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Resilience of healthcare systems in natural disaster - A case study in Henan rainstorm

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Abstract: Resilience assurance of a healthcare system, including pre-disaster planning, emergency response and post-disaster recovery, plays an important role in saving lives and reducing severe injuries in sudden natural disasters. To clarify the effect and importance of healthcare system resilience in natural disasters, as well as the system resilience improvement paradigm, this study takes the Henan rainstorm in China, on 20 July 2021, as an example, analyzes the adverse impacts of sudden natural disasters on the healthcare system, and comprehensively presents the response situation of the system. Based on the case, this paper also presents the challenges the healthcare system faces, such as those in preparation, and emergency supplies to reserve capability. Strategies and recommendations to improve the resilience of the health system are then proposed. Finally, a resilience assurance framework for healthcare systems in a natural disaster is developed. This paper serves as a call and as a reminder that preventive measures and preparatory investment toward resilience is more than important for the entire healthcare system and well-being in consideration more extreme weather events in future under climate change.

Keywords: Healthcare systems, Resilience, Henan rainstorm, Natural disaster, Resilience Assurance.

1. Introduction

In recent decades, sudden natural disasters including earthquakes, floods, rainstorms, tsunamis, typhoons, wildfires, and other extreme weather events have occurred in almost every country. In the period 2000 to 2019(CRED and UNDRR 2020), there were 7,348 major recorded disaster events worldwide claiming 1.23 million lives, affecting 4.2 billion people. In 2021 (CRED 2022), a total of 432 catastrophic events were recorded worldwide, and floods dominated these events with 223 occurrences. These sudden natural disasters bring huge losses, endanger human health and lives, cause serious economic losses, and even affect social stability and sustainable development. In the face of all sudden natural disasters, a resilient healthcare system is highly needed, where the disaster resistance, the disaster relief and restoration capacity of healthcare system are the key factors to the efficient operation of the system.

Discussions about healthcare systems and resilience can be found in many literatures. For example, Turenne et al(2019) reviewed papers working on the concept of "healthcare systems resilience" from three dimensions of term, sense, referent. The capacity of hospitals surviving from disasters was generally discussed by words such as 'crisis management' in the past. Gradually, the emerging concept 'resilience' has been accepted to represent improving the effectiveness of managing crisis in preparedness, response, and recovery phases(Shirali, Azadian, and Saki 2016). Most of the studies mention that sudden shocks come from not only the natural disasters themselves

but also the accompanying influences such as pandemic, armed conflict or a financial crisis(Blanchet et al. 2017). Although there is no definitive definition yet, we insist a conceptual elaboration in our case: healthcare system resilience refers to the ability of hospital and other health institutions to maintain the essential functions during shock, namely natural disaster in our investigation, as well as ability to retain same level after shock.

During a disruptive event, a resilient healthcare system can efficiently adjust to changing situation. Healthcare systems are complicated in and of themselves, as are the factors that influence their resilience. An overall and systematical framework to address this issue is therefore required. To make this framework more practical and acceptable, this paper locates the challenges for the healthcare system resilience and emergency response capacity based on "7·20 Henan Rainstorm" in China and summarizes them in the framework, which provides references for hospital leaders and managers to further improve the resilience of the healthcare system. More specifically, this comprehensive and practical framework can be utilized for conceptualizing and measuring resilience in the healthcare system managerially.

2. Case Description

Since the night of 17 July 2021, continuous heavy precipitation has occurred with heavy rain in many places in Henan Province, China. From 16:00 to 17:00 on 20 July, according to the National Meteorological Centre of China, the rainfall in Zhengzhou reached 201.9 mm in one hour (NMC 2021), which has exceeded the historical maximum rainfall of 198.5 mm of record in Henan Province. Fig.1 depicts the map of floods in Henan Province.

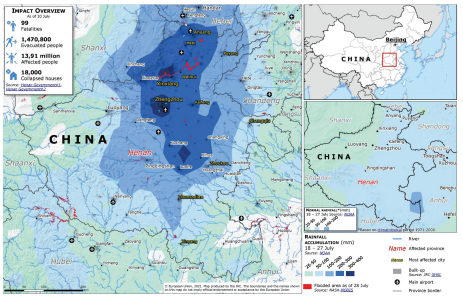

Fig. 1 Map of the floods (EC 2021).

Due to the heavy rainfall, reservoirs Changzhuang and Guojiazui and other water conservations in Zhengzhou appeared major hazards. In addition, waterlogging occurred and seriously hindered the railway, highway, and civil aviation traffics in Zhengzhou. Fig.2 shows examples of consequence of the heavy rainfall on the street, subway station and hospital. According to the governmental statistics (CCTV 2021a), the fatality number due to Henan Rainstorm has reached 302. Such catastrophic flood leads to a direct economic loss of 120.06 billion yuan (Council 2022).

Hospitals are an important part of the healthcare system, but a complete healthcare system includes not just hospitals, but other healthcare organizations, coordination across governance sectors, and engagement with residents or communities since the others also affect the healthcare system functionality. In the He Hