive statistics, reliability, validity, correlation, and difference analyses were conducted to determine the results. The research team examined the NGO EPC program activities in Hubei and found the following emergency goods supply problems. (1) Because of the traffic controls, there were only a limited number of vehicles authorized to transport goods, which meant that many goods were not delivered on time. (2) There was serious information asymmetry. When the goods collected by the NGOs were delivered, the receiving party's demand was saturated. (3) Because there were many different models and medical materials, the distribution was often incorrect.

These problems were not confined to the NGO relief goods transportation as they also affected the efficiency of the community EPC activities. Therefore, this study sought to systematically analyze the complete NGO emergency goods supply process to determine the key factors affecting its efficiency.

3. Methods

This section reviews the systems dynamics approach, outlines the data analysis procedures, and details the model development.

3.1. SD model development

The empirical SD research involved five consecutive steps (Figure 1): (1) problem definition; (2) systems analysis; (3) scenario analysis; (4) the building of the causal loop diagram (CLD) and the stock and flow diagram (SFD); and (5) conducting the simulation system analysis.

3.1.1. System analysis

Environmental constraints regulate system behavior and system construction. Before describing the system structure, the supply system context needs to be further explored. As the NGO emergency relief goods dispatch and transportation is a complex process that had multiple links; materials procurement, collection, transportation, and distribution; it is necessary to balance the supply and the demand under resource, time, information, and transportation constraints. Therefore, it was necessary to first analyze the system structure and functions.

The NGO relief goods supply chain is a complete process from the receipt of goods to the final distribution to the victims, that is, the process involves relief goods acquisition, procurement, transportation, storage, sorting, and distribution.

The system structure analysis examined all system elements, the interdependencies between these elements, and the mutual interactions. As dynamic behavior comprises information feedback, circular causalities, and the influences of these loops on the system variables (42), the supply system was divided into three subsystems: a supply subsystem; a transportation subsystem; and a consumption subsystem. The main task of the supply subsystem was to collect the relief goods and supply them as required, the actions of which were inevitably influenced by the government and media attention. The main transportation subsystem task was to transport the relief goods and feedback the actual disaster area needs to the NGOs; therefore, transportation and information delays needed to be accounted for. The main consumption subsystem function was to reflect the disaster area needs and the degree to which these needs were being met, as shown in Figure 2.

3.1.2. Building the causal loop diagram

The dynamics of a system are related to the interactions between the reinforcing feedback loops and the balancing feedback loops (43). The feedback loop visualization embedded in the SD model is known as a causal loop diagram (CLD), the aim of which is to identify the interactions within the model components (44). The definitions for the components used for the CLD creation in this study to explain the dynamics that stimulated changes in the selected supply effect indicators are given in Table 1.

Sterman (45) divided the generic stock management control problem into two parts: (1) a stock and flow system structure, and (2) a decision rule to be used by managers (Figure 3). There was one reinforcing loop and two balancing loops in the system. An increase in loss leads to a continuous increase in order and stock, which further increases the loss, which is the reinforcing loop. An increase in stock reduces the gap between stock and expected stock, reduces the adjustment for stock, and finally leads to a reduction in stock, which is the balancing loop. Similarly, the supply line reduces the gap between supply line and expected stock, which leads to a reduction in the adjustment for supply line, further reduces the order and finally leads to a reduction in the supply line, which is the balancing loop.

As outlined in NGO relief goods supply in Hubei during the COVID-19 crisis section, compared with general storage and supply models, the NGO emergency goods supply is more specialized. First, the coordination center rather than a supplier makes the order decisions, which can result in information delays between the disaster areas, the coordination center, and NGOs. Second, the demand satisfaction rate for the relief goods supply is far more important than the other evaluation indicators. Third, the factors affecting supply and transportation are more complex, such as focused media attention and government support. This paper, therefore, took Sterman's generic stock-management system model as the framework and then combined it with the emergency relief goods supply characteristics to develop the causal circuit diagram shown in Figure 4.

The CLD shown in Figure 4 has two balancing loops representing the influence of the delivered goods on the goods transportation decision-making. The two links between goods transit and decision-making are marked for time delays depending on the delay characteristics, that is, material delays, information delays, or transit delays, such as volume restrictions, road conditions, government support, and other factors.

As NGOs have accumulated emergency relief experience, NGOs in China and other countries have gradually formed NGO networks, which has significantly enhanced the ability of NGOs to obtain emergency relief information (46). However, because of limited resources and capacity, and the government's leading role as a most

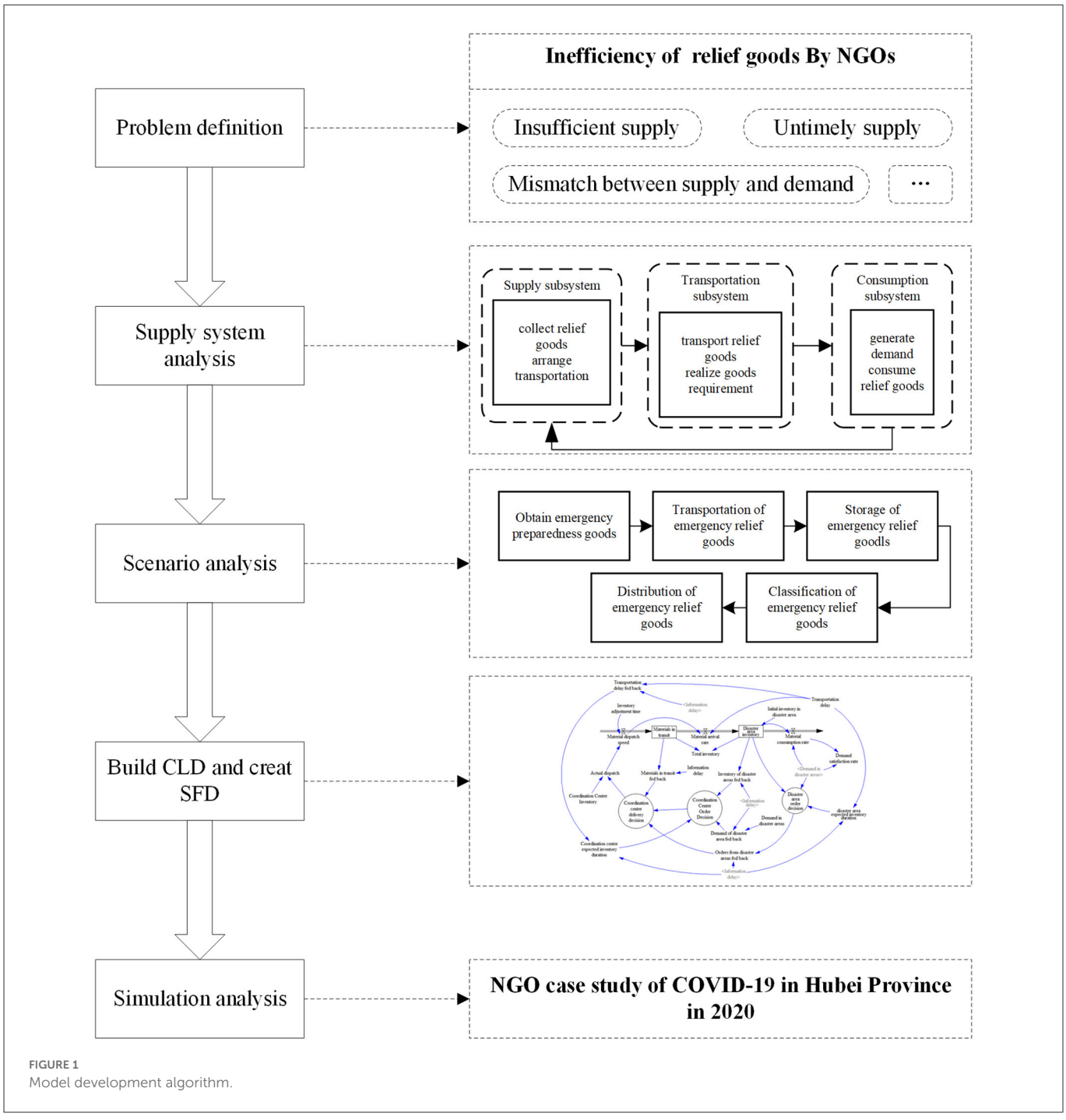

FIGURE 1
Model development algorithm.

responsible emergency relief provider (47), if the level of government support is improved and a transparent, efficient information platform is established for the disaster areas and the NGOs, the information delay is significantly reduced. The CLD with government support is shown in Figure 5.

3.1.3. Creating the stock and flow diagram

The SFD distinguishes the nature of each variable and describes the system elements and overall framework. Intuitive symbols depict the logical relationships between the elements to allow for an exploration of the system's feedback and control rules (48). In the system flow diagram shown in Figure 6, the level variables represented by the boxes reflect the system state, the values for which are determined from the materials accumulation and information flow results from an initial point to a particular moment, such as the goods in transit and the disaster area inventories. The rate variables reflect the system state changes per unit time, such as transportation delays, and the constant variables are the system's parameters, which change little over time scope and reflect certain elements, such as the consumption rate.

Based on the CLD, the resulting SFD is shown in Figure 7.

The relief goods volume is the core variable in the model. Depending on the relief scenario, the goods are divided into *goods in transit* and *disaster area inventory*. Goods dispatch and goods delivered, respectively result in increases and decreases in the *goods*

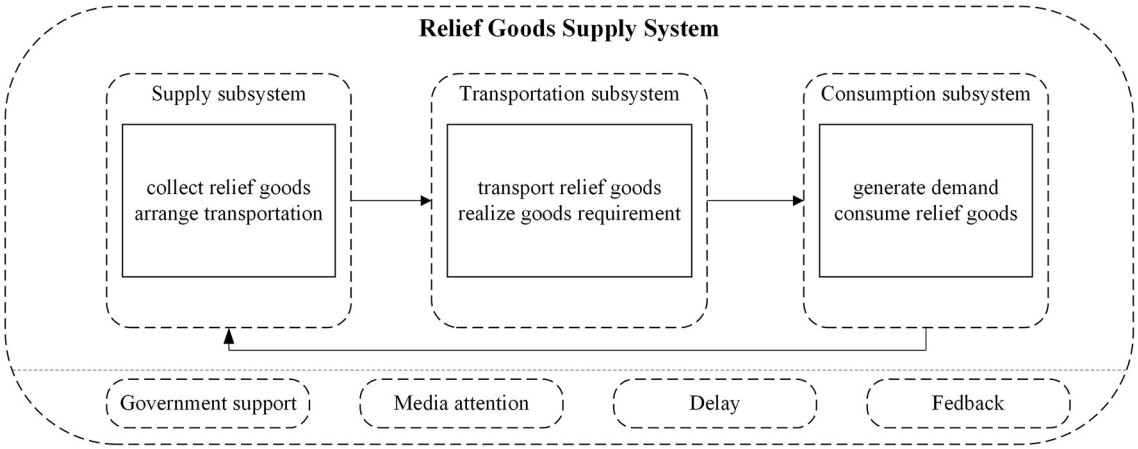

FIGURE 2
Supply system framework.

TABLE 1 CLD components.

Component type	Description of purpose	Visual representation
Variables	Indicates the variables in the system dynamic model	Text
Link	Indicates the links between the variables	
Link with time delay	Indicates the links between variables with a time delay	
Reinforcing loop	Indicates that a loop has a reinforcing effect on the initial variable value	
Balancing loop	Indicates that a loop has a balancing effect on the initial variable value	

in transit, and goods dispatch and goods consumption, respectively result in increases and decreases in the *disaster area inventory*.

The demand satisfaction rate is the core evaluation index for this model. Nutrition research has found that when the daily adult energy intake is <70% of the general level for some time, it has an adverse impact on health and can result in malnutrition and various diseases (49). Therefore, the time when satisfaction falls below 70% needs to be paid attention to.

The decision variable is the adjustable quantities in the actual decisions, which are represented by a circle in this model, such as the *coordination center delivery decision* and the *disaster area order decision*. The *coordination center delivery* volume is determined after the information delay by the *disaster area order decision* and the *coordination center order decision*.

There are two main NGO sources for relief goods and funds; donations from caring enterprises and people, and government service purchases. For the first source, the direct influencing factor is social donation enthusiasm, which is mainly related to the disaster severity, the number of affected people, and the media attention but can also be affected by government policies (support or restrictions). For instance, the release of Indian government documents improved the fund-raising capacities of local NGOs (50), and in another case study, NGO activities were found to be significantly restricted by a lack of *government support* (51). The second source of resources and funds is affected by the government's actions.

Therefore, because of donor and government influences, NGOs can experience goods supply discontinuities and uncertainties. Taking into consideration the above characteristics, a donation dimension SFD was built (Figure 8).

3.2. Data collection and analysis

Precise time series data are required to develop effective relief goods supply system dynamic models and test the accuracy of the model parameters. The required data were: (1) donation numbers and quantities in the period after the COVID-19 outbreak in Hubei; (2) the number of people affected by the pandemic and the goods consumption rate; and (3) the estimates for the road transport capacity and transportation and information delays.

To find the data for (1), a crawler was applied to the Baidu public donation information disclosure website (https://gongyi.baidu.com/dist/open-info.html) to obtain the donation information related to "COVID-19", the results from which are shown in Figure 9.

Because of the Hubei lockdown that commenced on January 23 and attracted significant nationwide attention, there was a large number of donations from January 25 to 26. From January 25 to January 27, Baidu launched an "Aid Hubei EPC" fund-raising project, which received a large number of donations from caring people. When the interference of this factor was excluded, after February 1,

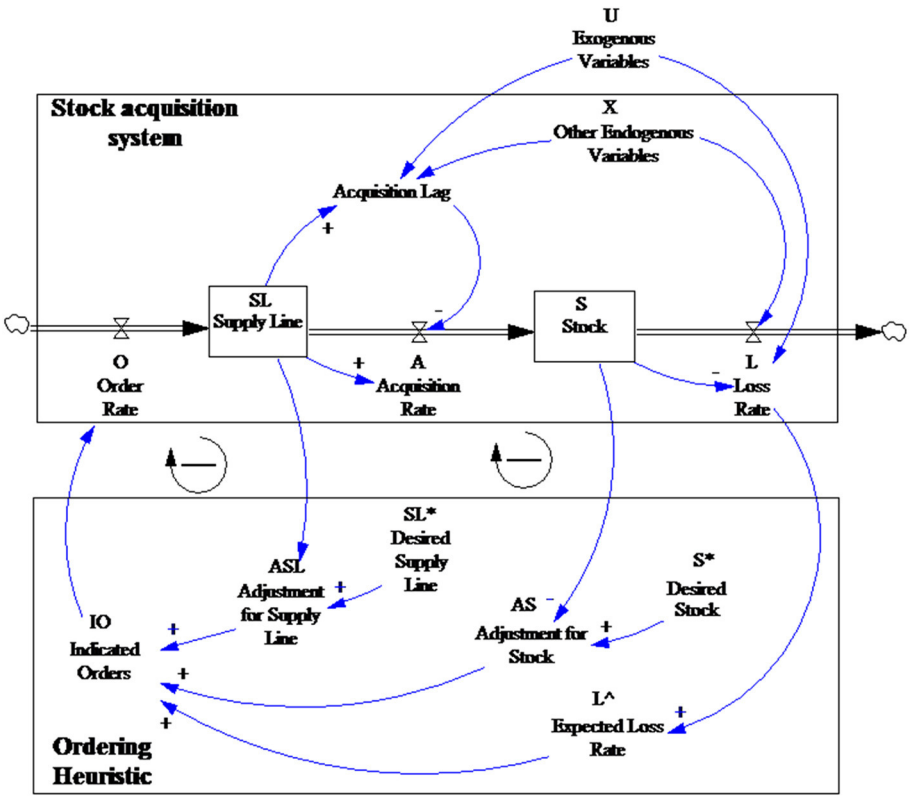

FIGURE 3
The generic stock-management system by Sterman.

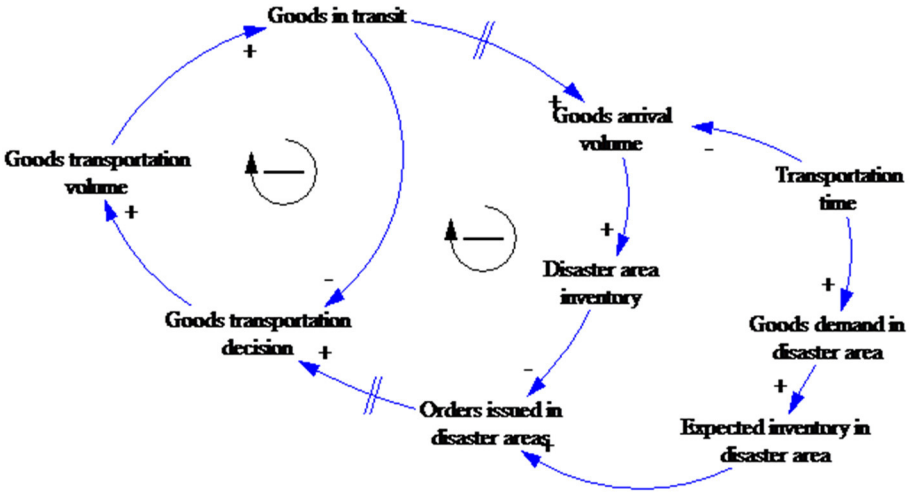

FIGURE 4
Relief goods supply system casual loop diagram.

the donations and the number of people related to COVID-19 peaked within a week and then began to slowly decline. With the input of rescue forces after the pandemic outbreak, the situation was gradually controlled, the demand in the pandemic area reduced, and public attention on COVID-19 gradually weakened, as shown in Figure 9.

Different from a general supply chain, the emergency relief supply chain has urgency and uncertainty characteristics. The relief goods can be divided into two categories: (i) cumulative demand, such as tents and disaster relief equipment, which if not met in time, increases the subsequent demand; and (ii) non-cumulative demand, such as drinking water and food, which is fixed in each time period, that is, the unmet demand does not accumulate.

To find the data for (2), previous studies have examined emergency relief goods demand based on disaster information and historical data (52–54). Because this study was focused on the impact of the dynamic disaster area environment on NGO relief

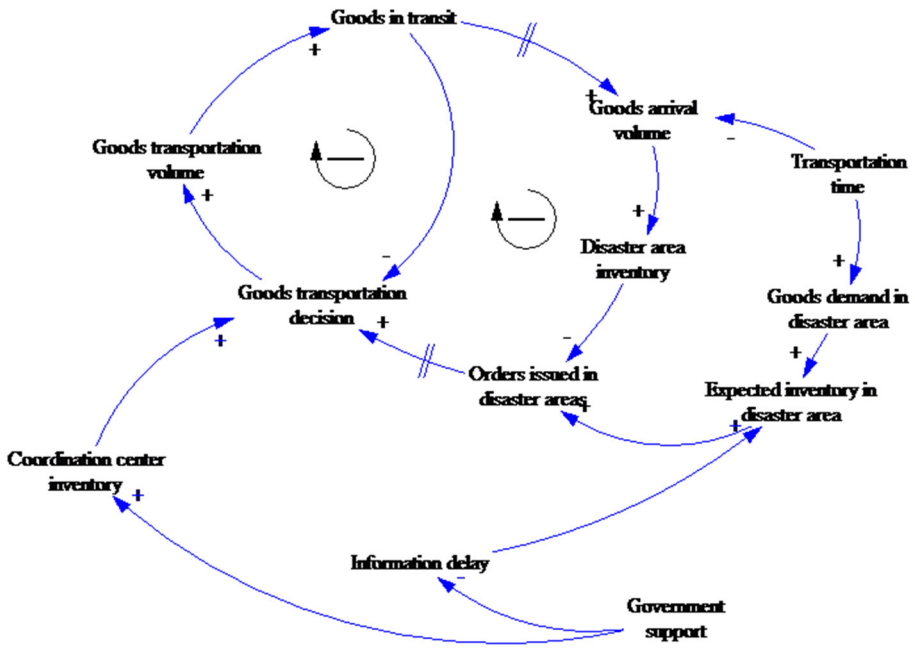

FIGURE 5
Relief goods supply system casual loop diagram (including government support).

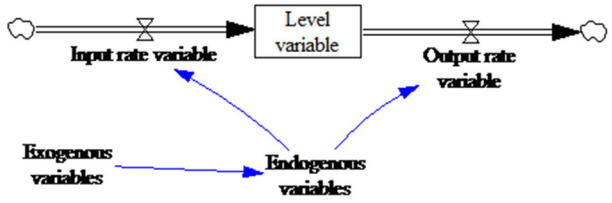

FIGURE 6
Stock and flow diagram symbols.

goods supplies, only the non-cumulative demand was considered. Therefore, based on the research, a negative exponential function was used to describe the gradual decline in demand after the emergency, to which a random variable was added to represent the noise, as shown in (1).

$$EXP\left(-RAMP\left(\{slope\},\{start\},\{finish\}\right)\right) {}^{*}RANDOM\ NORMAL\left(\{\min\},\{\max\},\{mean\},\{stdev\},\{seed\}\right) \quad (1)$$

When examining the data for (3), because NGO rescues are confronted with road and communication obstacles, the transportation and information delays are generally high. However, as actions are taken to repair the roads, these delays gradually decrease. Therefore, a negative exponential function $EXP(-RAMP(\{slope\},\{start\},\{finish\}))$ was employed to superimpose the random variables $RANDOM\ \ UNIFIRM(\{\min\},\{\max\},\{seed\})$ and describe the changes in the transportation and information delays. Three different delay levels were set to reflect the different emergency types and severities, as shown in Table 2.

To study the impact of different government attitudes on NGO relief goods supply, the government's attitudes toward the NGOs' emergency relief were divided into three types: restriction, noninterference, and support; with the respective government support variable values set at −0.5, 0, and 0.5.

4. Results

4.1. Demand simulation

Because different emergencies have different casualty and goods requirements, the needs were divided into low, medium, and high scenarios, the simulation results for which are shown in Figure 10.

The results showed that the three demand curves all peaked at 0 days and then gradually declined, which aligned with the post-disaster relief goods demand characteristics, that is, the more serious the disaster damage, the higher the demand, and the greater the demand fluctuations caused by secondary disasters.

In the COVID-19 case in Hubei, the wide variety of material types and specifications aggravated the information delay and often resulted in a mismatch between the supply and demand of relief goods. To simplify the model and focus on the supply chain characteristics, only a single type of relief goods was focused on.

4.2. Delay simulation

Based on the data in Table 2, three different transportation and information delays were simulated, with the results shown in Figure 11.

It was found that the change trends in transportation and information delays were basically the same and were only affected by secondary disasters and post-disaster maintenance. However,

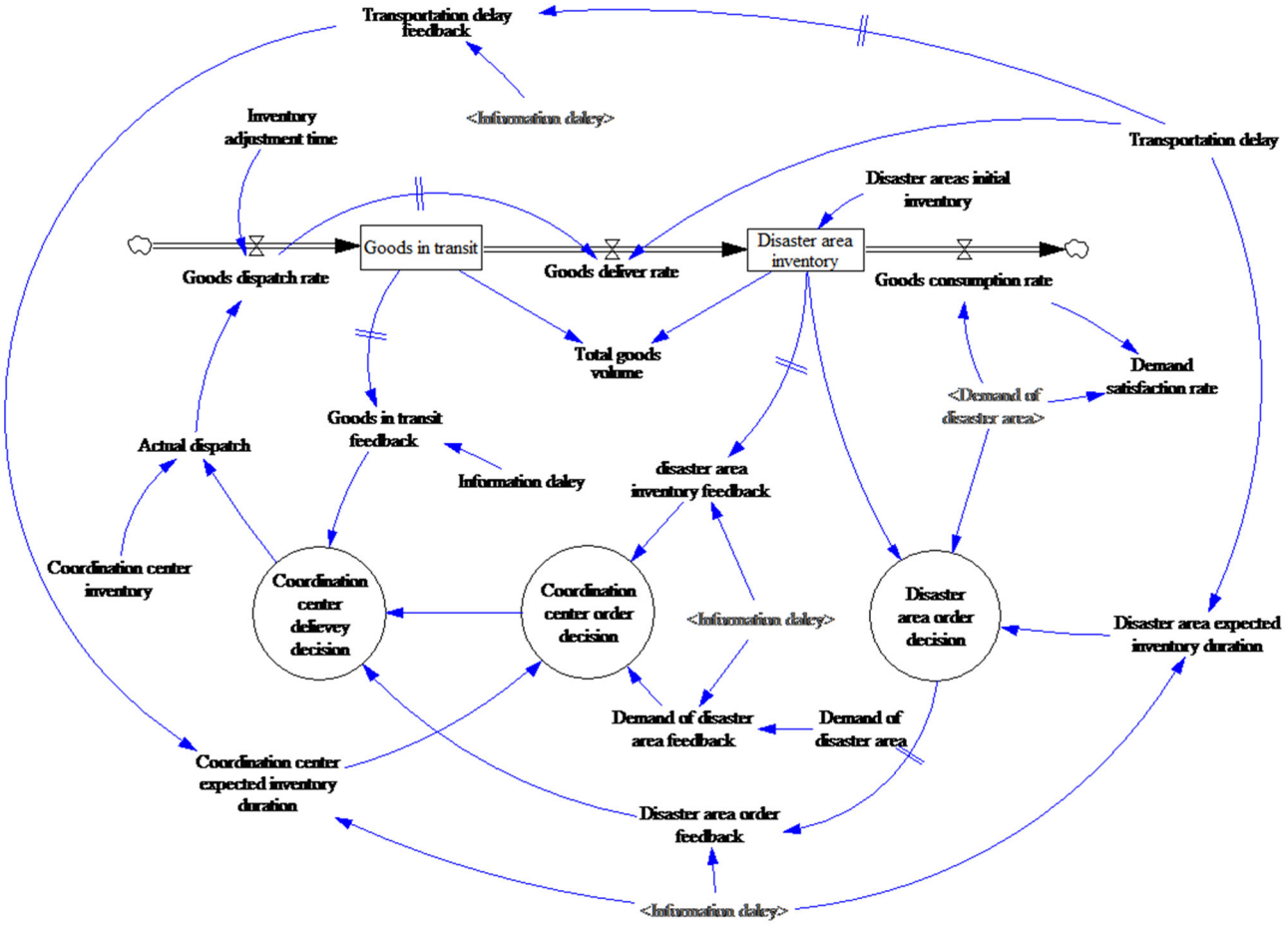

FIGURE 7
Relief goods supply system stock and flow diagram.

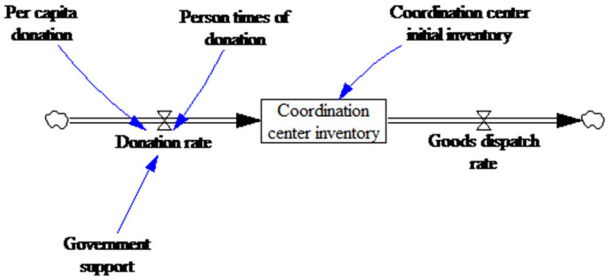

FIGURE 8
Donation dimension stock and flow diagram.

because communication equipment is easy to replace and less difficult to maintain, the information delay decreased rapidly in the short term after the disaster while the transportation delay decreased more slowly. In the simulated case, COVID-19 was surmised to result in traffic restrictions and increased transportation delays.

The adequacy of NGO funds is also an important factor affecting delays. For example, NGOs can increase transportation capacity and reduce transportation delays by purchasing additional vehicles and can reduce information delays by increasing manpower or equipment inputs. However, during the investigation of the NGOs participating in supplying relief goods during the Hubei 2020 COVID-19 crisis, it was found that the most significant NGO problem was a lack of funds, which meant that the delays did not fall quickly to acceptable levels.

4.3. Supply simulation

(1) Impact of demand fluctuations in the pandemic areas

The NGO relief goods supply simulation results under different dynamic demand levels in the pandemic area are shown in Figures 12A, B.

Due to the information (medium) and transportation (medium) delays, it was found that the NGOs received information about the relief goods demand in the pandemic area some time after the disaster, which meant the NGO materials were delayed in reaching the pandemic areas, as can be seen by the fluctuations in the curve. Further, because of the long-term nature of the demand and delays, the downstream supply chain fluctuations were amplified compared to the upstream fluctuations, that is, there was a bullwhip effect (55).

When white noise was added to the periodically fluctuating demand, the whole system fluctuated, as shown in Figures 12A, B. This was primarily because of the transportation delays as the demand lag resulted in a decline in inventory, which meant that the actual dispatch volume and demand satisfaction were no longer

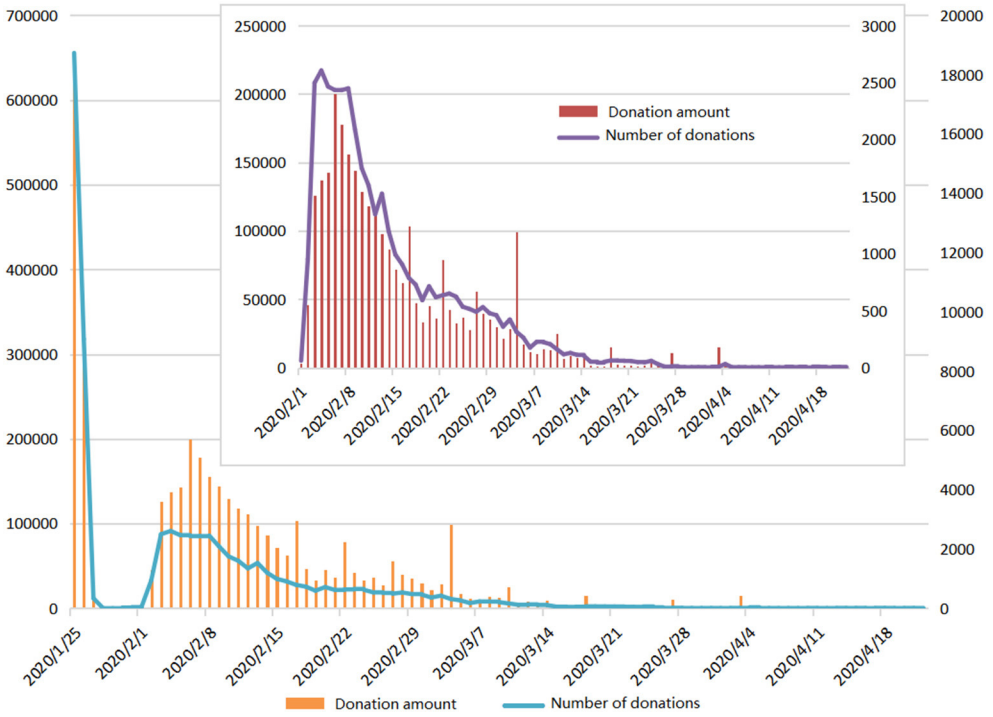

FIGURE 9
Hubei COVID-19 donation information.

TABLE 2 Transportation delay and information delay parameter settings.

Delay level	Transportation delay	Information delay	Interpretation
High	Exp [−RAMP(1/10,0,60)] ∗ RANDOM NORMAL (0, 8, 4, 4, 0)	EXP [−RAMP(1/5,0,60)] ∗ RANDOM NORMAL (0, 6, 3, 3, 0)	Traffic and communication are seriously affected or destroyed by the disaster
Medium	Exp (−RAMP(1/10,0,60)] ∗ RANDOM NORMAL (0, 4, 2, 2, 0)	EXP [−RAMP(1/5,0,60)] ∗ RANDOM NORMAL (0, 3, 1.5, 1.5, 0)	Traffic and communication are affected by the disaster and need some time to repair
Low	Exp [−RAMP(1/10,0,60)] ∗ RANDOM NORMAL (0, 2, 1, 1, 0)	EXP (−RAMP(1/5,0,60)] ∗ RANDOM NORMAL(0, 1.5, 0.75, 0.75, 0)	Roads and communications were slightly affected by the disaster

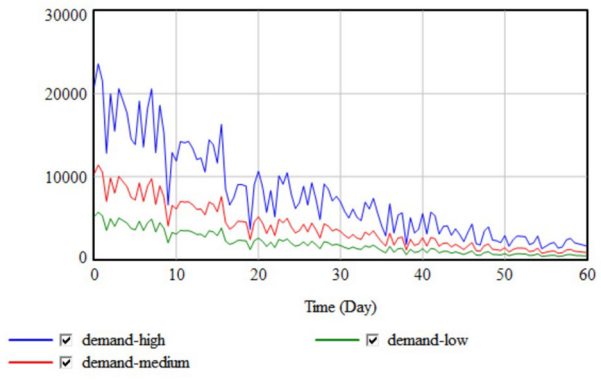

FIGURE 10
Demand simulation results.

stable. Compared to the case without white noise (SS01), the total inventory means and variance, respectively increased by 5 and 150%.

With the dynamic changes in demand, the changes in the relief goods supply chain became more complex. When demand dynamically changes, the inventory fluctuates, and the greater the demand fluctuation level, the more intense the shock to the whole system (SS12), and the worse the material supply effect on the system. As shown in Table 3, the supply rate decreased from 57 to 28%, and the total inventory increased by 92%. Even though the demand fluctuated and decreased, the inventory first increased and then decreased, which was due to the following.

(i) The dynamic transportation and information delay changes meant that the expected inventory was no longer stable as the order information was no longer changing regularly with the demand.
(ii) The coordination center was short of goods. Immediately after the emergency, the materials demand reached its peak; however, the insufficient donations led to insufficient inventory at the coordination center to meet the order demands, that is, the system had short supplies in the early stages. As the attention toward the emergency increased, donations increased but demand decreased, which meant that there was a rise in the inventory.

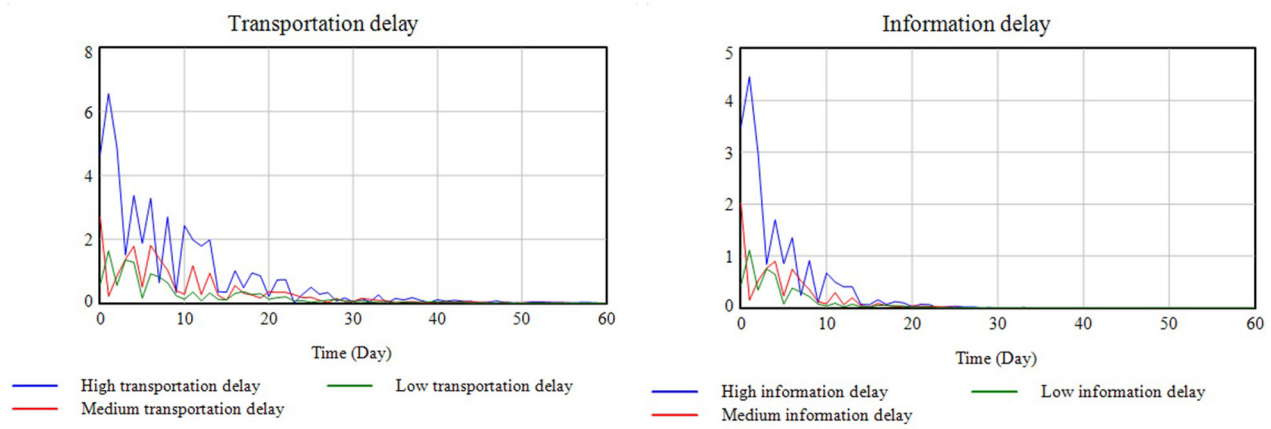

FIGURE 11
Delay simulation results.

(2) Delay impacts

The impacts of the different delays on the relief goods supply system are shown in Figures 12C–G. Note that all other factors are assumed to be at a medium level,

Figure 12C shows that with an improvement in the transportation delay situation, the dispatch increased significantly in the early stage and was relatively consistent in the later stage. This was because the transportation delays decreased over time, which meant that the differences between the two scenarios were also gradually disappearing.

Figure 12D shows the impact of the different transportation delay levels on the inventory in the pandemic areas, indicating that the higher the delay level, the greater the inventory fluctuations, which resulted in goods shortages in the early stage. Table 3 shows that under severe transportation delays, the goods supply rate increased by 1%, and the total inventory increased by 27%.

The simulation results in Figure 12E show that as the information delay increased, the dispatch tended to have more irregular fluctuations, which was because the information delay affected the expected inventory in the pandemic areas, which then affected the order decisions. And the information delays affected the coordination center decisions by affecting the inventory and demand feedback from the pandemic areas.

The information delays also affected the coordination center information regarding the goods in transit. Figure 12G reflects the transit goods backlogs during transportation, which formed a negative feedback loop with the dispatch of the materials, prevented the coordination center from sending excessive materials, and avoided unnecessary congestion. When the information delays increased, the goods in transit also increased, which the results in scenarios SS31 and SS32 in Table 3 also confirmed.

(3) Insufficient supply impacts

In the early emergency relief stage, there was a very large demand for goods in the disaster area, but because inventory had been damaged, there were insufficient supplies. Consequently, it took time for the NGOs to collect the necessary goods, which when complete, were subject to information and transportation delays at the coordination center. In the 2020 Hubei COVID-19 crisis, because there were no reliable procurement channels and the procurement price and quality were difficult to control, it was difficult to convert the raised cash into relief goods. Therefore, the actual dispatch at the initial stage was far less than the demand and available transportation; however, there was better consistency in the latter stages, as shown in Figure 12H.

After February 8, 2020, the goods demand in the pandemic area were basically guaranteed, which was consistent with the simulation results. The 11 emergency scenarios established in this paper indicated that there would be no supply shortages after 20 days. Therefore, the initial goods inventory factor was the main factor affecting demand satisfaction.

(4) Impact of government support

Government support affects the relief goods supply chain by affecting the delay change rate. The government supports NGO emergency relief by sharing information and giving them traffic priority. Therefore, increased government support results in reduced transportation delays and an increase in the efficiency of the goods supply and emergency relief. Increased government support also improves the speed and accuracy of the NGOs' access to information; therefore, an increase in government support results in a reduction in transportation and information delays, as shown in Figures 12I, J.

Second, the government's strict EPC regulations can increase the public's attention on the disaster, which can assist the NGOs to raise funds and acquire materials, that is, the goods supply is promoted. Scenarios SS51 and SS52 (Figure 12K) show the situation when there is full government support and the effect on the goods raised by the NGOs; therefore, government support can have a significant impact on the effectiveness of NGO relief goods collection.

5. Discussion

5.1. Complementary to the simulation results

The results of the research team's investigation in Hubei further confirmed the above simulation results and made supplements to the results.

(1) Effects of delay and use of wechat

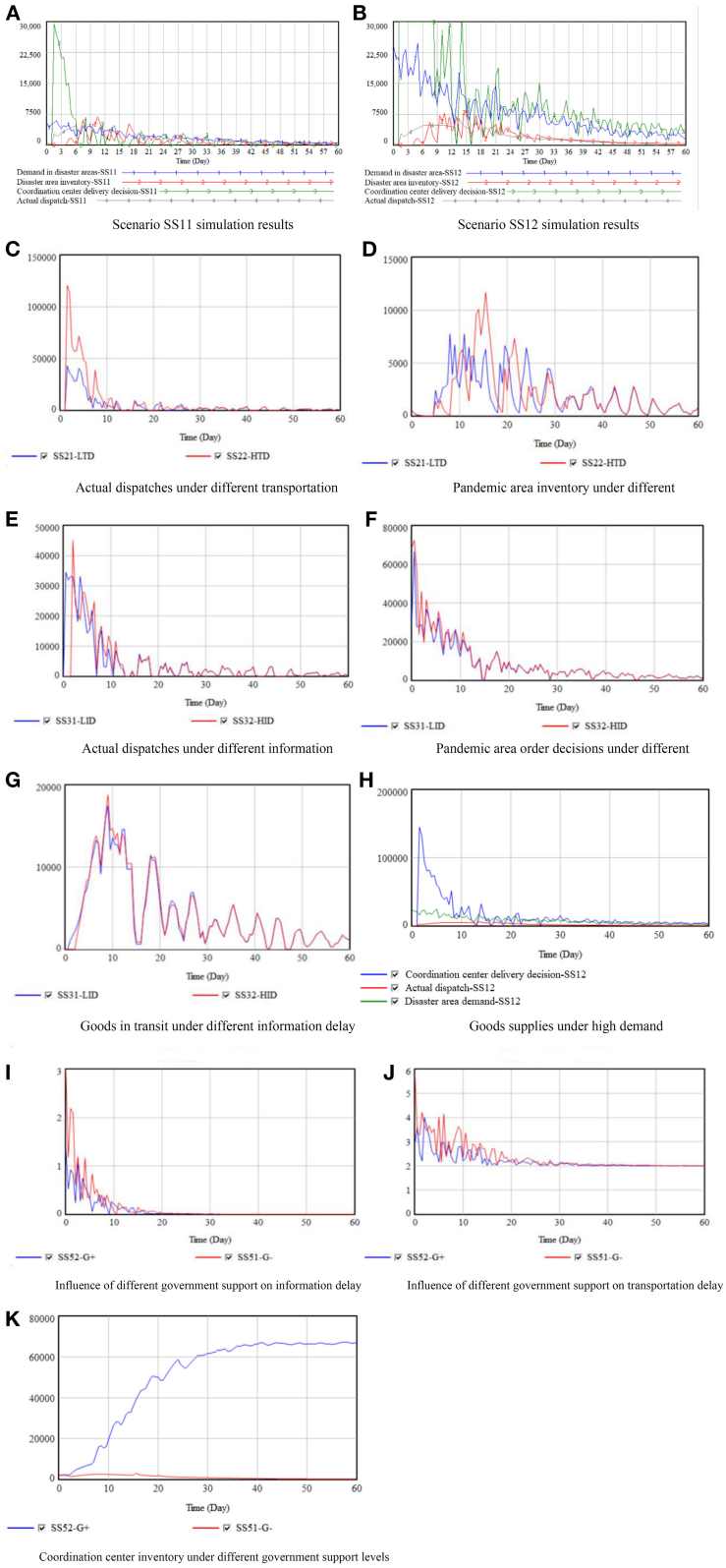

FIGURE 12
Goods supply simulation results.

Through investigation, delay, especially information delay, had a great negative impact on the efficiency of relief goods supply after the lockdown of Hubei. For example, NGOs have no channels to obtain sufficient relief goods, and the types and models of medical supplies needed in epidemic areas are not clear.

TABLE 3 Supply simulation results.

Scenario code	Exogenous variable				Evaluation indicator			
	Transportation delay (TD)	Information delay (ID)	Demand (D)	Government support (G)	Demand satisfaction rate		Total inventory	
					Mean value	Standard deviation	Mean value	Standard deviation
SS01	TD = 2	ID = 0.5	Low	Non-interference (G = 0)	0.980	0.090	2.550	0.500
SS11	Medium	Medium	Low	Non-interference (G = 0)	0.572	0.337	0.364	0.341
SS12	Medium	Medium	High	Non-interference (G = 0)	0.278	0.183	0.687	0.606
SS21	Low	Medium	Medium	Non-interference (G = 0)	0.532	0.344	0.584	0.456
SS22	High	Medium	Medium	Non-interference (G = 0)	0.538	0.357	0.742	0.705
SS31	Medium)	Low	Medium	Non-interference (G = 0)	0.534	0.339	0.620	0.513
SS32	Medium	High	Medium	Non-interference (G = 0)	0.541	0.339	0.630	0.544
SS41	Low	Low	Medium	Non-interference (G = 0)	0.528	0.342	0.575	0.434
SS42	High	High	Medium	Non-interference (G = 0)	0.539	0.360	0.754	0.733
SS51	Medium	Medium	Medium	Restriction (G = −0.5)	0.286	0.161	0.362	0.320
SS52	Medium	Medium	Medium	Support (G = 0.5)	0.543	0.322	0.622	0.510

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Additionally, in the 2020 Hubei COVID-19 crisis, the popular Chinese social media app "WeChat" played an important demand assessment and goods distribution role, primarily because the NGOs lacked a unified relief goods supply information sharing platform. If this problem were solved, the information delay would have reduced and the transportation efficiency would have significantly improved.

(2) Government influence

Through investigation, the research team found that the NGOs assisting in the Hubei COVID-19 crisis had had significant difficulties because there were no stable, high-quality procurement channels. When many hospitals in Wuhan were reported to be short of medical supplies, the government provided a large number of supplies to NGOs to help alleviate the shortage of supplies in Hubei. So government support will be an effective way to solving this problem. However, the effect of government support is not always significant. For example, the supply effect under government support in scenario SS52 was worse than the supply effect under government non-interference in scenario SS11.

5.2. Policy suggestions

Based on the simulation results, some policy suggestions are given to provide a reference for governments and NGOs when participating in emergency relief goods supply emergencies in the future. When the scale and type of emergency change, the SD model could also be employed to simulate the changed conditions.

(1) Increase the standby emergency relief goods inventories in disaster-prone areas and enhance the relief goods storage resistance capacities to reduce the possible damage to emergency preparedness materials from a disaster. This could effectively deal with the relief goods shortages in the early disaster stage.
(2) A bullwhip effect exists in the supply of NGO relief goods, which becomes more intense and irregular when there are transport and information delays. Therefore, reducing these transportation and information delays is needed to stabilize the system and improve supply efficiency through such means as simplifying approval procedures, establishing integrated information mechanisms, and establishing special roads for emergency supply transport.
(3) In small and medium-sized emergencies, NGOs can play important emergency relief goods supply roles. Governments should support NGO emergency relief operations through policy encouragement and media publicity. However, in large-scale emergencies, the NGOs' roles are smaller as the government undertakes the main emergency relief tasks.

6. Conclusion

Taking the 2020 Hubei COVID-19 crisis as an example, this study conducted SD simulation research on NGO emergency goods supply, from which the following conclusions were drawn.

(1) Secondary disasters cause demand fluctuations in disaster areas, which also have a bullwhip effect on the post-disaster emergency supply chain. Coupled with insufficient funding, the whole system can have large irregular fluctuations.
(2) Dynamic transportation and information delays cause greater system fluctuations and uncertainties. Transportation delays affect inventory by delaying the circulation of goods and influencing decision maker expectations, and information delays affect inventory by influencing disaster information feedback and decision maker expectations. The superposition of these two delays can further amplify system fluctuations and uncertainties.
(3) In all simulated emergency scenarios, it was found that the supply of the goods was sufficient 20 days after the disaster and that the initial inventory at the coordination center played a decisive role in the initial emergency goods supply. If there is a lower initial inventory, there could be chaos or even increased casualties in disaster areas because of the lack of relief supplies.
(4) Government support can significantly reduce transportation and information delays, which in turn can reduce relief goods inventory fluctuations in disaster areas and increase the demand satisfaction rate. However, government support for NGO goods supply was found to be limited. When there is significant disaster damage, the government support impact on supply efficiency was found to be slight.

However, there were some limitations to this study. First, because of its "big government, small society" context, the state-civil society in China is special (46), which also means that NGOs are usually constrained, even though they were fully authorized during the COVID-19 crisis, exploratory research in combination with other countries is needed to assess. Second, the problem structures and environment may change on the different system levels, which means that different methodological choices could be made. However, this study did not conduct a detailed analysis of each system level, which could be a valuable future research direction. Third, long city lockdowns are a rare occurrence; therefore, this research needs to be extended to other types of emergency scenarios, such as local wars or other humanitarian crises, to examine the differences.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

YL determined the research contents and methods, reviewed the manuscript, and provided fund support for the research. YW prepared Figures 1–12. All authors wrote the main manuscript text.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Effects of negative emotions and information perceived value on residents' risk perception during the COVID-19 pandemic: An empirical survey from China

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Background: The COVID-19 pandemic has spread rapidly and heavily hit the globe, and the mutation and transmission speed of the coronavirus have accelerated so that the world is still in danger. Thus, this study aims to investigate the participants' risk perception and explore the associations of risk perception of COVID-19 with negative emotions, information value perception and other related dimensions.

Methods: A cross-sectional, population-based online survey was conducted from April 4 to 15, 2020, in China. A total of 3,552 participants were included in this study. A descriptive measure of demographic information was used in this study. Multiple regression models and moderating effect analysis were used to estimate the effect of potential associations of risk perceptions.

Results: Those who showed negative emotions (depressed, helplessness, loneliness) and perceived video information in social media to be useful were positively correlated with risk perception, whereas individuals who perceived experts' advice to be useful, shared risk information with friends and thought that their community made adequate emergency preparation reported lower risk perception. The moderating effect of information perceived value ($\beta = 0.020$, $p < 0.001$) on the relationship between negative emotion and perception of risk was significant.

Conclusions: Individual differences in risk cognition during the COVID-19 pandemic were observed in subgroups of age level. Furthermore, the role of negative emotional states, the perceived usefulness of risk information and the sense of security also contributed to improving the public's risk perception. It is crucial for authorities to focus on residents' negative emotions and to clarify misinformation in accessible and effective ways in a timely manner.

KEYWORDS

risk perception, negative emotion, information perceived value, COVID-19 pandemic, psychology

Introduction

The new coronavirus disease (COVID-19) hit the whole world heavily in 2020. The rapid spread of the virus evolved into a global public health emergency, and many countries failed to contain the outbreak so that the world faced prolonged danger. According to the weekly epidemiological report, by the end of August 8, 2022, there have been about 5.81 hundred million

confirmed cases of COVID-19, including 6,410,961 deaths (1). The public faced uncertain and excessive risk information due to the high risk, infectivity, and severity of the COVID-19 pandemic. This information poses significant challenges to people's behavioral (e.g., irrational behavior) and psychological resilience (2, 3). Timely and accurate risk transmission helps eliminate people's fear of being infected and stabilize public sentiment. However, social media such as WeChat and Weibo are communication modes of group organization and interaction, which could make public opinion regulation and gatekeeping difficult under the impact of information tsunamis. Given the urgency of the pandemic risk, social media may provide convenient ways for users to receive and share uncertain and inaccurate information much faster *via* social networks (4), especially those targeting heterogeneous risk perceivers (5). When emergencies impinge on the tolerable cognitive schema, people become prone to allostatic overload, which could lead to psychological crisis and irrational behavior (6).

Risk perception acts as a buffer between information exposure and decision-making behavior. It is generally defined as a cognitive judgment of the likelihood of encountering hazards when received risk information is minimal (7, 8). In general, it comprises two components: perceived risk susceptibility and perceived risk severity (9). This is a subjective judgment made by people when characterizing and evaluating hazards, and the evaluation of risks is influenced by numerous individual and societal factors and the exposure of people to external pressures (10). Studies have shown that risk perception could trigger the decision-making process to accept health behaviors, especially in an emergency (11). To eliminate the negative effects of emergency hazards, it is necessary to explore public risk perceptions and the residents' underlying processes (7).

Lerner (12) and Lerner et al. (13) studied the impact of different negative emotions (such as dread, helplessness, and anxiety) on risk perception, and demonstrated that fear makes people exaggerate their assessment of risk, especially, in the absence of risk information, individuals will actively seek information related to risk to reduce their information disadvantage. During crises, information disseminated in a public health emergency is another key determinant of risk perception. Different information channels can either heighten or attenuate risk perception (8). As the social amplification of risk framework states, it is important to understand how people interpret the information and the risk propagation path (14). Residents who relied on unofficial sources, such as Weibo and WeChat, were more likely to exaggerate the risk (5), which then affected health information adoption intention by generating fear (15). The risk people perceived was formed by the synthetic assessments of all kinds of information; thus, information disclosure could amplify an individual's risk perception.

Meanwhile, previous studies have focused on many intervening factors related to risk perception, such as demographic characteristics, trust, social environment, and government (16–18). However, few studies have focused on the perspectives of negative emotional states and perceived value of information. Hence, there is a need to understand both negative emotions and information exposure risk factors influencing effective risk management strategies to the people in communities at risk. More efforts are needed to strengthen trust and communication among the government, social media and vulnerable groups to adjust their risk perception regarding the COVID-19 outbreak. Therefore, this study aims to analyze the factors of individuals' risk perception of COVID-19 at different levels.

Abbreviations: WHO, World Health Organization; CNY, China Yuan; SARS, Severe Acute Respiratory Syndrome.

Methods

Study design

To assess the public's reaction to COVID-19, we used a cross-sectional online survey of citizens in China in early April 2020. Participants were recruited from the eastern, central, and western regions of China by using a directional convenient sampling method. Regarding the severity of the epidemic, two severely affected provinces with the highest number of confirmed patients and one province with the lowest number of patients based on the prevalence of COVID-19 in the early pandemic stage were selected from each region (19). Eight provinces, including Guangdong, Zhejiang, Fujian, Hunan, Hubei, Shanxi, Sichuan, and Gansu, were selected. In each province, provincial capitals and another neighboring city based on the feasibility of conducting the survey were selected, and 60 families from rural and urban areas of each city were selected. Finally, 3,552 individuals were included in this survey. Inclusion criteria were as follows: (a) aged 18 years or older; and (b) the place of residence was the local community during the completion of the survey.

We used a self-designed questionnaire containing 168 questions guided by prior studies and related theories in the literature (7, 20, 21). The questionnaire included structured items about basic demographic variables, such as age, gender, education, marriage, region, and household income. Then, items regarding community emergency preparation, forwarding information and perceived value of risk information were set as independent variables. We assessed community emergency preparation by using a single item: "At the beginning of the epidemic, do you think the community management department or village committee was fully prepared?". Perceived value of risk information was measured by 9 items: "(1) How helpful is the information a family member has told you? (2) How helpful has the information you have been told by a friend or relative been? (3) How helpful is the information exchanged with others by phone, WeChat and QQ? (4) How much does watching TV program information help you? (5) How much does reading newspaper articles (electronic versions) help you? (6) How much does it help you to follow the articles and opinions of social figures forwarded on WeChat, Weibo and QQ? (7) How much does WeChat, a QQ group or forwarded video information from a circle of friends help you? (8) How helpful is authoritative expert advice? (9) How helpful are official mobile phone messages, calls and voice messages to you?". The scale's Cronbach's α coefficient was 0.800, and it has good validity (KMO = 0.790).

Negative emotions were measured by using these questions, as follows. (1) Depression was measured by the following question: "Would you say since the beginning of the pandemic you have been feeling depressed?" (2) Would you say since the beginning of the pandemic you have been feeling helpless? (3) Would you

say since the beginning of the pandemic you have been feeling loneliness? (22). Participants answered the question using a three-point scale from 1 "none" to "totally agree." In addition, 6 questions were designed to measure participants' risk perception level of COVID-19 based on the related research conducted in China (22). We made risk perception scale (shortened version) as three dimensions: intuitive perceived sensitivity, perceived severity and cognitive judgments. The Cronbach's α coefficient for this dimension was 0.825.

1. Since the outbreak of COVID-19, I have been afraid of being infected with this disease.
2. Since the outbreak of COVID-19, I have been afraid of dying from this disease.
3. Since the outbreak of COVID-19, I have felt nervous after hearing news about COVID-19.
4. I am worried about being infected with COVID-19, so I have difficulty sleeping.
5. Since the outbreak of COVID-19, it has been difficult for me to stay at home for a long time.
6. When someone mentions COVID-19, my heart beats faster.

Risk perception was set as the outcome variable. It was evaluated with the use of a five-point Likert scale ranging from 1 (strongly disagree) to 5 (totally agree), and all 6 items were summarized from 0 to 30. Higher scores indicate greater risk perception level.

Finally, this study examines the common method biases test by exploratory factor analysis, and the variance explanation rate of all the first factor is 29.34% (<40%), which means common method deviation is not serious. Next, confirmatory factor analyses were conducted. Model fitting results show that GFI < 0.9, most RMSEA > 0.08. These results verified that common methodological variance was acceptable in this study.

Research model

Previous work and studies address a number of crucial determinants that are important for risk perception (19, 23, 24). We hypothesize that residents' negative emotions, forwarding information, community emergency preparedness and trust of risk information may affect risk perception directly. Information perceived value may exert a moderating effect on the relationship between negative emotion and risk perception in the model (Figure 1).

TABLE 1 Demographic characteristics of participants and risk perception score of COVID-19.

Variables	Total ($N = 3,552$)	Risk perception score	*P* value
	No (%)	Mean ± SD	
Age (years)			0.005
<20	440 (12.39)	17.44 ± 4.23	
21–40	1,351(38.04)	18.05 ± 4.21	
41–60	1,171 (32.97)	17.95 ± 4.34	
>60	590 (16.60)	18.39 ± 4.53	
Gender			0.137
Male	1,692 (47.64)	17.88 ± 4.34	
Female	1,860 (52.36)	18.10 ± 4.29	
Marriage status			0.247
Unmarried	1,445 (40.68)	17.90 ± 4.19	
Married	2,107 (59.32)	18.07 ± 4.40	
Household income			0.350
<CNY 100,000	1,520 (42.79)	18.04 ± 4.33	
CNY 100,000–400,000	1,289 (36.29)	18.07 ± 4.43	
>CNY 400,000	743 (20.92)	17.79 ± 4.08	
Education			0.130
≤6 years	1,728 (48.65)	18.15 ± 4.47	
7–12 years	1,626 (45.78)	17.87 ± 4.16	
≥13 years	198 (5.57)	17.76 ± 4.16	
Community preparation			0.000
Bad	2,092 (58.90)	17.60 ± 4.36	
Fair	793 (22.33)	18.52 ± 4.02	
Good	667 (18.77)	18.61 ± 4.39	

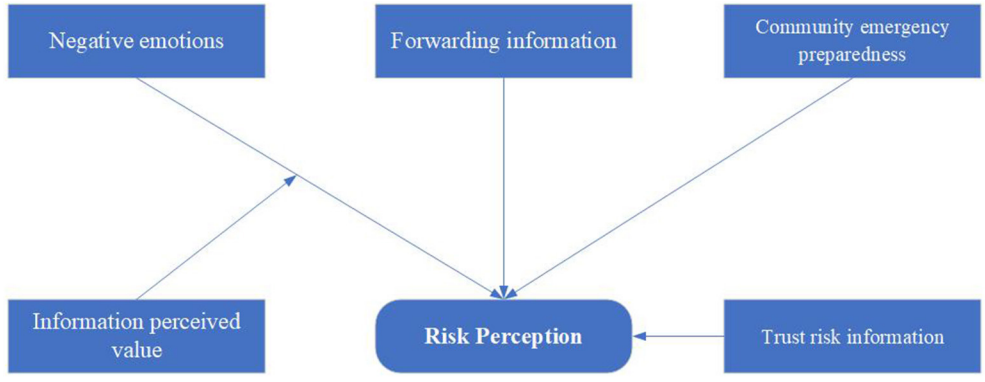

FIGURE 1
Hypothesized model depicting factors influencing risk perception.

Data collection

This investigation was conducted online from April 4, 2020, to April 15, 2020. To ensure the randomness of sampling and the reliability of inferences, trained project managers were recruited to coordinate the selected provincial survey and supervise the local investigations. Consenting participants were enrolled and asked to fill out the online questionnaire, which took ∼15 min to complete. After receiving the data collected online, we arranged for a dedicated reviewer to be responsible for filtering questionnaires by answering time, content quality, and data format.

Data analysis

For statistical analysis, we used descriptive methods to summarize data on demographic information. Data were reported as frequencies (n) and percentages (%) for categorical variables among different groups of risk perception. Then, we calculated the means and standard deviations. Multiple regression and moderating effect analysis were used to identify associations between various factors and respondents' risk perception. Statistical analysis in this study was performed by Microsoft Excel and R 3.6.0 software packages. The alpha level was set at $P < 0.05$ for all the analyses.

Ethical considerations

The study protocols were approved by the Ethics Committee of Tongji Medical College, Huazhong University of Science and Technology (#2020S107). Oral informed consent was obtained from each participant before conducting the online survey.

Results

Demographic characteristics of respondents

The average age of the 3,552 participants was 40.67 years old (SD 18.32 years old; age range 10–93 years old). Of these, 52.36% (n = 1,860) were women, and 40.68% (n = 1445) were unmarried. Older adults (>60 years) accounted for 16.60% (n = 590) of the total sample. Furthermore, 51.35% (n = 1824) had attained a junior high school degree or higher. Nearly 42.80% of the participants' annual household income was <CNY 100,000. Examination revealed significantly higher mean for risk perception scores in the elderly (>60 years), and the individual who thought their communities made adequate preparation for emergencies (Table 1).

The greatest percentage (55.49%) of participants feared being infected; 52.51% feared death from COVID-19; and 46.03% were nervous about reports and news of COVID-19. Respondents did not have difficulty sleeping (52.59%) and had no trouble staying at home (50.53%). When the COVID-19 pandemic was mentioned, 42.15% of respondents did not have symptoms of rapid heartbeat (Figure 2).

Factors associated with risk perception

Multiple regression analysis showed that participants' risk perception was significantly affected by age, helplessness, depression, loneliness during the pandemic, the usefulness of expert advice, the usefulness of social media video, community's emergency preparation and information forwarding behavior. These variables accounted for 56.33% of the total variance (Table 2).

Table 3 shows the results of further evaluation of the moderation effects corresponding to the hypothesis mentioned above. The findings identified a significant moderating effect of information perceived value on the relationship between negative emotion and risk perception. The interaction term of information perceived value and negative emotion can positively predict risk perception (β = 0.020, $p < 0.001$).

An interaction plot was generated for visual illustration. Figure 3 indicates that for residents with high value of information perceived, the influence of negative emotion on their risk perception was positive and statistically significant ($\beta = 0.020$, $p < 0.001$), and it had a steeper slope, meaning it was even more statistically significant. This finding indicated that the relationship between negative emotion and risk perception would be stronger for those who have higher levels of

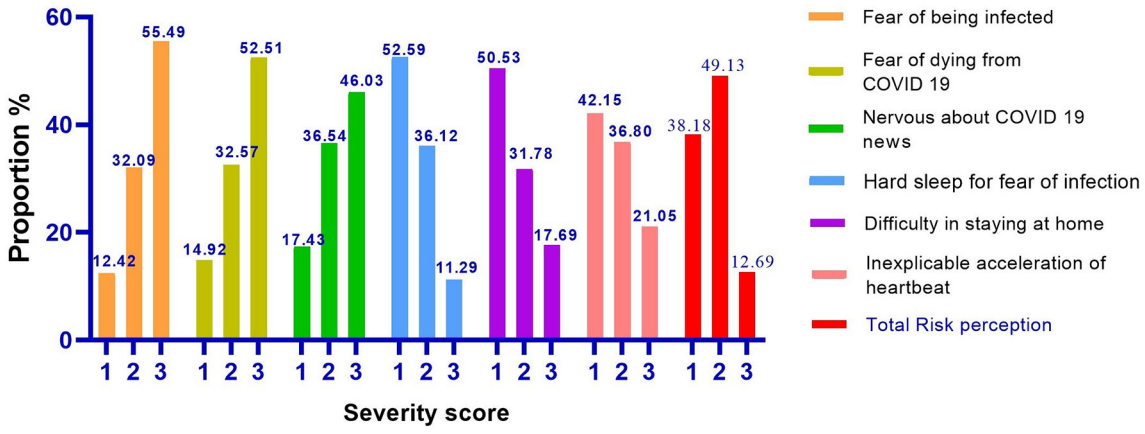

FIGURE 2
Distribution of the answers related to the participants' risk perception.

TABLE 2 Multiple regression results of risk perception.

Variables	β	SE	t	*p*
Intercept	17.59	0.72	24.44	0.000***
Gender (Ref: Male)	0.11	0.14	0.77	0.443
Age (years, Ref: ≤20)				
21–40	0.45	0.24	1.89	0.059
41–59	0.70	0.29	2.41	0.016*
≥60	1.18	0.31	3.87	0.000***
Education level (Ref: ≤6 years)				
7–12 years	−0.28	0.17	−1.65	0.099
≥13 years	−0.62	0.33	−1.87	0.060
Household income (Ref: ≤CNY 100 K)				
CNY 100 K—400 K	0.16	0.16	1.03	0.304
>CNY100 K—400 K	0.03	0.19	0.17	0.865
Marital status (Ref: Unmarried)				
Married	−0.08	0.19	−0.43	0.665
Helplessness (Ref: None)				
Moderate	1.84	0.35	5.25	0.000***
Serious	−0.05	0.21	−0.22	0.822
Depression (Ref: None)				
Moderate	0.91	0.18	4.95	0.000***
Serious	1.44	0.42	3.39	0.000***
Loneliness (Ref: None)				
Moderate	0.97	0.18	5.38	0.000***
Serious	1.20	0.38	3.13	0.002**
Usefulness of experts' advice (Ref: Useless)				
A little	−0.45	0.21	−2.13	0.034*
Very useful	−0.55	0.19	−2.97	0.003*
Usefulness of social media video (Ref: Useless)				
A little	0.54	0.18	2.94	0.003**
Very useful	0.55	0.19	2.90	0.003**
Forwarded information with friends (Ref: Yes)				
None	−0.97	0.25	−3.90	0.000***
Community preparation (Ref: Adequate)				
Moderate	0.75	0.17	4.42	0.000***
Inadequate	0.55	0.18	2.95	0.04*
Trust traditional media (Ref: No)				
Neutral	0.65	0.78	0.83	0.406
Trust	0.55	0.60	0.92	0.356
Trust friends (Ref: No)				
Neutral	−0.11	0.70	−1.55	0.122
Trust	−0.96	0.60	−1.59	0.112

*p < 0.05, **p < 0.01, ***p < 0.001.

information perceived value, as compared to those with the lower, but these relationships overall stay positive.

Discussion

Main findings of the study

This study indicated that risk perception varied at different ages. Participants who are over 60 years old reported the highest risk perception score in regard to the COVID-19 pandemic; Risk protection awareness of vulnerable and susceptible people and prior emergency experiences may have played a certain role among these participants (25). In addition, we found that factors such as emotion, information perceived value and forwarding behavior were related to an individual's risk perception of COVID-19 among Chinese residents. Moreover, information perceived value exerts a moderating effect on the relationship between negative emotion and risk perception.

This study also demonstrated that adequate community emergency preparedness can provide a vital measure for the government in helping people strengthen self-protection and reduce risk perception. One possible explanation is based on the unique "community grid governance model" in China (26), which is used to build a horizontal network of alliances with other grassroots epidemic prevention sectors (27). Specifically, each community staff member contacts the household to conduct health situation analysis and propagate anti-epidemic, self-protection knowledge and to support residents' interests and public needs (28). Hence, comprehensive community emergency preparedness could raise people's sense of safety.

The impact of public sentiment and information exposure on risk perception

Another finding of this study was that negative emotions were positively correlated with the perceived likelihood of risks and the perceived severity of the threats. Loneliness, depression, and helplessness were chosen to reflect an individual's negative emotions (psychosocial situation) (29). Some elegant researches by Lerner and Keltner (12, 20) highlighted the mechanism of emotion-specific on risk perception. They predicted and found that negative emotion such as fear and helpless had opposite effects on risk perception. Whereas the helpless people expressed pessimistic risk estimates and they were likely to induce and heighten a pessimistic assessment of perceived severity (30–33). Any perception of risk uncertainty, in turn, influences individuals' emotional response in a hazardous situation. Perceived hazards surrounding COVID-19 can again increase the public's anxiety, depression and fear (34). Furthermore, the spread of the hazard amplifies a strong negative emotional response, which disrupts people's cognition and decreases their belief that they can control negative outcomes (35). In particular, when the individual is under a highly threatening and psychologically stressful condition over a long period of time (36), it increases difficulties in understanding health information and balancing mental resilience protection.

The role of information exposure was positively associated with risk perception. Regression analyses confirmed that in

TABLE 3 Regression coefficients of moderating interaction effects test.

Variables	Model 1	Model 2	Model 3	Model 4
	β (*SE*)	β (*SE*)	β (*SE*)	β (*SE*)
Fixed effects				
Intercept	16.636** (0.404)	12.726** (0.420)	12.330** (0.494)	14.375** (0.870)
Control variables				
Gender	0.243 (0.144)	0.109 (0.136)	0.111 (0.136)	0.120 (0.136)
Age	0.017** (0.006)	0.020** (0.005)	0.020** (0.005)	0.020** (0.005)
Education level	−0.027 (0.072)	−0.089 (0.068)	−0.086 (0.068)	−0.085 (0.068)
Marriage	−0.180 (0.186)	−0.066 (0.175)	−0.058 (0.175)	−0.056 (0.175)
Predictors				
Forwarded information with friends	−0.827** (0.260)	−1.071** (0.244)	−1.079** (0.244)	−1.100** (0.244)
Community emergency preparation	0.303** (0.049)	0.196** (0.047)	0.198** (0.047)	0.206* (0.047)
Negative emotion		1.000** (0.046)	0.995** (0.046)	0.518** (0.173)
Information perceived value			0.018 (0.012)	−0.071* (0.033)
Negative emotion × Information perceived value				0.020** (−0.007)
R^2	0.016	0.130	0.131	0.133
F	9.359**	75.725**	66.580**	60.206**
Residual	4.281	4.025	4.024	4.020

*p < 0.01; **p < 0.001.

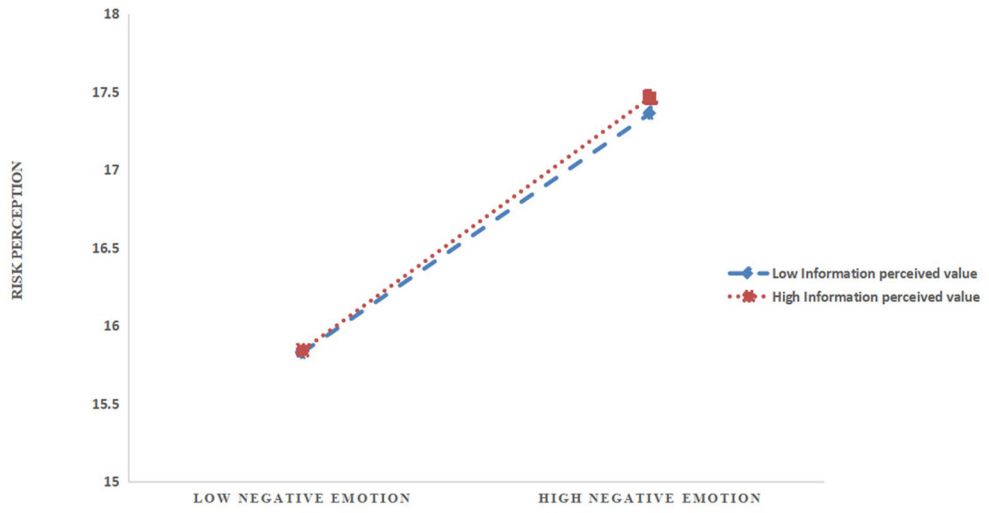

FIGURE 3
Interactive effects of information perceived value and negative emotion on risk perception.

the risk information dimension, participants had higher risk perception when they forwarded risk-related messages with their friends. People who are willing to share risk information usually seek out more media coverage of epidemic-related information in advance. Furthermore, their perceived stress response increases with excessive exposure to risk information (36–38).

Our survey indicated that individuals' perceived value of authoritative information sources has a critical effect on their health risk perception. This is in line with the results of Jian Raymond's and Qingchuan Liu's studies (38, 39). The premise of perceiving the usefulness of information is based on trust; compared with social media, people need to rely more on experts and government agencies' risk communication (40). This highlighted that suggestions from authoritative medical professionals (such as Zhong Nanshan, Li Lanjuan, and Zhang Wenhong) are public health efforts that can help relieve residents' tension and anxiety regarding the epidemic (41). As experts are trustworthy sources and communicate essential

protection knowledge to the public, they can help effectively mitigate risk perception (40, 42).

In addition, information perceived value exerts a moderating effect on the relationship between negative emotion and epidemic risk perception. At a high information perceived value, individuals with high negative emotion orientation are relatively more able to perceive the impact of risk (25). People with high perceived value of information rely more on external environment to judge the severity of risks. The original individual and local risk perception in the real world were amplified into the collective and overall risk perception through multiple channels of information dissemination (43). During the epidemic, potential risk and uncertain situations may lead to the public's urgent need for valuable and reliable information, but the volume of discordant and excessive information about COVID-19 makes the concerns over the pandemic seem greater. This is consistent with Mohmmed Salah Hassan's study that demonstrated that the quality of social media contents shaped the individual's perceived susceptibility to a particular public health hazard (44). In addition, this factor might induce a pessimistic assessment of risk information and can heighten feelings of fear and hopelessness with exposure to useless and misleading information. Negative emotional polarization could increase respondents' risk perception.

Limitation

This study had some limitations. First, many elderly individuals who had no access to the internet were not adequately investigated, and there was a lack of a random sample. Second, we omitted variable bias in this study, and there needs to be a more specific measure (standard questions) of the public's risk perception. Third, a cross-sectional design did not produce very precise or convincing results and made it uncertain. Last, there is a reciprocal cause-effect relationship between risk perception and emotion. It is impossible to determine the exact cause-and-effect relationship between them in this study. Further studies are needed to improve the scientific validity of these findings.

Conclusions

Perceived risks are important for residents' acceptance of government preventive measures. However, the public's excessive dependence on social media weakens the effect of government trust on public risk perception. It is not conducive to the implementation of prevention measures and self-protective behavior. This study highlighted that individual differences in risk perception were not only related to the age factor. Emotion, perceived usefulness of the information, forwarding behavior and thought community made adequate emergency preparation important. It is crucial for authorities to strengthen the management of new media and guide the release of risk information during the epidemic. In addition, the government should pay attention to the complex negative emotions that threaten residents during the epidemic. Effective health communication and education interventions advocated by public health experts are the most accurate sources of information, which could clarify misinformation and answer public concerns in accessible ways.

Strength

We conducted a nationwide online survey during the peak of the COVID-19 outbreak in China. The results were a satisfactory reflection of respondents' risk perception status during the crisis situation. This is based on two important dimensions of individual perception analysis, namely, information usefulness and negative emotions. Exploring and analyzing the above factors and their association with risk perception have implications for the adjustment of the public communication and risk prevention strategies adopted by the government.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by Ethics Committee of Tongji Medical College, Huazhong University of Science and Technology. The patients/participants provided their written informed consent to participate in this study.

Author contributions

CC: conceptualization, data curation, formal analysis, investigation, methodology, software, validation, and writing—original draft. ZF: investigation, project administration, and supervision. ZY: data curation, investigation, and methodology. CS: data curation, investigation, and visualization. ST: conceptualization, investigation, editing subsequent versions of the manuscript, and revising the original manuscript. LJ: support participant recruitment, support data analysis, and interpretation. XS and RW: investigation, writing—review and editing, and supervision. All authors have read and approved the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Experience of frontline nurses who managed the COVID-19 crisis: A qualitative study

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Background: The health system was challenged during the COVID-19 pandemic. Nurses, as part of the health system, were expected to manage themselves in a situation where everyone was in crisis and to be able to do their work quietly and calmly. This study was conducted to show how Iranian nurses faced the COVID-19 crisis.

Methods: In a qualitative content analysis study, 16 participants, including eight nurses, five supervisors, and three head nurses of a university hospital in Tehran, Iran, were interviewed between February and December 2020. Using purposive sampling, nurses who were working with patients with COVID-19 were selected to be involved. Data were analyzed using MAXQDA 10 software, and codes were categorized based on similarities and differences.

Finding: Data analysis revealed 212 codes. These codes were classified based on similarities and differences in 16 categories, and four main themes emerged: unpreparedness, positive adaptation, negative coping, and reorganization.

Conclusion: Since nurses are on the frontline in times of biological disaster, the COVID-19 pandemic provided an opportunity to demonstrate the role of nurses in reducing the burden of disease, identifying problems and opportunities, and planning appropriate interventions.

KEYWORDS

nursing, COVID-19, disaster planning [MeSH], coping skills, care burden

Introduction

On 31 December 2019, Chinese health officials reported a cluster of cases of pneumonia of unknown cause (1). Later, the cause was identified as the novel coronavirus. It was later named COVID-19 and then SARS-CoV-2. After it spread to most countries, the World Health Organization (WHO) declared it an emergency and a pandemic (2, 3).

In the COVID-19 crisis, Iran was one of the most affected countries in the world. On 19 February 2020, the first case of COVID-19 was confirmed in Qom city, Iran. The disease then spread rapidly throughout the country (4).

This pandemic created many challenges for countries and their health systems. Increasing the number of deaths and involvement of all society sectors was a threat to global public health and the economy (5). After the severe acute respiratory syndrome (SARS) outbreak in 2003, hospitals, the nursing system, and nurses were expected to be well-prepared to deal with a similar viral epidemic (6). The year 2020 was named by the WHO as the Year of Nursing and Midwifery (7). Director-General Mr. Tedros stated that healthcare workers are "the glue that holds the health system and the outbreak response together" (8). Historically, nurses have played an important role in community health and the prevention and control of infection, but the COVID-19 situation was different (3).

Nurses faced an unprecedented challenge. On the one hand, they wanted to do their job properly, and on the other hand, personal protective equipment (PPE) was not sufficiently available (6). In addition to worrying about themselves, they feared contaminating relatives, friends, and other family members (9). Previous studies have shown that nurses experienced severe physical and psychological stress (10, 11). Every nurse has a story to tell, and they can help us to understand this situation better. This qualitative study was carried out to show how Iranian nurses faced the COVID-19 disaster.

Methods

Materials and methods

To understand how Iranian nurses faced the COVID-19 disaster, the conventional method of content analysis proposed by Graneheim and Lundman was used (12). In this study, using purposive sampling, 16 participants including eight nurses, five supervisors, and three head nurses working with COVID-19 patients were interviewed from February to December 2020. In this qualitative research, we did not have a predetermined sample size. Sampling continued until data saturation (13). This means that the exploration of participants' views and experiences was continued until the researchers concluded that there were no new data and the concepts were sufficiently captured.

Healthcare workers who were working with patients with COVID-19 and had extensive firsthand experience in caring for these patients were included. For enhancing the maximum variation, healthcare professionals, with different work experiences and different educational levels, were selected. Furthermore, the duration of working with patients with COVID-19 was a basis for sampling.

Data collection was performed using semi-structured interviews, each lasting from 20 to 45 min. Participants offered the interview place, usually in a quiet place in the hospital resting rooms.

Interviews were conducted by the first author of this article, an associate professor in nursing who has published several qualitative research papers and managed and supervised more than six Ph.D. projects using the qualitative research method. Some complementary interviews and data analysis were carried out by the second author, a professor in nursing who is experienced in emergency nursing and has good experience in qualitative research, especially the grounded theory method.

The initial questions of these interviews are the result of preliminary work in the field and the experiences and knowledge of the researchers. The interview guide was developed by the consensus of researchers. These questions were only a general framework to start the interviews, and later, with the progress of the interviews and the completion of the concepts, fundamental changes were made to the questions and their priority. The type and order of questions were changed as the data collection flow progressed. With the progress of the study and the formation of the categories, the subsequent interviews were guided to clarify the main categories and their connections.

Before each interview, the researcher introduced himself to build a good relationship and trust. Then, the objective of the research and the reason for interviewing were described. Next, written informed consent was obtained from the participants. After several warm-up questions, interviews began with a general open-ended question followed by more detailed and specific questions. Participants were asked to narrate their experiences in as much detail as possible. Probing and explanatory questions such as "Can you explain more?" Or "What did you mean by that?" were used for additional clarification of the answers given by participants. Finally, we asked the participants, "Is there any further data that you think will help us?" They were given the researcher's phone number and email address, and arrangements were made to contact them to confirm their statements or to have a follow-up interview. Two follow-up interviews were conducted for supplementary data and better explanations of quotations. Along with the interview text, participants' moods and characteristics, such as laughter and facial expressions, were also recorded.

The qualitative content analysis method was used for data analysis. Immediately after each interview, it was transcribed verbatim and then read several times to obtain a general sense of the participant's words. The MAXQDA 10 software was used for data analysis. First, meaning units were extracted, then they were coded and organized into different subcategories and categories based on their similarities and differences. Based on the interviews and constant comparison method, the underlying meanings were expressed in themes.

The Lincoln and Guba criteria for rigor and trustworthiness were used in this study (14). The researcher had a long-term engagement with the data and research field. Member checking was performed by summarizing the primary result of each interview and the final results with three nurses. In addition, the analysis process was carried out with the agreement of two members of the research team and was audited by two external supervisors. In cases of disagreement, discussion continued to reach an agreement. Furthermore, in the findings section, quotes from the participants are presented.

The aim and objectives of the study were clarified for participants and informed written consent was obtained from them. Moreover, their permission for recording the interviews was obtained. The time and place of the interviews were determined by participants and they were able to stop if they were exhausted or distressed.

Findings

A total of 16 participants, including eight nurses, five supervisors, and three head nurses, were interviewed. The demographic characteristics are presented in Table 1. Data analysis revealed 212 codes, which were then classified based on similarities and differences into 15 categories. Further evaluation for hidden meaning resulted in the emergence of four main themes: unpreparedness, positive adaptation, negative coping, and reorganization. The details are presented in Table 2.

1. Unpreparedness: Based on the findings of this study, participants reported being surprised and unprepared

TABLE 1 Demographic characteristics of participants.

Health care workers		
Age, years (mean ± SD)	38.52 ± 5.60	
Gender	Male (%)	10 (62.5)
	Female (%)	6 (37.5)
Type of job	Supervisor (%)	3 (21.4)
	Head nurse (%)	5 (35.7)
	Nurse (%)	2 (14.3)
job experience, years (mean ± SD)	11 ± 4.72 (minimum 1 and maximum 22 years)	
Interview duration, minutes (mean ± SD)	34.58 ± 6.97	
Working with COVID-19 patients, months (mean ± SD)	6.12 ± 3.26 (minimum 1 and maximum 11 months)	

TABLE 2 Findings in the form of themes, sub-themes, and codes.

Theme	Sub-theme	Code
Unpreparedness	Surprising	Different from what we knew previously
	Shortage and deficiency	Lack of PPE
	Crowdedness	Unbearable number of patients
	Inconsistency	Working without standard
Positive adaptation	Prayer and spirituality	Reading the prayer
	improving patient mood	Celeries as mode improver
	Self-sacrifice	Putting oneself at risk to save the patient
Reorganization	Meeting the emergency needs	Opening a new ward to deal with crowding
	setting a hospice	A hospice to cut off the transmission chain
	Rationing	Rationing for managing shortages
	Informing the staff	Training on the standards of care
	Immediate encouragement of effective staff	Encouraging effective employees
Negative coping	Anxiety and fear of death	Feeling close to death
	Sick leave	Burden to others due to sick leave
	Helplessness	Severe sadness due to patient death

as a major problem. This concept consists of four categories: surprise, shortage and deficiency, crowdedness, and inconsistency.

1-a. Surprise: Surprise was one of the main properties of this experience. For example, a supervisor with 26 years of experience said:

> *"In the first Supervisor Shift after COVID-19, I realized that this is not a simple disease.*
>
> *Standard accreditation programs and other programs were abruptly dropped. Even the ministry of health shut down auditing to improve hospitals' disaster management."*

1-b. Shortage and deficiency: Another characteristic of this crisis was shortage and deficiency. An expert nurse with 16 years of experience said:

> *"The first thing I remember at the beginning of the crisis was a severe shortage of equipment and human resources that was visible and remained until the following days. Emergency department nurses, as the frontline soldiers, sacrificed themselves to save the lives of patients, even without the effective PPE. Some of them later were infected." [sic]*

1-c. Crowdedness: Crowding was a common experience for almost all participants. A nurse with 3 years of experience stated:

> *"There were no longer empty beds, some patients were lying on the floor and tied their drugs to the curtain holders. When I went for dinner, more than 50 people were standing in line for fever and SPO_2 check [sic]."*

1-d. Inconsistency: Disorganization and dissonance were other features of this crisis. For example, supervisors with 13 years of experience declared:

> *"Of course, these inconsistencies existed until the last ward of the hospital was polluted by Corona."*

Another supervisor with 26 years of experience said:

> *"So the standards aren't useful at this time? Or...? Maybe saying these things in my language as a supervisor that trying to implement every single standard would be incorrect, but I still haven't answered my question." [sic]*

2. Positive adaptation: Based on the findings of this study, participants used positive adaptation techniques, including self-sacrifice, prayer, spirituality, and improving patient mood.

2-a. Self-sacrifice: Sacrifice was one of the most seen behaviors during this crisis. A supervisor with 12 years of experience responded:

> *"Thanks to God, despite the many problems, my colleagues using high responsibility and sacrificing themselves took great strides in controlling this great crisis." [sic]*

2-b. Prayer and spirituality: Participants cited prayer as one of the positive methods of copping. A supervisor with 13 years of experience stated:

> *"I wanted God to save us from this affliction. I have unconsciously remembered a verse from the Qur'an that says: In the stormy seas they read to me, and when they are saved, they don't remember who helped them to survive the storm. Of course, we are still in the stormy sea of Corona. We are praying the Seventh Prayer of Sajadiyya, but we read it in the hope of salvation from the storm of Corona, I hope we don't forget this exclamation after being saved from this storm. Remember these prayers that only God has saved us."[sic]*

2-c. Improving patient mood: Another positive thing nurses did to adapt was to use the hospital's potential to improve patients' moods. The typical experiences of a nurse with 9 years of experience are described as follows:

> *"The best thing was activating the hospital's advertising department to broadcast happy and exciting programs for patients through the hospital's internal network and the presence of clerics on [sic] patients' bedside during non-peak caring hours."*

3. Reorganization: One of the positive ways to modify the existing organization system and make adjustments to manage the coronavirus was reorganization. This concept has multiple categories including making meeting the emergency needs, setting up a hospice, rationing, informing staff, and immediate encouragement of effective staff.

3-a. Meeting the emergency needs: emergency need to response the COVID-19 were managed in the organization. A supervisor with 14 years of experience said:

> *"There were various suggestions for solving problems ranging from opening new departments to reducing emergency workload to using university nursing staff and senior nursing students to help. Almost all hospital wards were occupied by corona patients."*

3-b. Setting up a hospice: Another positive way to deal with corona was to create a hospice to cut off the transmission chain, using public hospital facilities such as parking spaces to optimize space. A contributor said:

> *"The important thing about the hospice is that it is a very interesting project, but it takes time to complete because it is a nascent plan."*

3-c. Rationing: Managers followed a rationing strategy when faced with the threat of running out of equipment. A head nurse with 30 years of experience stated:

> *"I rationed the staff with protective aids like masks, so we wouldn't get into trouble. I told the nurses and the other staff that the meal and pray program should be synchronized to reduce the consumption of masks and gloves."*

3-d. Informing the staff: Nursing managers were tasked with explaining the standards of care to their colleagues. For example, a head nurse with 10 years of experience said:

> *"I notified all the staff in the ward that the situation is not normal and that they have to comply more." [sic]*

3-e. Immediate encouragement of effective staff: Another effective way of coping was to encourage and motivate nurses. A supervisor with 13 years of experience stated:

> *"The incentive plans are needed to continue to work, today we had a good example. We hope this incentives continue, because they are imperative for maintaining the spirit." [sic]*

4. Negative coping: Based on the findings of this study, some participants used negative coping mechanisms such as anxiety and fear of death, absence from work, sick leave, and feeling helpless in dealing with the crisis.

4-a. Anxiety and fear of death: The sense of anxiety and stress was common. This is how a nurse with 10 years of experience described his experience:

> *"I get stressed out in the morning. I have a strange apprehension, but I have dedicated myself to God."*

Another nurse with 12 years of experience said:

> *"It was a bad night. Everyone's faces were angry. Nurses, physicians, and patients all had stress."*

4-b. Sick leave: Some nurses, many of whom were women, used sick leave. A supervisor with 11 years of experience confirmed this, saying:

> *"Some staff were not cooperating at this time; they used sick leave. They put pressure on other staff, especially those sacrificing themselves."*

4-c. Helplessness: Due to the characteristics of the disease, some participants felt helpless and unable to deal with patients with COVID-19. A nurse with 15 years of experience said:

> *"There was a time when you wanted to die from the severity of sadness, and it was a time when your friends were dying in front of your eyes and you couldn't do anything. It was really sad."*

Discussion

The study showed that hospitals and health systems were not prepared to deal with COVID-19. Although Iran was not the first country affected, and there was almost a preparedness in the country's officials, Iran's health systems were still surprised. One of the main concepts of the present study is a lack of preparedness. Experience has shown that, even after similar experiences, there is a vulnerability in health systems. The SARS crisis experience is similar to the COVID-19 pandemic, but the available trends show that insufficient lessons were learned from that crisis (15). During the flu outbreak of 1918, the actions of the affected countries were almost similar to the COVID-19 measures, for example, the quarantine measures (16). Studies show that tabletop maneuvering can be helpful, especially for countries that have not yet been affected by this type of crisis (17). The experiences of Iran, China, and other countries that have been affected by this problem can be helpful.

The lack of PPE equipment was another of the problems mentioned by nurses. Perhaps due to the awareness of the arrival of the disease, the equipment shortage in Iran was not severe, but this problem still existed. According to the interviews, part of this problem was due to differences in expectations. The nurses expected to wear the N95 mask and other protective clothing, but the managers wanted to comply with WHO and CDC recommendations, and these organizations did not recommend masks or other PPE to this extent. Of course, the recommendations changed over time.

A lack of PPE has also been reported in previous studies (18). Protection is one of the most important issues; when medical personnel are not properly protected, they will be infected. For example, approximately one-third of SARS victims were healthcare staff (19). There have also been reports of COVID-19 infections in healthcare workers (20). In other countries, the supply of surgical masks also declined and prices increased 5-fold (6).

In addition to fighting illness, nurses must risk their lives in difficult conditions such as a lack of protective equipment. In some hospitals in China, the staff was even forced to wear their raincoats and plastic bags for protection (19–21). Another key concept highlighted in this study is frequent management decisions for proper crisis management. The preparation of health centers plays an important role. Due to disaster-related shortages, most hospitals could not continue their routine for a week (22). Crisis resource depletion must be well-managed.

Another important category that emerged in this study is the psychological response to the crisis. Nurses experienced anxiety and fear of death. They were also concerned about contaminating family members. Psychological interventions for the treatment team were not well-planned.

Medical staff members were under severe physical and psychological pressure, and anxiety and stress were common (23). There were several causes of stress, from the lack of protective equipment to the fear of contaminating others (24, 25). In China, a series of psychological measures were planned and implemented. They also used online mental health services (26). In particular, interventions were needed for nurses. Nurses were expected to manage themselves in a situation where everyone was in crisis and to be able to do their work quietly and calmly (24).

Due to high psychological pressure, some staff members refused to return to work. Other studies also attribute this to the severity of psychological symptoms (27). For this reason, appropriate psychological interventions have been emphasized. Most nurses, of course, remained on the frontline to carry out their duties, and some of them died in the SARS 2002/2003 and COVID-19 crises while performing their duties (24).

The limitation of this study is related to the nature of the qualitative approach and the problem with generalizability. Most head nurses and supervisors in this hospital were men. As a result, in participant selection, most managers were men. This could result in gender bias.

Conclusion

The results of this study show different aspects of nurses' responses to the interview questions, from negative to positive coping and adaptation. Lack of preparation and surprise were the initial observations and experiences of the healthcare system and nurses. Given that nurses are on the frontline, COVID-19 provided an opportunity to demonstrate the role of nurses in reducing the burden of illness, identifying problems and opportunities, and planning appropriate interventions. In addition, there is a large burden on the healthcare system and nurses, which should be considered in healthcare policymaking.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Baqiyatallah University of Medical Sciences. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

SM: study conception, design, and drafting of manuscript. HM and SM: acquisition, analysis, and interpretation of data. HM: critical revision. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Main social vulnerability indicators in the COVID-19 pandemic in Iran

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Background: Social factors play the main role in the vulnerability of exposed countries to disasters. The COVID-19 pandemic as a disaster is not an exception to this fact. This study aimed to determine the main social vulnerability indicators in the COVID-19 pandemic in Iran.

Methods: This study was conducted during the period of 2021–2022 in three phases, including a systematic review, a virtual panel expert, and the Analytical Hierarchy Process. First, the draft of social vulnerability indicators in COVID-19 was extracted through a systematic review. Then, the extracted indicators were finalized and prioritized by the expert panel and the AHP, respectively.

Results: Initially, the literature review found five domains and 38 indicators of social vulnerability in COVID-19. The outcome of the expert panel increased the related domains to six but decreased the indicators to 31. The three prioritized social vulnerability indicators that were determined by the AHP were population density, accessibility to healthcare facilities, and relevant services and vulnerable groups.

Conclusion: Measuring social vulnerability with the identified indicators is valuable for addressing high COVID-19 incidence among socially vulnerable hotspot areas. Regarding the result of this study, further research should be conducted to validate the identified indicators.

KEYWORDS

social vulnerability, COVID-19, pandemic, indicators, Iran

1. Introduction

Social vulnerability plays the main role in exposing communities and countries to disasters and emergencies, even more so than other forms of vulnerability such as physical, economic, or environmental (1). Scholars have used a variety of terms to describe social vulnerability and also have determined the relevant indicators, especially in natural disasters. Cutter, as one of the first scientists in this field, described the social vulnerability concept as social factors that influence or shape the susceptibility of various groups to harm and that also govern their ability to respond (2–4). Several years later, Flanagan et al. developed the hierarchical social vulnerability index for the U.S. Center for Disease Control (CDC). He used indicators such as housing and transportation, minority status, household composition, and socioeconomic status for measuring the Social Vulnerability Index (SoVI) in disaster management in 2011 and updated this index in 2018 (5, 6). The SoVI is a tool that uses census

data to identify and map places where a community may have more difficulty preventing human suffering and financial loss in a disaster. This tool is important for responding to incidents and disasters in an equitable way (7–9). Additionally, the literature review indicates that the communities with higher social vulnerability have more adverse outcomes during and following a disaster (10–12). Iran is a disaster-prone country, and due to its geographical and ethnic diversities, we have few studies and inadequate information about indicators of social vulnerability in Iran (1, 13, 14).

The incidence of COVID-19 in 2020 and its conversion to a pandemic worldwide in a short time confirmed the importance of social vulnerability among societies and countries again (15, 16). Iran, like many other countries, has been severely affected by the coronavirus pandemic (17). The pandemic caused casualties as well as great and irreparable economic and social damage to society, and the healthcare system was overwhelmed during the peaks of the pandemic (18–20). As social vulnerability is one of the effective factors in disaster impacts, this point had been generalized to the COVID-19 pandemic as a disaster in societies and countries (21–23). Therefore, one of the research priorities in Iran should be to identify the indicators of social vulnerability regarding COVID-19 and find strategies to decrease the social vulnerability to this tragic pandemic.

This study aimed to develop and prioritize the indicators of social vulnerability against the COVID-19 pandemic by applying the Analytical Hierarchy Process (AHP) approach in Iran.

2. Methods

This research was conducted in three stages in 2021–2022, as follows: First, a literature review to identify the social vulnerability indicators; second, an expert panel and consultation with experts to assess the feasibility of using the retrieved indicators due to the data accessibility and the context of Iran; and finally, using AHP to prioritize and give weight to the final main indicators.

2.1. Review of literature

A literature review was performed to review available published articles, documents, and reports. First, the research question and search strategy were developed. Then, to determine the nature and format of the main social vulnerability indicators in the COVID-19 pandemic, available evidence, including articles, documents, and reports, was searched and reviewed. This literature review was performed in partnership with a research team and medical information specialists through December 2020. The Web of Science, PubMed, and Google Scholar were searched for relevant articles. For keywords, the combination of the following Medical Subject Headings (MeSH) in consultation with our research team and experts, including an experienced medical information specialist, was used: "COVID-19," "social vulnerability", "management", "indicator", "epidemic", "pandemic", "outbreak", and "infectious disease". In addition, we searched specialized databases and websites such as the World Health Organization (WHO), the Federal Emergency Management Agency (FEMA), and the Michigan Department of Health and Human Services (MDHHS) with the mentioned keywords. Then, references and bibliographies of all relevant articles were reviewed to identify additional studies. All found studies and literature were entered into the EndNote software version X7.

Articles were selected by applying the inclusion and exclusion criteria. The inclusion criteria were as follows: (1) addressing the social vulnerability indicators and infectious diseases and (2) the availability of the full text of articles for free. The exclusion criteria were as follows: (1) articles published in non-English languages; (2) studies that solely focused on concepts or theoretical frameworks and did not provide metrics or measurement indicators; and (3) news articles, abstracts, and those studies for which full texts were not available.

Duplicate articles were eliminated *via* the EndNote software. Articles were screened by assessing the titles and abstracts for eligibility by two reviewers independently. The full text of the retrieved articles was reviewed by the research team. After screening studies based on the inclusion criteria, the final set of studies was summarized using a data extraction form. Data were charted and presented according to the research objective. The process of doing this phase with more details had been published earlier by one of the members of the research team in the present study (24).

2.2. Expert panel and consultation with experts

Expert panels in two rounds were planned from 15 January 2020 to 20 February 2021 to discuss the findings and examine the feasibility of the recommended indicators in Iran. Due to the conditions of COVID-19, a face-to-face panel was not possible, and telephone, mobile social media applications (Skype), and email were used to provide the experts' opinions. For this purpose, academics, policymakers, infectious disease specialists, and social and welfare experts in Iran were invited to develop discussions about the indicators of social vulnerability during the COVID-19 pandemic based on the results of the literature review.

A list of participants was prepared. After obtaining their permission and approval for the dates and time of the panel, an official invitation letter along with a research brief was sent to them by email or Skype. However, before participation, they were informed of the study's objective and considered a topic in the expert panel session. A discussion guide, due to the literature review (social vulnerability indicators in the COVID-19 pandemic), was developed to assess the feasibility of using the retrieved indicators in the data accessibility and context of Iran. Two members of the research team served as facilitators, presenting the questions most appropriate according to the participants' backgrounds and in relation to the study objective. Additionally, the participation was voluntary, and the participants could withdraw from the study without any consequence. The facilitators used an informed consent form for the participants and ensured that they felt free to answer any question, had the possibility of ending their participation

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TABLE 1 The nine-point scale and description of its items.

Definition	Degree of importance
Equally importance	1
Moderately importance	3
Strongly importance	5
Very Strongly importance	7
Extremely importance	9

in this study, and had the right to prevent or stop the recording. In total, eight experts participated in the study in addition to the research team. Two meeting sessions were coordinated *via* Skype for each round of the expert panel. Additionally, the comments of two experts were collected *via* email in each round of the expert panel. The Skype sessions were recorded.

Finally, the consensus between the opinions of the experts was reached by the facilitator of the meeting in such a way that at least 70% of the members agreed with including the indicators in the study (25). The indicators of social vulnerability in the COVID-19 pandemic in Iran that received less agreement than 70% were eliminated.

2.3. Prioritizing indicators using AHP

After finalizing the main social vulnerability indicators in the COVID-19 pandemic in Iran, a questionnaire was designed based on a pairwise comparison of all indicators, and finally, we estimated relative weights for selected indicators using the AHP technique.

The university professors who are specialists in the fields of disaster and emergency health, infectious disease, and social and welfare were asked to prioritize the importance of each of these indicators. To assess the reliability of the results, the consistency ratio (CR) was evaluated (26). In this stage of the study, 12 experts participated and estimated relative weights. The participants had to choose an indicator in the pairwise comparison questionnaire and identify the degree of more or less importance of each selected indicator. To help with the comparison, a nine-point scale of importance was created (27). The suggested numbers were used to express the degree of importance between each of the two indicators based on the nine-point scale as shown in Table 1. Then, the researchers calculated the weights for each indicator.

3. Results

A total of eight and twelve experts with years of experience in disasters and emergencies, infectious disease, and social and welfare participated in the expert panel and AHP phases of this study, respectively. The mean age of the participants was 40.3 ± 4.7, and their mean work experience was 12.1 ± 5.5 years.

TABLE 2 Finalized domains and relevant indicators of social vulnerability in COVID-19.

Domain	Indicator
Household composition and disability	Aged 65 years or older
	Aged 17 years or younger
	Sex ratio
	Older than age 5 with a disability
	Single parent household
	Average number of family members
Race and minority status	Minority
	Immigrant population
Socioeconomic status	Percentage Living Below Poverty Line
	Gini coefficient
	Unemployment rate
	Proportion in at risk industries
	Proportion in at risk occupations
	Median household income
	Food security
Housing and transportation	Place of living (urban or rural area)
	Percentage of housing in structures with 10 or more units
	Percentage of mobile homes
	Percentage of persons in institutionalized group quarters such as prisons, nursing homes (already described), dormitories or schools
	Population density or crowding
	Percentage of households with no vehicle available
	Working population access to public transportation
	Means of essential transport during a crisis
Public health infrastructures	Percentage of healthcare service workers
	Reserved medical stocks
	Access to health insurance
	Number of healthcare facilities in the area
	Ratio between the number of hospitals to the number of population
	Percentage of households without access to safe drinking water
Education	No high school diploma
	The percentage of population with university education

3.1. Review of literature

The most repeated domains of social vulnerability to COVID-19 in studies were family composition and disability, public health infrastructures, racial and ethnic minorities, socioeconomic status,

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TABLE 3 Group decision matrix and relative importance (priority) vector.

Indicator	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	Relative importance (priority) vector
C1	1.000	8.045	7.042	5.180	5.200	1.874	3.686	3.698	2.226	2.182	0.229
C2	0.124	1.000	0.171	0.150	0.887	0.131	0.136	0.161	0.126	0.118	0.014
C3	0.142	5.832	1.000	2.451	5.337	0.373	0.254	1.308	0.225	0.383	0.055
C4	0.193	6.681	0.408	1.000	2.874	0.323	0.295	0.938	0.171	0.143	0.038
C5	0.192	1.127	0.187	0.348	1.000	0.153	0.143	0.170	0.123	0.120	0.017
C6	0.534	7.622	2.682	3.093	6.520	1.000	0.352	1.345	0.212	0.315	0.082
C7	0.271	7.346	3.939	3.394	7.001	2.841	1.000	1.190	0.194	0.233	0.095
C8	0.270	6.210	0.765	1.066	5.890	0.744	0.841	1.000	0.173	0.183	0.057
C9	0.449	7.944	4.441	5.850	8.132	4.719	5.152	5.770	1.000	0.610	0.206
C10	0.458	8.485	2.610	7.007	8.310	3.175	4.283	5.462	1.639	1.000	0.208

C1, population density or crowding; C2, sex ratio; C3, aged 65 years or older; C4, unemployment rate; C5, university education; C6, average number of family members; C7, immigrant population; C8, place of living; C9, older than age 5 with a disability; C10, number of healthcare facilities in the area.

housing status, and transportation. Additionally, the relevant indicators for the mentioned domains, such as the percentage of single-parent households, the immigrant population, population density, unemployed rate, percentage of healthcare service workers, and percentage of the population who had access to health insurance, were extracted from the literature review. Then, they were adjusted as a draft of social vulnerability, including five domains and 38 indicators for the next stage.

3.2. Expert panel and consultation with experts

The expert panel was conducted in two rounds subsequently. For each round, two sessions were organized *via* Skype. During these two rounds, the experts discussed and reached a consensus agreement on domains and indicators that would be useful as a basis for developing a tool for assessing social vulnerability in COVID-19 in Iran. Additionally, the collected comments of two experts *via* email were involved in the including or excluding of domains and indicators in two rounds of an expert panel.

In the first round of the expert panel, the number of extracted domains from the literature review increased from five to six, according to the consensus of experts. In the draft version of domains from the literature review, education was accounted for as one of the indicators of the "household composition and disability" domain. The experts reached an agreement to categorize education as an individual domain of social vulnerability in COVID-19. Moreover, the five indicators that received <70% agreement were eliminated. The eliminated indicators in the first round were "no high school diploma" and "percentage of households with heads aged 60 years or older" from the socioeconomic domain, "income" and "percentage of children under poverty" from the socioeconomic status domain, and "population does not have a safe home to shelter in place" from the housing and transportation domain. Then, the following two indicators were defined for the education domain: "no high school diploma" and "percentage of the population with university education." In total, there were 35 indicators at the end of the first round of the expert panel.

The second round of the expert panel was held by the same participants as the previous round. The domains and indicators were discussed again, and the number of domains remained unchanged but the number of indicators decreased from 35 to 31. The eliminated indicators included "percentage of households with children aging from 0 to 4 years" from the household composition and disability domain, "percentage of children with no access to the internet" from the socioeconomic status domain, "working population spend more than 60 min on commute" and "percentage of pedestrian and bike commuters" from the housing and transportation domain, and "hospital bed per capita" from the public health infrastructure domain. Additionally, the indicator of "place of living (urban or rural areas)" was added to the housing and transportation domain. Consequently, the final version of domains and indicators of social vulnerability in COVID-19 included 6 and 31 items, respectively (Table 2).

3.3. Prioritizing indicators using AHP

The indicators were assessed due to the availability of data during the COVID-19 pandemic in Iran. Finally, 10 main indicators were selected. By applying the AHP method during the collective discussion, a group of twelve experts defined the importance of each indicator of social vulnerability in the COVID-19 pandemic. For determining the importance, the experts completed the pairwise comparison matrix by comparing all indicators in pairs.

The results of the pairwise comparison matrix and relative importance vector are presented in Table 3. According to Figure 1, the most important indicator is population density (ωC1 = 0.229); the second-most important indicator is access to healthcare facilities and relevant services (ωC10 = 0.208); vulnerable group is also the third-most important indicator (ωC9 = 0.206). Further, gender is the least important indicator (ωC2 = 0.014). The sum of the relative importance vectors is equal to 1. The consistency of the

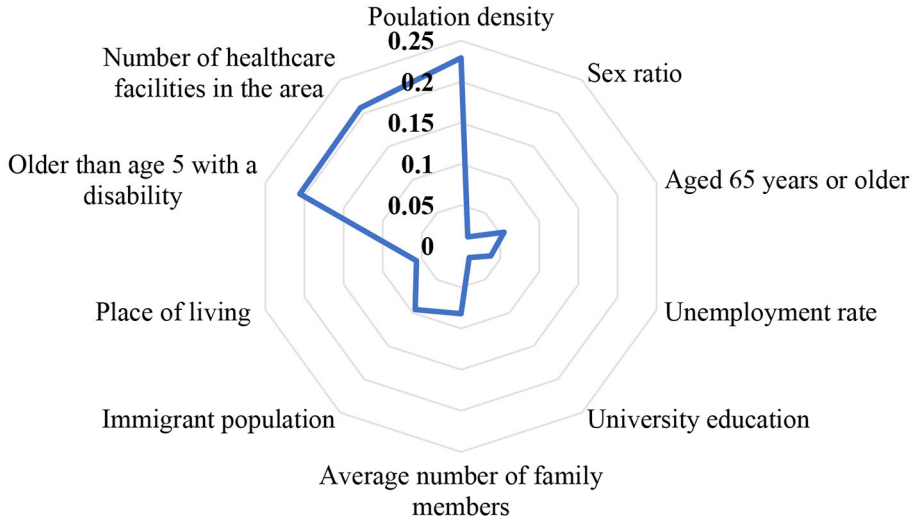

FIGURE 1
Radiated diagram of social vulnerability indicators in the COVID-19 pandemic in Iran.

pairwise comparison was checked through face-to-face interviews with experts. Next, the consistency ratio was calculated to check the consistency of the judgments. The consistency index was (CI = 0.129), the consistency ratio was (CR = 0.087), which was lower than 0.1. This demonstrates that the pairwise comparison matrix is consistent.

4. Discussion

This study aimed to develop the main domains and indicators of social vulnerability in the COVID-19 pandemic. Across the world, there have been many studies on the assessment and measurement of social vulnerability but most of them focused on natural disasters such as earthquakes or floods. Although these studies yielded significant insights into the conceptual meaning of social vulnerability, only a few of them included valid indicators (5, 7, 28–31). A few social vulnerability investigations have been conducted individually in Iran, but most of the studies in the world collected and weighed the relevant social vulnerability indicators in four broad categories, including population, housing, socioeconomic status, and physical distance (13, 24, 32). The literature review shows that epidemics are also affected by social vulnerability indicators such as housing, economics, transportation, and the environment in different communities (33, 34) and COVID-19 is no exception. One study in the United States showed that greater social vulnerability has a direct effect on the increased risk of COVID-19 infection and mortality (35).

Based on the results of this study, the main social vulnerability domain and indicators were housing and population density, respectively. Previous findings from the studies of vulnerability-relevant factors for COVID-19 have also confirmed our results. Living in high-density populations causes the spread of COVID-19 due to crowded areas and high physical contact with other people (36–38). Furthermore, vulnerable groups (*aged 65 years or older, aged 17 years or younger, older than age 5 with a disability, and single-parent households)* and public health infrastructure (*number of healthcare facilities in the area*) were the other considerable domains and indicators with the highest weight. These findings were confirmed by some worldwide studies during COVID-19. For instance, the results of two studies in Iran and the United States showed that children and the elderly are at higher risk of COVID-19 infection and related mortality and more vulnerable to receiving various medical, financial, and emotional needs during COVID-19 and previous epidemics (39, 40). Additionally, the literature review indicated that people with disabilities need support from rehabilitation centers and relevant service organizations to receive healthcare related to COVID-19 infection (41, 42). The results of one study showed that discrimination in access to healthcare facilities and services may lead to a higher prevalence of COVID-19 and the continuity of the transmission chain of the pandemic (39). Furthermore, one study in Brazil found that the great heterogeneity in hospital capacity across the country posed an important challenge for resource allocation to patients during the pandemic (43).

Since scientific data and viewpoints of experts were considered in the development of the main social vulnerability indicators in COVID-19, remote sensing methods and GIS are the appropriate tools for mapping social vulnerability in the COVID-19 pandemic in the case of existing data related to social vulnerability indicators (1, 16, 44). The output of this study, in the form of a questionnaire, is hoped to be used by most disaster scholars and practitioners in this field to improve the recognition of more vulnerable areas and prioritize the distribution of resources to ensure equity for residents during COVID-19 and other probable epidemics in the future.

There are some limitations to this study. First, only English articles, documents, and books were used in the literature review stage, and some important published training materials in other languages must have been missed. Second, due to social distancing principles in the COVID-19 pandemic, holding the expert panel sessions and AHP *via* social media or email was a time-consuming process. Data saturation was not also obtained, unlike

in the physical environment of expert panel sessions, where the experts express their viewpoints face-to-face. Furthermore, more focus was on the indicators of social vulnerability in this study because quantitative data were available from the latest census in Iranian databases.

5. Conclusion

The main social vulnerability indicators in COVID-19 were determined in Iran during this study. The previous studies showed that regions with higher social vulnerability experienced greater mortality rates during the COVID-19 pandemic. Thus, we determined the main social vulnerability in the COVID-19 pandemic in this study. In the future, we need to measure the social vulnerability index in different regions of Iran and compare the results with other parts of the world that have done similar social vulnerability studies. In the next stage, public health actions will be predicted for the regions that were socially vulnerable to becoming COVID-19 hotspots in Iran. Additionally, recognizing the social vulnerable regions from COVID-19 helps to prepare the multiagency response teams and required measures for future epidemics or pandemics management.

However, there is a need to conduct empirical studies on the validity and generalizability of identified indicators in the COVID-19 pandemic in different regions of Iran. Although collecting data about considered indicators would be difficult because of inadequate secondary data, there may be a need to decrease the number of developed indicators in this study.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/Supplementary material.

Ethics statement

This study was approved by the Ethics Committee Review Board at Semnan University of Medical Sciences (IR.SEMUMS.REC.1399.110). All the participants signed a consent form and were informed on the purpose of the study prior to interview as per local protocol on research ethics.

Author contributions

FF and BP collected data and contributed to entering data into the dataset. FF, SM, and AD designed the study, analyzed data, and prepared the manuscript. All authors read and approved the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1080137/full#supplementary-material

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Assessment of disaster preparedness and related impact factors among emergency nurses in tertiary hospitals: descriptive cross-sectional study from Henan Province of China

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Background: The aim of this study was to investigate the current state of disaster preparedness and to determine associated factors among emergency nurses from tertiary hospitals in Henan Province of China.

Methods: This multicenter descriptive cross-sectional study was conducted with emergency nurses from 48 tertiary hospitals in Henan Province of China between September 7, 2022–September 27, 2022. Data were collected through a self-designeds online questionnaire using the mainland China version of the Disaster Preparedness Evaluation Tool (DPET-MC). Descriptive analysis and multiple linear regression analysis were used to evaluate disaster preparedness and to determine factors affecting disaster preparedness, respectively.

Results: A total of 265 emergency nurses in this study displayed a moderate level of disaster preparedness with a mean item score of 4.24 out 6.0 on the DPET-MC questionnaire. Among the five dimensions of the DPET-MC, the mean item score for pre-disaster awareness was highest (5.17 ± 0.77), while that for disaster management (3.68 ± 1.36) was the lowest. Female gender ($B = -9.638$, $p = 0.046$) and married status ($B = -8.618$, $p = 0.038$) were negatively correlated with the levels of disaster preparedness. Five factors positively correlated with the levels of disaster preparedness included having attended in the theoretical knowledge training of disaster nursing since work ($B = 8.937$, $p = 0.043$), having experienced the disaster response ($B = 8.280$, $p = 0.036$), having participated in the disaster rescue simulation exercise ($B = 8.929$, $p = 0.039$), having participated in the disaster relief training ($B = 11.515$, $p = 0.025$), as well as having participated in the training of disaster nursing specialist nurse ($B = 16.101$, $p = 0.002$). The explanatory power of these factors was 26.5%.

Conclusion: Emergency nurses in Henan Province of China need more education in all areas of disaster preparedness, especially disaster management, which needs to be incorporated into nursing education, including formal and ongoing education. Besides, blended learning approach with simulation-based training and

disaster nursing specialist nurse training should be considered as novel ways to improve disaster preparedness for emergency nurses in mainland China.

KEYWORDS

disaster preparedness, emergency nurses, tertiary hospitals, descriptive cross-sectional study, disaster nursing specialist nurse training

Introduction

Continuously occurring yet unpredictable disasters remain a serious threat to global public health and property (1). In mainland China, the main forces of disaster relief contain national emergency medical rescue teams, private rescue organizations and healthcare facilities (2). Among them, healthcare facilities are regarded as vitally important emergency response resources because they are central to providing timely and good quality healthcare services for the injuries (3). With the increasing disaster events, healthcare facilities are expected to enhance frontline force to cope with disaster disruptions. As the major frontline workforce in disaster relief, nurses, especially emergency nurses, are of particular importance. When a disaster strikes, emergency nurses can detect threats, provide direct nursing care to patients, manage healthcare teams and facilities, reduce or eliminate injuries and deaths, develop healthcare policies, and work in collaboration with other organizations (4, 5). In addition, increasing studies have shown that disaster preparedness is a crucial factor in disaster response that can reduce the damaging effects of emergencies and disasters (6, 7). Therefore, mobilizing emergency nurses to improve disaster preparedness capability has become a pivotal strategy to enhance the capability of healthcare facilities to respond to different types of disasters.

Disaster preparedness is defined as the reserve of knowledge and capacity to effectively respond to disasters (8). More and more attention has been paid to investigate disaster preparedness of emergency nurses in recent years. At present, most of studies abroad on disaster preparedness of emergency nurses clearly reported a weak-to-average or a low-to-moderate level of disaster preparedness and concluded that emergency nursers remained inadequately prepared on all domains of disaster nursing competencies (9–11). A recent study in Guangdong Province of China reported that emergency nurses had a moderate level of disaster preparedness, and addressed that hospitals and nurse managers should carry out interdisciplinary and multidisciplinary cooperation to improve emergency nurses' disaster preparedness (12). Assessing the extent of disaster preparedness among emergency nurses and identifying associated influencing factors can contribute to refine the practical strategies for enhancing their disaster preparedness capability. However, current study on disaster preparedness among emergency nurses in China is extremely limited.

As the second largest economy in the world, China became the third most disaster-prone country in Asia in 2021, after Indonesia and India (13). Due to the complex topography and high density of population, China's Henan Province are constantly exposed to a variety of unexpected disasters including geological disasters, fire disasters, traffic disasters, meteorological disasters, and infectious diseases, thus always suffer catastrophic consequences, such as human casualties and property damage. For instance, in July 2021, Henan Province was struck by an extraordinarily heavy rainstorm that caused severe flooding, resulting in 352 deaths, 14.5 million population affected, and a cost of $16.5 billion (13). This sudden mega-disaster not only posed unprecedented challenges to disaster emergency management system but also exposed the poor disaster preparedness among municipal government, healthcare facilities and medical personnel (14). Considering the vital role of emergency nurses on the frontline of disasters response, the disaster preparedness of emergency nurses in Henan Province is of great concern. However, little is known regarding the prevalence of disaster preparedness among emergency nurses in Henan Province of China, which may impede further improvement of the quality and efficiency of disaster relief provided by healthcare facilities.

Thus, the present study aimed to investigate the current state of disaster preparedness among emergency nurses from tertiary hospitals in Henan Province of China, and to determine key related factors affecting disaster preparedness to improve disaster preparedness capability.

Methods

Study design, setting, and participants

This descriptive cross-sectional study was conducted with emergency nurses from 48 tertiary hospitals, which all have >1,000 beds and spread out across 17 cities in Henan Province, China, from September 7, 2022 to September 27, 2022. To be eligible to participate, nurses were required to be (1) certified registered and full-time nurses; (2) formally working for a minimum of 1 year in emergency department; (3) active during the data collection stage; (4) sufficiently agree to participate. Nurses with older than 50 years were excluded from the study because they were basically no longer frontliners in the hospital.

Ethical consideration

The Ethics Committee of Henan Provincial People's Hospital approved the study. All participants were provided a description of the study and informed that participation was voluntary, and anonymity assured. In addition, participants were informed that they could withdraw from the study at any time.

TABLE 1 Demographic and work-related characteristics of emergency nurses ($N = 265$).

Variables	*n*	%
Age		
20–30 years	100	37.7
31–40 years	151	57.0
41–50 years	14	5.3
Gender		
Male	55	20.8
Female	210	79.2
Marital status		
Married	187	70.6
Single	78	29.4
Educational level		
Post diploma	15	5.7
Bachelor's degree	233	87.9
Master's or PhD degree	17	6.4
Health condition		
Fitness	156	58.9
Good	73	27.5
Average	32	12.1
Poor	4	1.5
Work duration		
≤ 5 years	85	32.1
6∼10 years	92	34.7
11∼15 years	58	21.9
≥ 16 years	30	11.3
Professional title		
Primary title	106	40.0
Intermediate title	157	59.2
Senior title	2	0.8
Having attended disaster nursing courses at school		
Yes	146	55.1
No	119	44.9
Having participated in the theoretical knowledge training of disaster nursing since work		
Yes	158	59.6
No	107	40.4
Having participated in the disaster rescue simulation exercise		
Yes	133	50.2
No	132	49.8
Having participated in the disaster relief training		
Yes	221	83.4
No	44	16.6
Having participated in the training of disaster nursing specialist nurse		
Yes	52	19.6
No	213	80.4
Having experienced the disaster response		
Yes	150	56.6
No	115	43.4
Willingness to participate in the disaster relief mission		
Yes	245	92.5
No	20	7.5

Questionnaire

The online questionnaire consists of two parts. The first part focused on the demographic and work-related characteristics, and the second part focused on the assessment of disaster preparedness. All items of the demographic and work-related questionnaire were shown in Table 1. The Mainland China version of the Disaster Preparedness Evaluation Tool (DPET-MC) scale, a modified version of the DPET (15), is constructed by Yibing Tan (16) (as shown in Supplementary material) and is a validated instrument to assess disaster preparedness of emergency nurses in mainland China. The DPET-MC scale consists of 34 items within five subscales: pre-disaster awareness (3 items), pre-disaster knowledge (8 items), disaster management (10 items), knowledge and skills in the workplace (6 items), and post-disaster knowledge and skills (7 items). The Cronbach's alpha coefficients of the DPET-MC are 0.79, 0.88, 0.94, 0.90, 0.96 and 0.97 for the five dimensions and the overall scale, respectively. The 34 items were assessed using a 6-point Likert scale (1= "strongly disagree"; 6 = "strongly agree"). The total score ranges from 34 to 204, with a higher score indicating a higher level of disaster preparedness. The DPET-MC was used in our study with permission from Yibing Tan (16).

Data collection

Data were collected through the aforementioned online questionnaire via a software of Questionnaire Star (17), which was conducted through WeChat software based on the smartphone. Participants who agreed to participate in the study were required to open the questionnaire and submit it only after completing all questions, so it was impossible to submit an incomplete answer. To avoid repeated access and completion of the questionnaire, an internet provider number was used for access restriction. Completed questionnaires were collected automatically and exported to an Excel file after the respondents answered the questions.

TABLE 2 Emergency nurses' disaster preparedness' scores ($N = 265$).

	Total score range	Total score Mean (SD)	Item score Mean (SD)	Skewness	Kurtosis
Total scale	62–204	144.19 (34.00)	4.24 (1.00)	0.067	−0.666
Pre-disaster awareness	9–18	15.51 (2.32)	5.17 (0.77)	−0.529	−0.714
Pre-disaster knowledge	16–48	36.86 (7.65)	4.61 (0.96)	−0.097	−0.754
Knowledge and skills in the workplace	6–36	26.09 (6.54)	4.35 (1.09)	−0.357	−0.123
Post-disaster skills and knowledge	7–42	28.97 (8.26)	4.14 (1.18)	−0.339	−0.133
Disaster management	10–60	36.76 (13.63)	3.68 (1.36)	0.081	−0.805

Data analysis

Descriptive statistics were performed to summarize the demographic and some work-related characteristics of the entire study population. Continuous data were expressed as mean ± standard deviation (M ± SD), whereas categorical data were presented as an absolute number and percentage. Independent sample *t*-tests and one-way analysis of variance (ANOVA) were carried out to determine the differences and associations between demographic and work-related variables and disaster preparedness. Variables with $p < 0.10$ were included in the multivariate analysis. The multiple linear regression model was performed to identify salient variables associated with disaster preparedness among demographic and work-related factors. All *p*-values are two-sided. $p < 0.05$ was considered as statistically significant. All analyses were conducted using SPSS statistical software version 25.0 (IBM Corporation, Armonk, NY).

Results

Demographic and work-related characteristics

Of the 365 questionnaires handed out, 280 were returned, resulting in an 76.7% response rate. 15 were excluded due to various combinations of age (>50 years), work duration (<1 year), and nonregistered nurses. Finally, a total of 265 questionnaires were analyzed in this study.

Demographic and work-related characteristics are summarized in Table 1. Of the included participants with age from 20 to 48 years, 151 (57.0%) were in the 30 to 40 age group. 210 (79.2%) were female. 187 (70.6%) were married and 233 (87.9%) had a bachelor's degree. 85 (32.1%) respondents had a work duration of <5 years. More than half of respondents had attended disaster nursing courses, trainings and exercise, while only 52 (19.6%) had participated in the training of disaster nursing specialist nurse. 150 (56.6%) had the disaster response experience. Notably, 20 (7.5%) expressed less willing to participate in any disaster relief mission.

Disaster preparedness among emergency nurses

The total score range, mean ± SD score, mean item score, skewness, and kurtosis for the DPET-MC scale and for its five dimensions are presented in Table 2. The total scale score ranged from 62 to 204, with a mean score of 144.19 (SD = 34.00) and a mean item score of 4.24 (SD = 1.00) out 6.0. The dimensions with the highest and lowest mean item scores were pre-disaster awareness (5.17 ± 0.77) and disaster management (3.68 ± 1.36), respectively.

Univariate analysis of factors affecting disaster preparedness

Independent sample *t*-tests and one-way analysis of variance revealed that nurses with male gender, single and fitness health condition, those who had attended disaster nursing courses at school, those who had participated in the theoretical knowledge training of disaster nursing since work, those who had participated in the disaster rescue simulation exercise and the disaster relief training, those who had participated in the training of disaster nursing specialist nurse, and those who had experienced the disaster response were more likely to report higher item scores of the DPET-MC, indicating better disaster preparedness. Nevertheless, factors such as age, educational level, work duration, professional title, and willingness to participate in the disaster relief mission showed no correlation with disaster preparedness (Table 3).

Multiple linear regression analysis of factors affecting disaster preparedness

Ten variables with $p < 0.10$ obtained in univariate analysis were entered into a stepwise multiple linear regression model with disaster preparedness score as the dependent variable. The final model had an R^2 of 0.265 and adjusted R^2 of 0.233 ($F = 8.284$, $p < 0.001$), by which 23.3% of variation in disaster preparedness score could be explained (Table 4). Results showed that female gender ($B = -9.638$, $t = -2.003$, $p = 0.046$) and

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TABLE 3 Univariate analysis of factors affecting disaster preparedness ($N = 265$).

	Pre-disaster awareness	Pre-disaster knowledge	Disaster management	Knowledge and skills in the workplace	Post-disaster skills and knowledge	Item score for the DPET-MC
			Mean (SD)			
Age						
20–30 years	5.12 (0.77)	4.58 (0.98)	3.81 (1.37)	4.37 (1.02)	4.13 (1.15)	4.27 (1.01)
31–40 years	5.17 (0.79)	4.58 (0.95)	3.53 (1.36)	4.29 (1.14)	4.09 (1.22)	4.17 (1.01)
41–50 years	5.52 (0.62)	5.10 (0.72)	4.34 (1.06)	4.76 (0.91)	4.64 (0.91)	4.76 (0.71)
F	1.659	1.960	3.143	1.228	1.389	2.321
p (ANOVA)	0.192	0.143	0.045	0.295	0.251	0.098
Gender						
Male	5.25 (0.80)	4.93 (0.93)	4.25 (1.22)	4.85 (0.86)	4.69 (1.01)	4.69 (0.89)
Female	5.15 (0.77)	4.52 (0.95)	3.53 (1.36)	4.22 (1.11)	4.00 (1.18)	4.12 (1.00)
T	0.913	2.800	3.592	3.901	3.971	3.860
p (t-test)	0.362	0.005	0.000	0.000	0.000	0.000
Marital status						
Single	5.22 (0.78)	4.68 (0.97)	3.78 (1.39)	4.44 (1.12)	4.26 (1.21)	4.33 (1.02)
Married	5.05 (0.76)	4.44 (0.91)	3.43 (1.27)	4.12 (0.99)	3.85 (1.07)	4.02 (0.91)
T	1.677	1.877	1.873	2.245	2.618	2.359
p (t-test)	0.095	0.062	0.062	0.026	0.009	0.019
Educational level						
Post diploma	5.11 (0.79)	4.72 (1.03)	3.63 (1.44)	4.40 (0.88)	4.27 (1.01)	4.28 (0.98)
Post diploma	5.18 (0.78)	4.62 (0.96)	3.70 (1.37)	4.36 (1.11)	4.14 (1.20)	4.25 (1.01)
Master1.01)alevele DPE	5.04 (0.60)	4.36 (0.86)	3.46 (1.20)	4.12 (1.00)	4.07 (1.03)	4.06 (0.89)
F	3.266	3.992	4.911	10.954	5.715	7.161
p (ANOVA)	0.727	0.508	0.781	0.661	0.887	0.720
Health condition						
Fitness	5.75 (0.32)	5.22 (1.06)	4.33 (1.58)	4.75 (1.66)	4.36 (1.52)	4.74 (1.20)
Good	5.22 (0.78)	4.75 (0.97)	3.83 (1.33)	4.49 (1.05)	4.28 (1.18)	4.38 (0.99)
Average	5.11 (0.73)	4.41 (0.87)	3.43 (1.31)	4.25 (1.31)	3.99 (1.28)	4.03 (1.12)
Poor	5.00 (0.84)	4.30 (0.97)	3.43 (1.53)	4.08 (1.00)	3.88 (1.08)	4.01 (0.93)
F	1.629	4.004	2.086	2.677	2.224	3.073
p (ANOVA)	0.183	0.008	0.102	0.048	0.086	0.028
Work duration						
$\leq$ 5 years	5.05 (0.73)	4.56 (0.86)	3.68 (1.31)	4.15 (1.04)	3.99 (1.11)	4.16 (0.96)
6–10 years	5.22 (0.81)	4.61 (1.05)	3.72 (1.46)	4.41 (1.14)	4.19 (1.28)	4.28 (1.08)
11–15 years	5.17 (0.79)	4.58 (0.98)	3.56 (1.31)	4.50 (1.08)	4.22 (1.12)	4.24 (0.97)
$\geq$ 16 years	5.34 (0.70)	4.80 (0.89)	3.73 (1.37)	4.41 (1.09)	4.26 (1.19)	4.35 (0.98)
F	1.277	0.463	0.187	1.402	0.701	0.363
p (ANOVA)	0.283	0.708	0.905	0.243	0.552	0.780
Professional title						
Primary title	5.15 (0.78)	4.65 (0.95)	3.82 (1.36)	4.38 (1.03)	4.15 1.18)	4.30 (0.99)
Intermediate title	5.18 (0.77)	4.58 (0.97)	3.58 (1.37)	4.32 (1.13)	4.12 (1.19)	4.20 (1.02)

(Continued)

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TABLE 3 (Continued)

	Pre-disaster awareness	Pre-disaster knowledge	Disaster management	Knowledge and skills in the workplace	Post-disaster skills and knowledge	Item score for the DPET-MC
Senior title	5.33 (0.00)	4.75 (0.35)	4.25 (1.06)	4.75 (0.35)	4.86 (0.20)	4.68 (0.50)
F	0.091	0.223	1.161	0.245	0.387	0.522
p (ANOVA)	0.913	0.800	0.315	0.783	0.680	0.594
Having attended disaster nursing courses at school						
Yes	5.14 (0.78)	4.74 (0.85)	3.89 (1.21)	4.45 (0.98)	4.30 (1.04)	4.38 (0.89)
No	5.20 (0.77)	4.45 (1.06)	3.41 (1.49)	4.22 (1.21)	3.94 (1.30)	4.07 (1.10)
T	−0.659	2.413	2.804	1.722	2.459	2.55
p (t-test)	0.511	0.017	0.005	0.086	0.015	0.011
Having participated in the theoretical knowledge training of disaster nursing since work						
Yes	5.19 (0.77)	4.80 (0.90)	3.98 (1.25)	4.58 (0.96)	4.43 (1.05)	4.48 (0.91)
No	5.15 (0.78)	4.33 (0.98)	3.23 (1.41)	4.01 (1.18)	3.71 (1.24)	3.90 (1.03)
T	0.405	3.985	4.508	4.348	5.071	4.822
p (t-test)	0.686	0.000	0.000	0.000	0.000	0.000
Having participated in the disaster rescue simulation exercise						
Yes	5.31 (0.73)	4.89 (0.91)	4.08 (1.26)	4.65 (1.05)	4.51 (1.13)	4.57 (0.94)
No	5.03 (0.79)	4.34 (0.92)	3.27 (1.35)	4.04 (1.05)	3.76 (1.12)	3.91 (0.95)
T	3.083	5.006	5.059	4.77	5.436	5.667
p (t-test)	0.002	0.000	0.000	0.000	0.000	0.000
Having participated in the disaster relief training						
Yes	5.23 (0.75)	4.66 (0.96)	3.78 (1.36)	4.46 (1.03)	4.23 (1.15)	4.33 (0.98)
No	4.86 (0.80)	4.33 (0.91)	3.15 (1.26)	3.78 (1.19)	3.66 (1.23)	3.80 (0.97)
T	2.919	2.102	2.830	3.915	2.976	3.291
p (t-test)	0.004	0.036	0.005	0.000	0.003	0.001
Having participated in the training of disaster nursing specialist nurse						
Yes	5.41 (0.75)	5.08 (0.84)	4.51 (1.08)	4.95 (0.87)	4.90 (0.91)	4.88 (0.82)
No	5.11 (0.77)	4.49 (0.95)	3.47 (1.35)	4.20 (1.09)	3.95 (1.17)	4.08 (0.98)
T	2.529	4.082	5.152	4.624	5.434	5.414
p (t-test)	0.012	0.000	0.000	0.000	0.000	0.000
Having experienced the disaster response						
Yes	5.26 (0.74)	4.79 (0.98)	3.96 (0.37)	4.60 (1.10)	4.39 (1.21)	4.47 (1.02)
No	5.06 (0.80)	4.37 (0.87)	3.30 (1.26)	4.02 (0.99)	3.81 (1.06)	3.94 (0.90)
T	2.076	3.626	4.039	4.421	4.087	4.449
p (t-test)	0.039	0.000	0.000	0.000	0.000	0.000
Willingness to participate in a disaster relief mission						
Yes	5.16 (0.77)	4.61 (0.96)	3.67 (0.38)	4.36 (1.10)	4.15 (1.20)	4.24 (1.02)
No	5.28 (0.76)	4.53 (0.90)	3.72 (1.20)	4.26 (0.92)	4.03 (0.88)	4.20 (0.80)
T	−0.683	0.401	−0.132	0.384	0.433	0.170
p (t-test)	0.495	0.689	0.895	0.701	0.665	0.865

TABLE 4 Multiple linear regression analysis of factors associated with emergency nurses' disaster preparedness scores ($N = 265$).

Model	B	SE	Beta	*t*	*P*-Value
(constant)	94.783	19.567	-	4.844	0.000
Gender (reference = Male)	−9.638	4.813	−0.115	−2.003	0.046
Marital status (reference = Single)	−8.618	4.132	−0.116	−2.086	0.038
Having participated in the theoretical knowledge training of disaster nursing since work (reference = No)	8.937	4.384	0.129	2.039	0.043
Having experienced the disaster response (reference = No)	8.280	3.922	0.121	2.111	0.036
Having participated in the disaster rescue simulation exercise (reference = No)	8.929	4.293	0.132	2.080	0.039
Having participated in the disaster relief training (reference = No)	11.515	5.122	0.126	2.248	0.025
Having participated in the training of disaster nursing specialist nurse (reference = No)	16.101	5.153	0.188	3.125	0.002

$R^2 = 0.265$; Adjusted $R^2 = 0.233$; $F = 8.284$; $p < 0.001$.

married status (B = −8.618, t = −2.086, $p = 0.038$) had a negative correlation with disaster preparedness. While the rest of five variables were positively correlated with disaster preparedness, including having participated in the theoretical knowledge training of disaster nursing since work (B = 8.937, t = 2.039, $p = 0.043$), having experienced the disaster response (B = 8.280, t = 2.111, $p = 0.036$), having participated in the disaster rescue simulation exercise (B = 8.929, t = 2.080, $p = 0.039$), having participated in the disaster relief training (B = 11.515, t = 2.248, $p = 0.025$), and having participated in the training of disaster nursing specialist nurse (B = 16.101, t = 3.125, $p = 0.002$).

Discussion

As the major frontline force in combating against disasters, emergency nurses must be adequately prepared to cope with them. The present study reported that emergency nurses in Henan Province perceived they had a moderate level of disaster preparedness, and determined seven factors affecting disaster preparedness among emergency nurses. The results are expected to provide valuable information for hospital administrators and nurse educators on how to improve the disaster preparedness capability and capacity of emergency nurses.

Multiple cross-sectional surveys of disaster preparedness among clinical nurses in various countries reported a same outcome that nurses had overall a low-to-moderate level of disasters preparedness using varied scales (5, 18–24). Studies in Hong Kong, Taiwan and Changsha also found that nurses were inadequately prepared for disaster response (25–27). However, nurses in Henan Province perceived that they had a moderate level of disaster preparedness using the DPET-MC questionnaire, and seemed to present a higher level of disaster preparedness in comparison with nurses in other cities/countries. The reason for this discrepancy might be that the respondents of previous studies were nurses, whereas those of this study were emergency nurses, who are first responders in disaster scenes and have more sufficient experience and knowledge about how to manage different emergency situation compared to nurses in other departments (28–30). Besides, this discrepancy might also be at least partially caused by the different instruments assessing disaster preparedness. The DPET-MC with internal consistency reliability and split-half reliability in this study had fewer items than the original DPET scale and could save time for emergency nurses in a fast-paced work environment (16). It therefore is targeted at emergency nurses in mainland China and is more suitable for our study. Of note, in the recent study among emergency nurses in Guangdong Province, Wang et al. also used the DPET-MC questionnaire and reported that the perceived disaster preparedness of emergency nurses was at a moderate level (12). At present, there have been only limited studies to investigate the disaster preparedness among Chinese emergency nurses. These findings might contribute to a comprehensive understanding of the level of disaster preparedness among emergency nurses in China.

Compared with the prior systematic review of literature that reported a general lack of disaster awareness among nurses abroad (1), it is worth noting that emergency nurses in the present study displayed the highest mean item score for pre-disaster awareness. This finding is congruent with another Chinese study by Wang et al. (12). The reasons for this gap might be associated with the high incidence of disaster events in China and that almost all Chinese emergency nurses experienced in fighting against COVID-19 pandemic. However, the mean item score for disaster management in the present study was the lowest, which is consistent with the results acquired from many previous studies (12, 24), reflecting that disaster management is the most challenging dimension in disaster preparedness and the disaster management ability of emergency nurses needs to be improved most urgently. Therefore, it is necessary for nursing education to incorporate the disaster management education into formal and ongoing education.

While emergency nurses in Henan Province were not fully prepared for disasters, in line with previous studies, several factors may improve disaster preparedness. Prior studies have established the associations between disaster preparedness and gender, as well as marital status (12, 31). Likewise, our study identified that both female gender and married status were negatively correlated with perceived levels of disaster preparedness. Reasons might be that female and married nurses have weaker physical and psychological qualities to undertake rescue work. Thus, hospitals should provide more physical, technical, and psychological education and training for female and married nurses to improve the ability of disaster relief, as well as more humanistic care for married nurses to avoid excessive worries about their families.

Previous studies have found experience is the basis of preparedness, and experienced nurses are better able to provide care in emergency situations than less experienced nurses (32). The present study also showed that having experienced the disaster response were positively correlated with disaster preparedness. It is recommended that participation by emergency nurses in real or mock drill experience is a useful adjunct for promoting disaster preparedness. In addition, three other factors positively affecting the disaster preparedness level of emergency nurses were reported in the present study, including having participated in the theoretical knowledge training of disaster nursing since work, having participated in the disaster rescue simulation exercise, and having participated in the disaster relief training. The above three factors can not only exert a pivotal impact on disaster preparedness (22, 33, 34), but also determine the education framework for emergency nurses, suggesting that the teaching approach and strategy for emergency nurse training should be refined. Blended learning is a combination of remote and face-to-face and synchronous and asynchronous teaching methods (35). Prior studies have demonstrated that blended learning is one of the most effective teaching methods in disaster medicine, via multiple teaching strategies it provides the opportunity to teach broad aspects of knowledge and skills (36). In addition, simulation-based training, such as tabletop exercises, drill, functional and full-scale exercise, and virtual reality simulation exercises, has become a realistic and effective approach to prepare the first responders for disaster management and increase the learner knowledge, enhance self-confidence and refine the skills (37–39). Therefore, blended learning approach with simulation-based training would be useful and feasible for disaster nursing education.

In the present study, the factor of having participated in the training of disaster nursing specialist nurse was also significantly and positively correlated with disaster preparedness, and it had never been explored before. Disaster nursing specialist nurse training is a unique disaster nursing model in China, which was launched by the Chinese Nursing Association in 2015 (40). International studies have found that more than half of the nurses had not received any education or training on disasters (5, 41–43). In this study, nearly half of participants lacked the disaster-related education and various training and disaster response experience. Notably, the training of disaster nursing specialist nurse exactly covers basic theory of disaster nursing, professional skills of disaster relief, virtual reality disaster simulation exercises, etc. (44). Although China's disaster nursing is still in its infancy and exploratory stage (45), this finding highlighted that disaster nursing specialist nurse training might be a novel and effective way to enhance disaster preparedness for Chinese emergency nurses.

The limitations of this study are as follows: firstly, given the largely perception-based and does not rely on objective data, the results regarding reflecting actual disaster responses need to be interpreted with caution. However, the findings provided a baseline that can guide planning for continuing disaster education programs and training activities to meet the needs of emergency nurses from mainland China. Secondly, the response rate was not particularly high due to the lack of direct communication between the researcher and participants, which could affect the generalizability of the results. However, the response rate is similar to prior studies (31, 46, 47) and may be applied to similar settings and contexts. Thirdly, causal relationships could not be established in the cross-sectional study. Further studies could collect time-based data to explore causal relationships between disaster preparedness and associated factors. In addition, the variables included in this study might be not comprehensive enough. More relevant factors should be considered in future studies, such as intensive care experience, military hospital, and income.

Conclusion

To our best knowledge, this is the first study on investigating the levels of disaster preparedness among emergency nurses in Henan Province, China. It is clear from the present study that emergency nurses had a moderate level of disaster preparedness, and their disaster management ability needs to be improved most urgently. Importantly, seven factors affecting disaster preparedness were determined, which offered practical strategies for improvement of disaster preparedness among emergency nurses. Optimizing and detailing these strategies will be an interesting issue that is worth pursuing in the future.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding authors.

Ethics statement

The Ethics Committee of Henan Provincial People's Hospital approved the study. All participants were provided a description of the study and informed that participation was voluntary, and anonymity assured. In addition, participants were informed that they could withdraw from the study at any time.

Author contributions

Conceived and designed the study: YC and PZ. Collected and analyzed data: JZ and XC. Designed the tables: LY, FC, and YR. Wrote the first draft of this article: JZ and YC. Revised the manuscript for important intellectual content: SZ, LQ, XH, LX, and PZ. All authors approved the final version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1093959/full#supplementary-material

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Domain and perception on community resilience: comparison between two countries

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The COVID-19 outbreak demonstrates how unprepared the world is for a different type of crisis, especially non-physical calamities. Revitalizing community involvement in disaster management is essential for making a community resilient. Due to differing sociocultural contexts, the resilience perceptions of communities in different parts of the world may vary. This study aims to understand community resilience factors after the COVID-19 disaster in Indonesia and Malaysia. Data from 2034 questionnaires using 5-interrelated domains in the Communities Advancing Resilience (CART) Toolkit Survey were collected. This study was conducted across Indonesia and Malaysia from March to April 2022. A quantitative-based cross-sectional study design and convenience sampling were applied. Respondents for this study were Indonesian and Malaysian citizens above 18years of age who met the inclusion criteria. A total of 2034 respondents, 715 from Indonesia and 1,315 from Malaysia responded to the survey. The results suggest that Indonesian and Malaysian communities' Transformative Potential and Informative-Communication domains differ significantly. Indonesian communities demonstrated a higher mean value on Transformative Potential domains than Malaysian communities did, while Malaysian communities indicated a higher mean value on Informative-Communication domains. This study concludes that compared to Malaysian communities, Indonesian communities have a more significant potential for transformation because they can frame collective experiences, gather, and analyze pertinent data, evaluate community performance, and develop resilience-building abilities. On the other hand, Malaysian communities are more resilient in providing information and communication. We found the need to develop a community resilience model that incorporates specific cultural and local requirements. Cooperation between the two countries would open many possibilities to emphasize the capability to bounce back sooner after a catastrophe such as the COVID-19 pandemic and achieve Sustainable Development Goals.

KEYWORDS

community, resilience, COVID-19, domain, perception

1. Introduction

The unique coronavirus (COVID-19) pandemic has been exerting pressure on the entire planet. It has demonstrated how unprepared the world is for non-physical disasters, a category of disasters that is frequently disregarded. It provides a unique learning opportunity because no one can predict with certainty when the COVID-19 pandemic will cease. It provides a unique learning opportunity because no one can predict with certainty when the COVID-19 pandemic will cease (1). People's physical and emotional health is now seriously threatened by this pandemic, which has profoundly affected day-to-day living and psychological repercussions globally. At present, it is unimaginable how this pandemic will affect public health. More than 210 nations have been affected by the pandemic, and most are still undergoing various infection control procedures, such as lockdowns, quarantines, wearing masks, and social distancing. Most notably, the lockdowns decreased employment and incomes, which caused an increase in extreme poverty, Some international institutions stated that the Covid-19 pandemic disrupted the progress of achieving Sustainable Development Goals (SDGs). The COVID-19 pandemic has clarified that resilience-based approaches to poverty reduction and climate change adaptation are needed (2–4). To deal with shocks and increase resilience, it is urgently necessary to reassess the design and implementation of poverty reduction efforts for infrastructure and basic services, social safety systems, and health (5).

Another aspect that could influence future public health emergencies is global climate change. The World Economic Forum reported that climate change was linked to the world's top risks in 2019 (6). Community involvement is important when managing disasters, as it helps make citizens more resilient during pandemics. Social networks can help people find information about a disaster before it occurs and assist them during and after the incident. Thus, social connectedness plays a vital role in health security. The government helps build community organizations that can help communities recover from disasters. These organizations help communities to be better prepared for disasters and to come back stronger afterward (7). The institutional response to any natural or artificial disaster begins at the local level, and it is here that preparation efforts are perhaps most critical (8).

Disaster is always related to emergencies. Public health faces a challenge because it needs to prepare limited resources and personnel to focus on pre-event preparations due to the range of possible emergencies. A focus on building, exercising, and sustaining public health capabilities are needed to effectively respond to most types of emergencies under an all-hazards approach. Disaster Risk Reduction (DRR) involves multiple disaster preparedness and response planning sectors. Wider sectors of society are needed to participate in planning for preventive or response activities related to particular threats in DRR planning. This approach was codified in the Sendai Protocol for Disaster Risk Reduction 2015–2030 (9). Resilience refers to developing the ability or capacity to build back better after a disaster (10). By using community resilience as a framework, we may better comprehend a community's enduring ability to overcome and recover from hardship (11). A resilient community is constructed based on four attributes: strength, capital, temporal, and level of achievement. For example, a lack of flood resilience can mean that the impacts of floods do not go as planned and can undermine progress toward Sustainable Development Goals (SDGs). Therefore, to ensure that flood impacts do not cause the SDGs to be undermined, greater investments need to be made in DRR, climate change adaptation, and climate-smart development (12). Different cultures affect community resilience; for example central Eurasia has a vision of a better tomorrow, which stimulates the mobilization of inherent resources, communal support infrastructures, and the resolve needed to cope with the crisis (13). A study in 2021 concluded that in both Indonesia and Malaysia, the government plays a significant role in developing cooperatives and fostering the growth of the entity resilience (14).

Using community resilience as a framework can help comprehend a community's enduring ability to overcome and recover from hardships. According to the conceptual framework developed by Chandra et al., some aspects of community resilience include communication, social connectivity, physical and psychological health, and integration and involvement of the organization. Civicmindedness and social duty are equally significant factors that this paradigm has not sufficiently highlighted. Combating COVID-19 requires teamwork and giving up personal preferences, especially when it comes to safeguarding vulnerable and at-risk populations (15).

This study assesses the community resilience level, SDGs related to community resilience, and the indicators for community resilience building. In accommodating the concern and interest in community resilience, a sound system that encompasses risk management and governance of community resilience will also be needed. Hence, this study provides initial mapping to support this objective (Table 1).

2. Materials and methods

2.1. Study design, setting, and participants

This study was conducted across Indonesia and Malaysia from March to April 2022 A quantitative-based cross-sectional study design and convenience sampling were applied. The inclusion criteria for this study were that participants are residents aged 18 years and above and Indonesian and Malaysian citizens. All participants must be able to provide voluntary informed consent for this study. Google Forms was used to gather data, and the distribution method used word of mouth and emails. We also used web-based applications like Facebook, Twitter, Telegram, and WhatsApp.

The study sample size was calculated using the single population proportion formula, giving rise to the final sample size, $n = 2034$ (715 in Indonesia and 1319 in Malaysia). Non-probability convenience sampling was used for sample collection.

This study used an online questionnaire in Malay, English, and Bahasa Indonesia. Three experts performed the back-to-back translation to ensure the original meaning was preserved. The online questionnaire consisted of four sections: (1) Socio-demographic information; (2) Disaster experience, participation, training, active membership, and interest in deployment; (3) Communication and interaction between respondents and the community; and (4) Core community resilience. The remote data collection method was used to gather the data. Both descriptive and inferential statistics were used to analyze the data.

2.2. Study instrument

This study used the Communities Advancing Resilience Toolkit (CART) study. The theory and evidence-based CART research utilized

TABLE 1 Community resilience score (domain and perception).

Community resilience (domain and perception)	Malaysia	Indonesia	*p* value	Malaysia	Indonesia	*p* value
Statements	Mean (SD)	Mean (SD)		Mean (SD)	Mean (SD)	
Domain 1: Connection and Caring						
1. People in my community feel like they belong to the community.	0.77 (0.17)	0.68 (0.16)	**0.00**	0.78 (0.15)	0.77 (0.10)	0.05
2. People in my community are committed to the community's well-being.	0.78 (0.17)	0.76 (0.13)	**0.04**			
3. People in my community have hope for the future.	0.77 (0.17)	0.81 (0.12)	**0.00**			
4. People in my community help each other.	0.80 (0.17)	0.80 (0.14)	0.78			
5. My community treats people fairly, regardless of their background.	0.78 (0.18)	0.79 (0.15)	0.61			
Domain 2: Resources						
6. My community supports programs for children and families	0.76 (0.19)	0.77 (0.13)	0.15	0.75 (0.017)	0.75 (0.11)	0.32
7. My community has the resources to take care of community problems.	0.73 (0.19)	0.74 (0.14)	**0.06**			
8. My community has effective leaders.	0.73 (0.20)	0.75 (0.14)	**0.01**			
9. People in my community can get the services they need.	0.75 (0.19)	0.75 (0.13)	0.87			
10. People in my community know where to go to get things done.	0.76 (0.18)	0.75 (0.12)	0.14			
Domain 3: Transformative Potential						
11. My community works with organizations and agencies outside the community to get things done.	0.72 (0.19)	0.74 (0.14)	**0.06**	0.74 (0.17)	0.76 (0.11)	**0.00***
12. People in my community communicate with leaders who can help improve the community.	0.73 (0.19)	0.75 (0.13)	**0.07**			
13. People in my community work together on solutions to improve the community.	0.76 (0.18)	0.77 (0.13)	0.15			
14. My community looks at its successes and failures to learn from the past.	0.73 (0.19)	0.77 (0.13)	**0.00**			
15. My community develops skills and finds resources to solve its problems and reach its goals.	0.74 (0.19)	0.76 (0.12)	**0.00**			
16. My community has priorities and sets goals for the future.	0.73 (0.19)	0.77 (0.12)	**0.00**			

(Continued)

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TABLE 1 (Continued)

Community resilience (domain and perception)	Malaysia	Indonesia	*p* value	Malaysia	Indonesia	*p* value
Statements	Mean (SD)	Mean (SD)		Mean (SD)	Mean (SD)	
Domain 4: Disaster Management						
17. My community tries to prevent disasters.	0.74 (0.19)	0.75 (0.14)	0.11	0.73 (0.17)	0.74 (0.12)	0.20
18. My community actively prepares for future disasters.	0.72 (0.19)	0.73 (0.14)	0.49			
19. My community can provide emergency services during a disaster.	0.74 (0.18)	0.74 (0.14)	0.41			
20. My community has services and programs to help people after a disaster	0.73 (0.19)	0.74 (0.14)	0.15			
Domain 5: Information and Communication						
21. My community keeps people informed (for example, via television, radio, newspaper, internet, phone, and neighbors) about issues that are relevant to them.	0.75 (0.21)	0.73 (0.15)	**0.01**	0.75 (0.18)	0.72 (0.13)	**0.00***
22. If a disaster occurs, my community provides information about what to do.	0.76 (0.19)	0.74 (0.14)	**0.04**			
23. I get information/communication through my community to help with my home and work life.	0.75 (0.19)	0.73 (0.15)	**0.01**			
24. People in my community trust public officials.	0.75 (0.19)	0.69 (0.16)	**0.00**			

The meaning of the bold values provided in table are the statistically significant values because its lower than 0.05.

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in this application include 24 core community resilience elements to address five interconnected CART areas that reflect and contribute to community resilience. The following topics are covered in the current online CART tool manual that are (1) Connection and compassion assessed using questions about participation, shared values, support and compassion, justice, hope, and community diversity. (2) resources assessed using questions regarding the community's natural, physical, human, social, and financial resources. (3) Transformative potential which is derived from the community's capacity to articulate the collective experience, gather and evaluate relevant data, evaluate community performance, and build capacity; (4) disaster management, which taking into account activities for community prevention and mitigation, preparation, response, and recovery and the last (5) communication and information which assessed the sources of information and how communication conducted in the community during a disaster.

2.3. Data analysis

Participants were required to respond to each survey item on a scale of 1 to 6, ranging from "strongly disagree" to "strongly agree." Average scores were calculated for each of the 24 individual core elements, each of the 5 CART domains, and the overall community resilience score. Regression models were used to assess covariates and associations with each domain score, overall community resilience score, community resilience strength, and community resilience challenge. Age, gender, marital status, employment status, experience of emergency/crisis while living in the community, and involvement were included as covariates. A stepwise procedure was used to select important covariates. Both descriptive and inferential statistics will be used to analyze data. Statistical analyses will be performed using Statistical Package for Social Sciences (SPSS) statistical software version 26.0. An Independent t-test will be performed, and a value of $p < 0.05$ will be considered statistically significant.

Data integrity will be maintained as questionnaires have been validated and tested for reliability before data collection. Participants provide valid phone numbers during the participation to ensure valid responses. The principal investigator will control Google form responses and be disabled for resubmission to prevent multiple responses from the same participant. Data collected will be stored carefully in Excel and is only accessible to the instigators conducting the study. Data encryption will be done to protect data confidentiality.

3. Results

All answers from all domains were converted to the top category that could be chosen so that all questions had a maximum value of 1 and a minimum of 0. Distributional assumption scoring was based on the mean, median, standard deviation, skewness, and kurtosis difference. The t-test was used because the conclusion of all questions in every domain fulfills the normal distributional assumption value.

Domains 3 (Transformative Potential) and 5 (Informative and Communication) were the domains of resilience community domains between Indonesia and Malaysia that are significantly different, with a value of $p < 0.05$. The mean value of Domain 3 was higher in Indonesia, but Domain 5 had a higher mean value in Malaysia.

In Domain 1 (Connection and Caring), the mean values of questions 1 to 3 differed significantly between Indonesia and Malaysia. In contrast, the mean values of questions 1 (People in my community feel like they belong to the community) and 2 (People in my neighborhood are committed to the community's well-being) in Malaysia were higher than in Indonesia. Still, the opposite occurred in question 3 (People in my community have hope about the future), where the mean value of the question in Indonesia was higher than that in Malaysia.

The mean values of questions 2 (My community has the resources it needs to take care of community problems) and 3 (My community has influential leaders) in Domain 2 (Resources) were statistically different between Indonesia and Malaysia; it was higher in Indonesia. Almost all questions in Domain 3 (Transformative Potential) had significantly different mean scores between the two countries. The median value of many questions in Indonesia was higher than that in Malaysia.

The opposite occurred in questions from Domain 4 (Disaster Management), where all questions had almost the same mean value between the two countries. However, there was no statistically significant difference in the mean value. All questions in Domain 5 (Information and Communication) had different mean values between the two countries, where Malaysia's mean value was greater than that of Indonesia.

The difference in the mean values was in Domain 1 (Connection and Caring), 3 (Transformative Potential), and 5 (Information and Communication). Malaysia had a higher mean value than Indonesia in Domain 1 (Connection and Caring) and 5 (Information and Communication), whereas Indonesia had a higher mean value in Domain 3 (Transformative Potential). There was no significant difference in the mean value in Domain 2 (Resources) and 4 (Disaster Management).

4. Discussion

Resilience is the ability to bounce back or cope successfully with stress, which can occur at individual and community levels. Community resilience is a dynamic and multifaceted phenomenon determining a community's ability to withstand a disaster's impact and functioning in its aftermath. The institutional response to any disaster, natural or artificial, begins at the local level, and it is here that preparation efforts are perhaps the most critical. Under the all-hazards approach, the focus is on building, exercising, and sustaining public health capabilities that will be important for an effective response to most, if not all, public health emergencies. In practice, public health preparedness approaches often include all-hazards and scenario-based planning (9).

Domains 3 (Transformative Potential) and 5 (Informative and Communication) were the perception domains of resilience community domains between Indonesia and Malaysia that differed significantly. The mean value of Domain 3 was higher in Indonesia, but Domain 5 had a higher mean value in Malaysia. Almost all questions in Domain 3 had significantly different mean scores between the two countries. The mean value of many questions in Indonesia was higher than that in Malaysia. In this study, Domain 3 (transformative potential) consisted of statements that communities work with organizations and institutions outside the community to get things

done. For example, the community communicates with leaders who can contribute to community improvement and collaborate on community improvement solutions. Additionally, the community sees successes and failures, learns from the past, develops skills, finds resources to solve problems and achieve goals, prioritizes, and sets goals for the future.

The most appropriate public health intervention in the wake of mass trauma is guided by the principles of psychological first aid, including ensuring access to safe housing and food and assisting people in reconnecting with family members and friends (16).

Given that *Gotong Royong* is an enduring cultural value in Indonesia, it is not a recent idea to refer to as Indonesia's national identity. In addition, it has been suggested that *Gotong Royong* was profoundly ingrained in Indonesian society as a heritage of Indonesian ancestors and an intangible asset. People are urged to be helpful to one another in *Gotong Royong* so that everyone can maximize their capacity for personal growth and social interaction. From this viewpoint, *Gotong Royong's* labor energy becomes essential for social solidarity, humanism, and unity (17).

Four ideas make up *Gotong Royong's* cultural values: (1) people are a part of the community; (2) people depend in all facets on their fellow humans; (3) people must constantly uphold good relations with one another; and (4) people must be fair to one another (18). Furthermore, as a cultural value, *Gotong Royong* emphasizes working hard together by showing care toward each other to support collectivism, collaboration, and cooperation (19). Given that most Indonesians traditionally value their relationships with their neighbors and families, *Gotong Royong* as a cultural value cannot be separated from the activities of Indonesians' daily lives (20).

Active participation can be in the form of support in material, financial, physical, mental, or spiritual skills, constructive thoughts or advice, or only praying to God (21, 22). Being aware of belonging to a powerful group leads to active participation in the *Gotong Royong* process (23). *Gotong Royong*, once put into practice, can serve as social capital for the neighborhood as it engages in the socioeconomic activity. Together, it will bring about favorable changes in people's life (24).

There are elements of reciprocity, giving, and receiving in *Gotong Royong*. Everyone desires to assist others genuinely without seeking recognition or material gain. Consequently, this practice has the potential to significantly impact society, particularly in terms of commitment and social engagement (25). Completing tasks involving shared interests suggests that *Gotong Royong* is active (26). The constants in *Gotong Royong* are family, harmony, and assistance. The value of helping one another still exists in isolated rural areas. If there is a change in the value, it is slower than it would be in a village close to the city (27).

The internet and social media penetration has helped Malaysia stay abreast with other developed countries and impacted its civil society. Additionally, an increasing number of Malaysians reveal portions of their lives online, if not the whole. Individual media outlets and social networking platforms allow Malaysians to conduct transactions, gather information, and create and share ideas, information, and life stories (28). Without giving up, some local businesses began to take inventive actions by running extra promos, utilizing internet delivery, selling on Livestream, and running numerous other social media marketing (29). Furthermore, in March 2021, Malaysia had more than 27 million Facebook users, representing more than 80% of the country's total population. This shows a growing need for mobile community networks, particularly during pandemics and lockdowns. Malaysians, especially those in the 16–29 age group, spend 9.17 h daily online and 3.01 h on social media (30).

5. Conclusion

The study findings revealed differences in community resilience between Malaysia and Indonesia. Malaysia appeared to have a more advanced level regarding the community's connection and caring as well as effective information delivery and communication compared to Indonesia. Although there were minor differences in the mean value from the Transformative Potential aspect of the people, Indonesia score higher than Malaysia. In terms of community resources, both countries exhibit similar level. These findings showed that each country could learn and implement lessons to enhance each other community resilience. A strong community resilience positively impacts the overall well-being of the community. Collaborative effort between the two countries could unlock numerous possibilities to highlight the ability to recover after a catastrophe, such as the COVID-19 pandemic, and achieve Sustainable Development Goals (SDGs).

6. Recommendation and future research

We recommend further research on the need to develop a community resilience model that incorporates specific cultural and local requirements to validate the findings presented in this paper, especially to promote communities' preparedness for a disaster with a leader's involvement.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

SI and RM: conceptualization. RM: methodology. TR: formal analysis. RJ: validation. TR and RJ: funding acquisition. HC: supervision. SI: writing –original draft. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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COVID-19 crisis management of German ICU clinicians in leadership – a metaphor analysis

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The COVID-19 pandemic coincided with an already long-standing crisis in health systems around the world characterized by economic pressure and increasing staff shortage. "Crisis" became a global metaphor to convey collective experiences of the COVID-19 threat. Little is known on how crisis metaphors influence thought and speech on crisis management and the challenging staff situation of intensive care unit (ICU) clinicians in leadership positions and how they act. Therefore, we were interested in (1) which metaphorical concepts ICU clinicians in leadership use to express experiences and strategies in dealing with coinciding crises, (2) how these change over time, and (3) how metaphors in speech reveal self-images of crisis management. We conducted a systematic metaphor analysis focusing on data from three participants of a qualitative interview study with twenty-four healthcare professionals in ICUs in Germany. The participants were interviewed at two time points between April 2020 and March 2021. We identified and reconstructed metaphorical concepts of three interviewees (ICU clinicians in leadership) with regard to the pandemic management, and developed a typology based on the dimensions of mood, modus operandi, location, and scope. The typology consists of eight self-images (protagonists) for the crisis management of ICU clinicians in leadership, such as the figure of the soldier ("to unite everyone behind this flag"), the distributor ("sometimes it is a crazy patchwork [*wahnsinniges Gestückel*]") or the critic ("we are the fool for everything"). They embody different qualities of a leader and refer to intra- and inter-role conflicts within multiple crisis conditions. Metaphor analysis reveals different self-images of ICU leadership clinicians in relation to crisis management. This illustrates that thinking and perceptions of crisis management may strongly differ between and within leaders and may change over the course of crises. Our findings highlight the need both to improve knowledge on challenges associated with leadership in crises and preparedness, and to support clinicians in their leadership by recognizing and addressing differences and changes in leaders' self-image.

KEYWORDS

healthcare professionals, COVID-19 pandemic, preparedness, hospital, qualitative study, leadership, crises, staff shortage

1. Introduction

The COVID-19 pandemic coincided with existing long-term and ongoing crises in health systems around the world: economic pressure and increasing staff shortage had already weakened hospitals years before (1, 2). Thus, in the beginning, the COVID-19 crisis manifested itself in the shortage of critical resources in the intensive care units (ICUs) and exacerbated challenges for healthcare professionals (HCPs) (3). The first COVID-19 wave in Germany occurred in weeks 10–20 of 2020 with a total of 175,013 registered cases throughout the country. Cases were more frequent among older adults and severe courses were observed. The second German COVID-19 wave (week 40 of 2020 to week 8 of 2021) peaked at the end of 2020, with 2,158,013 cases reported and considerably more severe courses in all age groups (4).

Generally, "crisis" describes a situation in which major challenges of adaptation, coordination, and possibly modifications and protection need to be solved in a short time (5). Historically, different disciplines understand crisis as constructed in narratives and, since the 20th century, as constitutive for meanings of economic, political, and social reality (6). Consequently, the concept of crisis also applies to the global spreading of SARS-CoV-2.

In contrast to the long-lasting crisis in health systems, in this article, we define the pandemic as a (societal) crisis by addressing its cyclical structure. Regarding the different waves of infection, we do not identify it as a long-term and lasting state, but consider within this phenomenon partially sequential (seasonal) crises ("crises within crisis") (7). We define a "crisis cycle" experience characterized by repetitive and changing events. This perspective allows us to address the temporality and dynamics of crisis structures as well as the subjective level of experiencing coinciding crises.

In framing the pandemic as a global emergency and "the outbreak of war" (8), politics, media, and the public made references to military scenarios and natural catastrophes to express collectively shared experiences of anxiety about the global virus spreading (9–13).

Especially at the beginning of the pandemic, we saw unimaginable situations in ICUs in some countries. In the media, scenarios of overcrowded hospitals spread around the world: temporary camps with care equipment to treat a mass of critically ill patients in hospitals, isolated dying SARS-CoV-2 infected persons, and health professionals gasping for breath, due to working with limited resources under ongoing pressure (14).

While the beginning of the COVID-19 crisis in hospitals was characterized mostly by limited protective equipment and limited health care capacities for an unusual increase in the number of critically ill patients, a concrete image of the fundamental crisis in health care systems was missing. Aspects of human resources and working conditions in hospitals became more visible under pandemic conditions in the public (15), especially at the beginning of the pandemic when people applauded on balconies to express their appreciation and sympathy towards HCPs (16). As time passed, however, their visibility diminished and precarious structures in healthcare persist even now.

Politics and the media used a variety of metaphorical concepts to express and order the complex experience of the pandemic that also became part of people's everyday language (12, 17, 18). The pandemic was portrayed as a health, economic, social, and political crisis, to influence individual behavior and to take preventive action against the pandemic, and in later phases to support the global promotion of vaccination (19).

According to a basic understanding of Aristotle, "a metaphor consists in giving the thing a name that belongs to something else; the transference being either from genus to species (…), or on the grounds of analogy (…). One will accordingly describe evening as the 'old age of the day' (…) and old age as the 'evening' or 'sunset of life'" (20). Following this, metaphors are figurative replacements on a linguistic level. Aristotle distinguishes between a literally realistic meaning ("age") and a poetically figurative description ("sunset of life").

From a cognitive linguistic perspective, Lakoff and Johnson take a broader stance and define the essence of a metaphor in understanding and experiencing a certain subject in terms of another (21). The main function of a metaphor is the understanding of abstract, emotional, or other experiences. Therefore, it is about a pattern of understanding and experiencing that is transferred to another field. Metaphors help us make sense of our experiences, especially if they are emotional and complex. A metaphor can be the best approach to organize aspects of individual experience in a coherent way (21). Different metaphors can structure different aspects of a single experience or phenomenon.

In the context of what has been described as a "collapsing system" in many countries (22, 23), research has highlighted experiences of changing working conditions, psychological burden, and well-being from the perspective of frontline workers caring for critically ill COVID-19 patients (24–27). While the study of the metaphors of the pandemic (9, 10, 18, 28, 29) as well as clinicians in general (30–35) in the pandemic or on policy-makers in leadership (36) is well developed, research on the use of linguistic images and crises management (CM) by clinicians in leadership positions during the pandemic experience is scant (37). However, participants in our previous study on pandemic experiences of HCPs in German ICUs (38) emphasized the need to explore leadership, too.

This study aims to help filling this gap by exploring the metaphorical expressions of CM in ICU clinicians' experiences in the co-incidence of the COVID-19 pandemic and staff shortage in health systems. By focusing on metaphors, we explore how words/word groups are transferred from their original context (source area) into a different one (target area) (39). Doing so allows us to reconstruct and summarize subjective and group-specific constructions of CM and their comprehensive description. The leading questions of our analysis were (1) which metaphorical concepts ICU clinicians in leadership roles use to express experiences and strategies in dealing with coinciding crises, (2) how these change over time, and (3) how metaphors in speech reveal self-images of CM.

2. Materials and methods

At the beginning of the COVID-19 pandemic, we initiated an exploratory interview study focusing on experience and practices of HCPs in German ICUs during the pandemic. We used a grounded theory approach. Between the end of March 2020 and March 2021 we conducted individual interviews with 39 ICU HCPs,

namely 19 nurses, 17 clinicians (nine clinicians with leadership position), and three medical students; 24 participants were interviewed twice. The participants were recruited through e-mail, telephone, professional networks, flyers, and personal contacts. For each interview, a protocol was prepared which reported important aspects. The interviews proceeded without interruptions or complications. In addition, the research group prepared for possible complications (e.g., emotional reactions of the interviewees), for example, by providing contact options for counseling services if necessary. A detailed description on the methodology can be found in Hörold et al. (38).

In our study, we described negotiations of social practice and interaction at the beginning of the COVID-19 pandemic in Germany and found a complex field of ambivalences between habits and the new normality of a "daily routine of preparation" (38). We repeatedly observed the challenging situation faced by the ICU leaders and metaphorical speaking of our participants to express experiences with CM. Therefore, we initiated analyzing metaphors in the interviews and performed a systematic metaphor analysis (40, 41) on interviews with ICU clinicians from the original study sample (38). Since we interviewed our study participants twice, we assumed to observe the progression of CM. Based on our empirical findings – the metaphorical concepts and their common characteristics – we developed a typology of protagonists on CM from the perspective of ICU clinicians in leadership.

2.1. Three German ICU clinicians

The three interviewees we focused on with metaphor analysis were clinicians in leadership positions working in ICUs, which we briefly portray below. We chose the three interviewees based on common characteristics. First, the clinicians were in a leadership position in hospitals of centralized care, had similar work experience, and were involved in the same way in structures and processes of working in the ICU during the crisis' phases. Second, the interviews were conducted at comparable time points (baseline interview May 2020 and the follow-up November/December 2020). Third, the three interviewees were of similar age (midlife) and ethnic background (white individuals). We do not include gender identity and use pseudonyms for our participants (cases 1–3).

Case 1 (C1) is an ICU senior clinician. C1 had more than 10 years of clinical work experience and a similar amount of experience in intensive care. C1 worked in a hospital in a COVID-19 hotspot and considered this time to be incredibly exhausting.

A further participant we interviewed was a head clinician defined as case 2 (C2). C2 had more than 10 years of work experience as a physician. Their perspective on working in the hospital changed from baseline to follow-up interview. While C2 was highly motivated in the first interview, C2 expressed being more vulnerable in the second interview.

Case 3 is the third participant in our study. The senior ICU clinician had more than 20 years of work experience at the time of the first interview. In the baseline as well as the follow-up interview, C3 was critical of the working conditions and the political CM. C3 described their own experiences in managing the first phase as a state between disbelief and anger.

2.2. Metaphor analysis: background and practice

We understand metaphors of ICU clinicians as cores of narratives. While narratives are used to deal with divergence in everyday experience, metaphors additionally mediate the meaning of them (42). Metaphors are expressions of strategic complexity reduction with the aim of (cognitively) ordering circumstances in crisis cycles, which are embedded in narratives. This ordering activity is a prerequisite to action. Martin and Lueckenhausen (43) described how people may not just use a single metaphor but several different metaphors to communicate their emotions or thoughts. Therefore, linguistic images represent complex cognitive processes in simple patterns and thus offer models of orientation (41).

Schmitt proposes a systematic approach to the analysis of metaphors that involves successive steps (44). Preparing the first step of metaphor analysis, we distinguished between three types of metaphors: (1) occupation-related metaphors (as an expression of professional practice in a healthcare), (2) metaphors of crisis in the healthcare system, and (3) pandemic-related metaphors. Prevailing occupational metaphors typical for the profession were not the focus of our analysis. We concentrated on newly occurring metaphors but were aware that these may have been influenced by prevailing metaphors. In the first analytical step, we defined CM as the target area (40, 41). We examined both sets of interview data (baseline and follow-up), segmented the text into metaphoric elements, and listed all the metaphors from each case. Based on this preliminary work, we selected the metaphors according to the target area. After that, we thematically sorted the metaphors through an inter- and cross-case comparison. The aim was to gather and order similar source areas of metaphors across the different interviews (39–41) and to build metaphorical concepts. Schmitt also notes that metaphors "(…) do not occur isolated in texts, but build metaphorical concepts being reconstructed" (44). We generated several metaphorical concepts from the three cases. Thus, at a certain point, we noticed a saturation of metaphorical concepts. Schmitt describes this analytical step as the "actual interpretative and reconstructive step" (45). We conceptualized a typology of eight CM protagonists (Table 1). The protagonists embody clinicians' metaphorical speech representing their tasks in leadership during the pandemic cycles. Each protagonist has a specific inventory of CM strategies. All eight types integrate characteristics of the interviewees, which is why single participants and protagonists are not congruent. Rather, the types are composed of common and different characteristics of the single cases.

3. Results

Our typology defines characteristics of CM protagonists on four dimensions (Table 2). The dimension "mood" describes the emotional state while the dimension "modus operandi" refers to the specific orientation of the protagonists' CM actions and interactions with other persons. The third dimension "location" describes the operating space of our protagonists, and the fourth dimension "scope" integrates temporality of perspectives taken by the protagonists (retrospective, present/in-process, or prospective) and enables describing changes through the cyclical structure of the COVID-19 crisis.

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TABLE 1 Main source areas and protagonists.

Interview quotes	Source area	Protagonists
"we say 'red button'. You push it and the person is exploding"	Action movie	Adventurer
"so-called (…) teams"	Action movie	
"we called (them) COVID-Angels"	Saviors	
"keep swimming, the land is coming"	Enduring an arduous journey	
"be run over"	Action movie	
"fear from perspective of a leader"	Sports team coach	
"we are in the second marathon this year"	Sporting event	
"very very exhausting"	Sporting activity	
"after 3 weeks there is still no coast in sight"	Seafaring	
"declaration of the pandemic"	Public political statement, begin of the battle	Soldier
"to unite everyone behind this flag"	Medieval war scenario	
"And now it's more like they have twelve different flags. And everyone is hanging out there on their own."	Medieval war scenario	
"they weaken us, too"	Physical violence	
"under constant fire for months"	War battle	
"my life was over"	Death and dying	Survivor
"absolutely madness"	Anarchy, chaos	
"first six weeks were the hell"	Suffering	
"a monstrous task"	Terrifying, danger	
"every pandemic passes by. That's how it was in history"	Storytelling, fairy tale	
"this will not be the end of the world now"	Storytelling, fairy tale	
"moving a little closer together again"	Cohesion, safety	
"we have already been through hell and back"	Journey, adventure	
"unlock material costs"	Open a lock	Distributor
"sometimes it is a crazy patchwork"	Processing leftovers	
"to shop (equipment) at the same time, to rebuild it"	Shopping, constructing	
"filling the gaps"	Pouring liquids into gaps	
"I also ordered some additional things that you need"	Shopping	
"the extreme bottlenecks"	Merchandise	
"people cohorted"	Group selection	
"have more people in the pot"	Cooking, preparing	
"selected the physicians who seemed to be the most suitable"	Cooking, preparing	
"every day you squeeze out another one (bed) somewhere"	Pressing out liquid	
"incredible pressure on the system"	Engineering	
"walls are torn down"	Crafting	Craftsman
"to pull up"	Building	
"built many PAX cabinets (IKEA furniture)"	Building	
"being a master at it"	Craft guild	
"we crafted something ourselves"	Building	
"helping clean hand"	Craft guild	

(Continued)

The protagonists show how clinicians take responsibility for CM in ICUs. They (inter)act in different ways. The order we present the types in this section mirrors their chronological development during the first pandemic year. In the course of data analysis, the majority of the protagonists appeared to us as either male or female. We found that the respondents already gendered the metaphorical repertoire of the protagonists. As a result, six out of eight protagonists are portrayed as gendered.

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TABLE 1 (Continued)

Interview quotes	Source area	Protagonists
"got to know a new disease"	Learning	Trainee
"during the dark times, in the beginning"	Storytelling, fairy tale	
"getting up and running"	Sports	
"countries that were already badly affected"	Attack	
"brainpower is needed"	Learning, scientific progress	
"tried to look at ways that had gone well"	Learning, experiences	
"the patients were really extremely bad"	Danger, threat	
"rocking along with you"	Companionship	
"that everyone can simply fall back on it"	Danger, accident	
"a journeyman's piece"	Completion of an apprenticeship	
"it's all in the drawer"	Packed, secured, hideaway	
"we can activate all this within less than a day"	Operating a system	
"The standard 2 days ago was so old that it (he) has already grown a beard"	Old man, fairy tale	
"I am calm but I had to learn that"	Caring	Parents
"COVID-19-Huddle"	Cheering each other on at a sporting event	
"Let us go and we can do it"	Cohesion	
"they are all doing great," "unbelievable performance"	Praising children	
"I would not like to put them through that right now either"	Caring	
"in the spring we were the heroes, now we are the bogeymen"	Storytelling, fairy tale	
"And now, Corona, who wants to do it?"	Task attribution to a person	Critic
"the profession is unattractive"	Description of a person	
"we are the fool for everything"	Devaluation	

3.1. The adventurer

We found the adventurer protagonist primarily in the baseline interviews. What is remarkable about this protagonist is his enthusiastic mood and motivation in finding CM strategies for the unexpected situation in the ICU, for which he assumes responsibility. By actively searching for an image of the future ("(…) we had no idea what was coming" – C1, 1), he pursues experiencing adventures inspired by action movies (modus operandi). With innovative ideas ("That's why I invented (…) so-called (…) teams" – C2, 1) and energy to "consistently" combat the pandemic, the adventurer aims to shape his workplace, has effective self-management skills, and restructures processes in teamwork in order to improve them ("we also established something we called COVID-Angels" – C2, 1). He regards CM as a sporting event ("keep swimming, the land is coming" – C2, 2) and he performs the role as a coach ("leader") who trains his team under time pressure ("breakneck speed" [*Schweinsverlauf*] – C1, 1). He is afraid of being defeated: ("But that was my biggest fear personally as a leader now that we would really be run over" – C2, 1).

The comparison of the baseline and follow-up interviews reveals a change in his prospective orientation (scope) as well as his mood from enthusiastic to pessimistic and exhausted, reflecting increasing routine and persistent workload. "We are now in the second marathon this year. It is very, very exhausting" (C1, 2). We can locate the adventurer in a sporting competition scenario, but he can also be the protagonist in an adventure picture in which he sets out on a journey and swims through a raging river in search of a shore. "How long shall I say, keep swimming, the land is coming. Keep swimming and it does not matter. Do they understand when they are practically breaststroke and paddle for three weeks and it always says the coast is coming soon. And after three weeks there is still no coast in sight" (*sic*) (C2, 2).

3.2. The soldier

The soldier is a protagonist who consistently embodies the CM of clinicians during the pandemic. He can be characterized as being brave and resolute (mood). However, the pandemic changes him during his (military) mission on the ICU.

He associates the "declaration of a pandemic" (C3, 1) with the declaration of a war. This figurative analogy symbolizes a life-changing experience in society from the clinicians' perspective.

For the soldier, CM means going to war to fight for a higher idealistic goal. He experiences his work surrounding as a battlefield scenario in which he orchestrates the staff and guides them through practicing various tactical skills to attack and defend. In preparing for the pandemic, the soldier focuses on building up a team that acts cohesively and effectively "(…) to unite everyone behind this flag, which fortunately also worked out great" (C2, 1). Based on the metaphorical concepts, we perceived a modification of his orientation: in the next phase of the COVID-19 pandemic, he changes his CM strategies from focusing on the team to an individual perspective. This

TABLE 2 Typology characteristics of CM protagonists.

Type	Mood	Modus operandi	Location	Scope
Adventurer	Enthusiastic	Experiencing events	Journey	Prospective
Trainee	Curious	Learning	School	Prospective
Craftsman	Eager	Crafting, building	Manufactory	Present/in process
Soldier	Resolute	Fighting	Battlefield	Present/in process
Survivor	Resistant	Bearing, escaping	Safety place	Retrospective
Distributor	Rational	Planning, allocating	Headquarter	Prospective
Parent	Prudent	Caring, protecting	Home	Prospective
Critic	Cynical	Reflecting, evaluating	Podium	Retrospective

is a strategy for him and his comrades-in-arms to deal with the situation. "And now it's more like they have twelve different flags. And everyone is hanging out there on their own" (C2, 2).

While at the beginning of the pandemic he feels prepared (among other things by "shutting down regular operations" – C3, 1), in the second phase he experiences less systematic support from decision-makers ("That means they are weakening us, too" – C3, 2). He perceives that he and his comrades are less well equipped and more and more incapable. Possibly this is the reason to focus on himself getting through. The soldier reveals that the work situation ("under constant fire for month" – C2, 2) in particular caused a decreasing team spirit and morale.

The metaphors in the follow-up interviews suggest a persistence of "firing" and show that the soldier and his comrades are permanently in defending action. He has no clear reference to the future; the scope of his actions is embedded in the current situation. He tries to manage it as best as possible. As a fighter, he is defensive and works hard to overcome the war.

3.3. The survivor

The survivor is a protagonist who only emerges in the follow-up interviews. He is currently in a safe place. CM is reconstructed negatively, in metaphors of strength and effort, but also marked by an underlying anxiety ("That is, from the ninth of March, my life was over for the time to come." – C2, 1). The survivor can be characterized as tough and resistant (mood), even though the pandemic took his strength. "I phoned through three batteries from the phone. That was absolute madness [*Wahnsinn*]," "I cannot describe it in any other way, (…) the first six weeks were hell" (C1, 1). We see the survivor as a protagonist who emerges from dealing with impositions. The metaphorical repertoire of this protagonist consists of an iconography of the inconceivable, expressed in images of the monstrous and evil. For him, CM means to overcome "a monstrous task" (C1, 1). The survivor shows a high level of confidence in CM to successfully deal with the crisis together ("moving a little closer together again" – C3, 2). At the same time, he is proud of personal and joint achievements ("After all, we have already been through hell and back." – C1, 2). His modus operandi is to live on. From this, he often feels powerless and yet prescribes a positive way of thinking, e.g., by repeating affirmations ("Every pandemic passes, so I'm a very positive thinker. Every pandemic passes. That's how it was in history." – C1, 2) or by telling a story of comforting endings ("this will not be the end of the world now, (…)" – C3, 2).

3.4. The distributor

We found the protagonist of the distributor to be a consistent embodiment of the CM of clinicians during the pandemic and the economic conditions in hospitals. He can be characterized as being engaged and creative, but also rational. He plans and allocates commodities/resources ("unlocks material costs", "normal patients moved out"- C3,2). He regards CM as a puzzle ("sometimes it is a crazy patchwork [*wahnsinniges Gestückel*]" – C3, 2) and considers his role as "filling the gaps" (C3, 2).

The distributor struggles with having equipment, beds, and human resources available, or not. Since he is prospectively oriented ("scope"), it is important for him to receive "very early and timely this stuff" (C1, 1). "Frankly speaking [*auf Deutsch gesagt*], that saved our asses, and then I also ordered some additional things that you need." (C1, 1). In the preparation phase, "the extreme bottlenecks [*Engpässe*] in basic deliveries" were very stressful because "the quality decreased significantly as the price increased" (C1, 1), for example in personal protective equipment. "At the moment, we have these filter bags [*Filtertüten*] that you put on there" (C1, 1). The distributor was responsible for the allocation and stocking of the materials – "we had to let people work with it (…)" (C3, 1). Another important point is the acquisition and deployment of (new) employees. He manages the staffing of the units and regulates absence rates. ("(we) have more people in the pot, so to say." – C3, 2). The distributor uses various possibilities to recruit staff for the ICU, e.g., by offering "experience tours"(C2, 1). He organized patient care ("respond with a lead-in system" – C2, 1) and at the same time "(…) selected the physicians who seemed to be the most suitable (…)" (C1, 1). In the course of the pandemic distribution got more arduous ("In order to cohort the people, a ward block was identified and adapted as a pure corona house" – C1, 1; "every day you squeeze out another one (bed) somewhere" – C3, 2). We have three scenarios for the protagonist "distributor": first, we can locate him in the headquarters of an industrial company, a location where he can oversee the entire situation. Secondly, he can also sit in front of a puzzle board, or be a cutter in a tailor's shop. The metaphorical repertoire shows him as a person who tries to be as best as possible in his leadership role with increasing burden at the same time ("incredible pressure on the system" – C3, 2).

3.5. The craftsman

The protagonist of the distributor is a close relative of the craftsman. He symbolizes the readiness to contribute to CM with manual skills. By emphasizing building and crafting, he expresses the

urgency and the willingness to act especially at the beginning of the COVID-19 pandemic. In this phase of crisis cycle, "walls are torn down" to "pull up" new ICUs (C1, 1). His mood is eager and pleasant and he is located in a manufactory.

The craftsman applies his knowledge of building modular furniture or elements and uses irony to talk about his professional work as a clinician: "I have built many PAX cabinets [*IKEA furniture*] in my life, I'm a master at it, I can do better than pneumology" (C2, 1). He identifies himself with practical activities that are carried out manually ("Finally, we crafted something ourselves" – C1, 1). Hands are presented in their functioning as creative tools of humans. They stand for empowerment to act. The image of a helping hand was adapted to a "helping clean hand" (C2, 1). It characterizes the craftsman's hygiene-compliant work in the hospital setting and represents a high-quality standard and a respectful treatment of patients. This protagonist obeys the traditions and virtues of his guild. He aims to manufacture a product that is useful in everyday life (e.g., furniture or architectural components). His modus operandi pursues the construction and reconstruction of high-functional elements. From this perspective, manual contribution is temporally limited (scope), as it is intended only to overcome a crisis in an unexpected scenario. Craftsmanship is not oriented towards technical progress, but it is used to process the resources that have been distributed in a high-quality way. In doing so, the craftsman is highly motivated and engaged.

3.6. The trainee

We found the protagonist of the trainee only in the baseline interviews. She is curious with a prospective modus operandi of learning ("We got to know a new disease" – C1, 1). She embodies acquiring knowledge under intense time pressure by gaining enlightenment "during the dark times, in the beginning, when none of us knew what COVID-19 was" (C2, 1). The protagonist "trainee" symbolizes the willingness to contribute to CM with new expertise and to learn during and from the pandemic. Metaphors of activity like "getting up and running" (C1, 1) express the fast pace of change and readiness to act, especially at the beginning of the pandemic.

In this crisis phase, "brainpower [*Gehirnschmalz*] is needed," and "teaching and training" to form strategies and new routines. That means she tried "to get as much information as possible from the countries that were already badly affected" (C2, 1) by watching many interviews from Bergamo in northern Italy. She "tried to look at ways that had gone well (C2, 1)" and screened research papers. Her mood is motivated, yet guided by concern, "especially since the patients were really extremely bad. And that is a point that we had to learn" (C1, 1).

The image of "rocking along with you" (C1, 1) characterizes the trainee (in leadership role). She wants to support and empower their employees – "that everyone can simply fall back on it and also know what is meant by it, also understand it" (C2, 1). Consequently, she associates learning with intellectual aspirations. The metaphors in the follow-up interviews describe CM as "a journeyman's piece [*ein Lehrstück*]" (C3, 2) as is required on completion of a professional education. It suggests that new routines are developed and professionalized ("It's all in the drawer [*Schublade*]"- C2, 2). That is perhaps also a difference. "We are much better prepared and have also learned that we can activate all this within less than a day" (C2, 2). From our point of view, the trainee is a lively and curious person who is in a school scenario. In this environment, she is confronted with information that quickly becomes outdated. "The standard two days ago was so old that it (he) has already grown a beard" (C1, 1). The metaphorical concept provides associations with a fairy tale scenario. Thus, at the end of a fairy tale, the reader is always entrusted with the message of a morale. In the crisis story of the pandemic, the trainee learned the lesson of effective preparation to take responsibility for her staff.

3.7. The parents

The parents are protagonists we found both in the baseline and in the follow-up interviews in a prudent mood. For parents, CM means caring and protecting each other; employees become their children ("already worried" – C3, 1/2). Parents evaluate the current conditions, and care on outcomes in the future (prospective scope) ("I do not sleep well" – C3, 2).

However, the pandemic changed the role of mothers/fathers. At the beginning, we observe parents who are concerned about health protection: "So now that I know, well, these are the best-protected employees, I am calm, but I had to learn that" (C1, 1). They reveal that it was important to build a sense of belonging to a community ("COVID-19-Huddle," "Let us go and we can do it" – C2, 1).

In the follow-up interviews, they are concerned about the workload. The employees "(…) (have to) do things now that we would not usually make them (to) do. And I would not like to put them through that right now either, but there's no other way and they are all doing great" (C3, 2). Parents feel responsible and helpless at the same time. They "put them (employees) in work situations where (the parents) know that they cannot do their job in the best possible way. (…) firstly, we overwork the employees, secondly, they go home and have the feeling 'I could not do my job optimally today'. Yes, and thirdly, they are always afraid of being infected" (C3, 2). Parents are proud of their children (employees) ("unbelievable performance" – C3, 2) and emphasize "to strengthen the team" (C3, 2). At the same time, they feel devalued by their fellow citizens, and perceive these reactions with skepticism and concern. "(…) in the spring we were the heroes, now we are the bogeymen for everything. So we are the bogeyman for everything, really" (C1, 2). We perceive parents in a conflicted life phase scenario. On the one hand, they intend to give their children the freedom to unfold freely, but on the other hand, they worry about them because of the evils of the world. In addition, they are disappointed that they receive little recognition for their achievements (care work) in society.

3.8. The critic

In the follow-up interviews, we found metaphors that emphasized the protagonist "critic" more explicitly. This person reflects on operating costs and hospital financing in the German health system. The critic is unisex. We used the singular they.

The critic introduces a meta-perspective on the system ("we are still relatively fine in Germany compared to other countries" – C3, 2) and on themselves as part of it ("Yes, welcome to this world" – C2, 2). They monitor and evaluate new policies regarding the COVID-19

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crisis with attention to the ongoing crisis in hospitals. The mood is "bitter" and cynical, the perspective is rather pessimistic and "worried" (C2, 2). They understand the pandemic as a huge, hard-to-solve task that coincides with an ongoing crisis in health systems ("And now, Corona, who wants to do it?" – C1, 2).

The viewpoint is detached from daily routines and enables taking up a transcendent position. They use critical voice as an evaluative tool to reflect on coinciding crises and thus compensate frustration. That is why another possible scenario of the critic is working as a staff council. As an advocate for patients and ICU staff, they shed light on the economic strategy of the healthcare system, while the work within is characterized as being physically challenging and brutal ("if we operate on a hip, we get much more money" – C2, 2). Besides a lack in equipment, they also critically mention the decreasing human resources in hospitals. They consider connections between workload and structural working conditions and the attractiveness of health professions ("The profession is unattractive. Weekends, nights, heavy workload" – C1, 2). In the leadership role, they oscillate between employees and hospital management. This leads to contradictory and ambivalent situations, because they refer to both positions. Therefore, "job" is personified as a not-appropriate romantic partner with whom a person spends a lot of time within their life. Similar to a dysfunctional relationship, the critic remains in the ambivalent role. He mediates between hospital management and staff.

The protagonist assesses current crisis conditions in hospitals, but does not have suitable suggestions for transformation, which is why their scope is limited. To make a comparison with the continuing situation ("we are the fool for everything" – C1, 2), they refer to events that lie in the past ("I mean, honestly, in 2008, the banks were propped up, too" – C3, 2). The scope is primarily retrospective or destructive, when imagining the future ("I do not think we are well prepared" – C3, 2). Their actions (reflecting, evaluating, and criticizing) depend on the system which is criticized. In case of a system change, the critic's mission will be fulfilled and this protagonist would disappear, at least until the next critic-worthy situation occurs.

4. Discussion

In our study we used metaphor analysis to explore images of CM within the metaphorical speech of ICU clinicians in leadership roles. We illustrated how metaphorical language helped clinicians in leadership to make sense of their experiences in coinciding and recurring crises. To contrast differences in the use of metaphors, we selected three interviewees from our original study (38). The metaphor analysis yielded a typology of eight self-images (protagonists) for the CM of ICU clinicians in leadership: the adventurer, the soldier, the survivor, the distributor, the craftsman, the trainee, the parents, and the critic. The protagonists are reconstructed personifications and embody different qualities of a leader; they refer to intra- and inter-role conflicts within multiple crisis conditions. The craftsman, for example, shows a constructive way of dealing with the current situation of coinciding crises – working with limited resources while maintaining day-to-day business. The way in which the protagonists emerge and disappear over time reveals changes in perspectives, orientations, actions, and emotions of the clinicians we interviewed. Some of the protagonists disappear after a pandemic crisis cycle at the beginning, while others are introduced as the pandemic routine of clinical practice is established. For example, an initially enthusiastic adventurer turns into a rather disillusioned survivor and, with increasing expertise, a trainee becomes a soldier or even a survivor over time. Thus, some of the protagonists are dependent on or related to each other. It is only with the experiences of the hardworking craftsman, the rational perspective of the distributor, or the viewpoint of the caring mother/father that the critic can undertake a reflection on the coinciding crises they experienced. The same applies, for example, to the distributor and the craftsman. The distributor plans and allocates resources, while the craftsman applies them to manufacture a product. Protagonists' internal changes do not necessarily lead to a new type as long as basic characteristics (modus operandi and scope) remain constant. However, mood and perception may change over time. For example, the more experiences the parent protagonists have on the ward, the more they are concerned about the children (staff). The modus operandi of care and support remains the same. As further examples, the adventurer shows less enthusiasm in the follow-up interview and the soldier gives up his team orientation in fighting and focuses more on himself. It is unclear whether our protagonists of CM will (re)appear in the future, especially considering the uncertain development of the crises. Possibly structures will be reorganized in the coming months and protagonists like the craftsman will appear again. Even the distributor will regain importance in case of a new pandemic crisis cycle. In contrast, we consider it unlikely that the adventurer and the soldier will reappear in this cycle. It is possible that they have run out of steam over the course of time.

We applied the metaphor analysis separately to the original study (38), and did not perform a method triangulation, but instead generated a new study with independent objectives. Empirically, we succeeded in exploring how the metaphorical language in three cases changed during the first year of the pandemic. The metaphorical repertoire in the data is likely influenced and contaminated with metaphors that were already established before the pandemic. The use of military metaphors has been observed in previous health crises, e.g., during influenza epidemics and the AIDS crisis (41, 46). Since the beginning of the COVID-19 pandemic, we have witnessed its recurrent use by political representatives and the media, especially on television (47). Military metaphors are also frequently used by both medical staff and patients. Thus, it is not surprising that we found the soldier as a protagonist of clinicians' crisis management (37, 48, 49). During the analysis, we had to consider the societal context. Throughout the pandemic, changes in the origin of metaphors (source areas) occurred, i.e., metaphorical speak of public discourses was/is as dynamic as the pandemic itself (50). However, our own viewpoints and associations changed as well, which impacted data interpretation. Local metaphorical concepts may have different meanings across individuals, groups, and cultures (51). Becoming aware of this was a fundamental condition for being able to identify metaphors in the data. It was also a challenge for us to translate metaphors adequately into English in their culturally specific semantic function. Our strategy for this article was to find equivalents in English and to show original expressions in square brackets. It would have been interesting to examine further heterogeneous examples beyond the German context.

With two exceptions, the protagonists are gendered. They embody professions or occupations that are traditionally ascribed as male or female in Western societies (craftsman, soldier, educator, and caregiver) (52, 53). Although we did not intend to underpin a binary gender perspective, we noticed that the metaphorical repertoire of these protagonists was already gendered by the interviewees. That is why the protagonists appeared masculine and feminine to us throughout the data analysis. Historically, health professions were gendered, and beliefs about gender came to be embedded in professional work. Thus, gender is still relevant in many ways. Studies document numerous challenges to women pursuing careers in male-dominated fields (54). We point out that attributing metaphorical concepts to masculine and feminine involves the risk of reproducing a gender binary bias, instead of understanding gender as socially constructed (41). We also portrayed two protagonists in the generic third person "they." Parents appear as a dyad of mother and father, while the protagonist critic appears as gender-fluid.

Our study was conducted in the context of the German healthcare system. Compared to other countries, there is a perceived need for reforms in terms of hospital structure and financing and, above all, an increasing shortage of nurses (55). Our findings provide insights into the pandemic working conditions of ICU clinicians in leadership positions, especially into their responsibilities and burdens (56, 57). However, they also reflect concepts and traits that are socio-culturally constructed, whether in relation to the German culture or to the medical setting in general. The trainee reflects a healthcare system in which training evidenced by certificates, diplomas, exams, and titles is seen as essential for ensuring quality of care. The distributor embodies a type of socialized medicine (related to the principle of solidarity (58), one of the key characteristics of German healthcare system). In particular, the protagonists "parents" and "critic" show their disappointment about the lack of social recognition of their achievements and the poor structural working conditions. The critic reflects a system under constant pressure, in which challenges, such as economic pressure (hospital financing), lack of digitalization, and resource shortages, put clinicians and hospital managers in conflict with current care needs and ethical duties (55, 59, 60). Literature on the burden of coping with the pandemic shows differences between professions (physicians and nurses). Durgun et al. (61) reflect on nurses' perceptions of the COVID-19 pandemic. The metaphors mentioned by nurses included, e.g., living organisms, emotion, danger, and death. Most expressions indicate hopelessness (61). Naamati-Schneider and Gabay (37) analyzed metaphors and their role in framing reality and shaping coping mechanisms among COVID-19 ward directors during the first wave of the pandemic in Israel. Effective coping was facilitated by war metaphors that communicated a sense of purpose and meaning at both the organizational and individual level (37). In contrast to our study, these two studies reveal only momentary observations. Our metaphor analysis shows transitions in experiencing crises in the first year of the pandemic by metaphorical speech. The typology embodies implicit emotions, norms, values, and attitudes related to CM and depicts changes in the mental state of ICU clinicians over a longer time. At the beginning of the pandemic, ICU clinicians had to be able to switch between different roles without the possibility to prepare for it. The exceptional situation increased the importance of leadership and resulted in new and parallel tasks, e.g., updating the state of knowledge on COVID-19 and taking into account policy regulations, in addition to being involved with patient care (62, 63). Moreover, it was impossible for senior clinicians to object to these tasks. Studies showed that inadequate working conditions, such as lack of supplies, equipment, or staff, lead to a decrease in motivation (64). However, the participants in our study were highly motivated for CM, especially at the beginning of the pandemic. We assume that the exceptional situation of the pandemic strengthened the cohesion in ICU teams. They developed the motivation to manage the situation together.

As the use of metaphors of CM changed during the first year of the pandemic, we encourage further research on how the pandemic and staff shortages, not only in ICUs, affect leadership self-image in the long-term. We showed that concepts and perceptions of CM might strongly differ between and within leaders as well as over time. This has implications for policy and practice, particularly for human resource management of hospitals and pandemic preparedness. In order to support clinicians in their role as leaders, it could be very important to consider their self-image and to acknowledge the differences and changes in self-images of leadership personnel in crisis situations as in general. This highlights the urgent need for policy and practice decision-makers to better understand the challenges associated with leadership in crisis and preparedness and to support clinicians in performing their leadership roles.

Data availability statement

The raw data supporting the conclusions of this article will be made available upon request by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Ethics committee at Otto von Guericke University Magdeburg, Faculty of Medicine (51/20) as well as University of Regensburg (20-1771-101). The participants provided their written informed consent to participate in this study.

Author contributions

JP: formal analysis, investigation, methodology, validation, visualization, writing/original draft, and writing/review and editing. MH: formal analysis, investigation, methodology, validation, visualization, writing/original draft, and writing/review and editing. SB: writing/review and editing. K-PD: project administration, data curation and writing/review and editing. IH: investigation and writing/review and editing. RS: methodology and writing/review and

editing. CA: conceptualisation, funding acquisition, project administration, supervision, and writing/review and editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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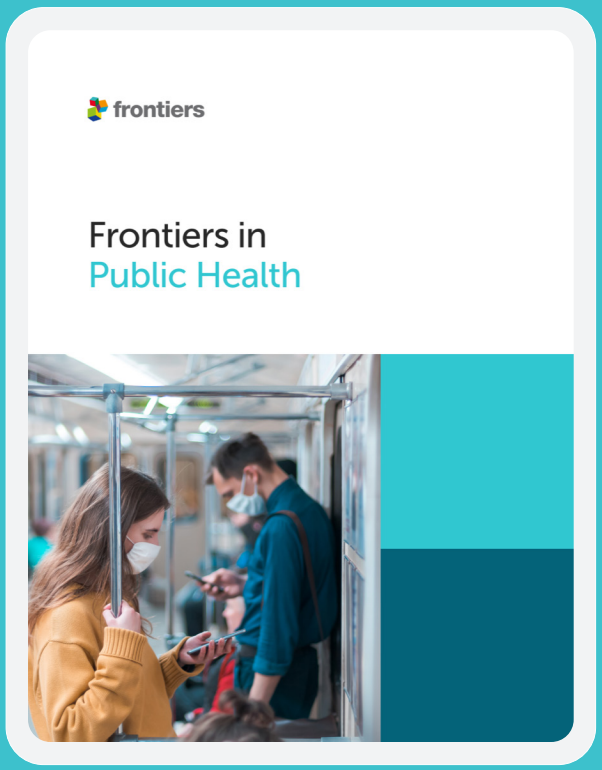

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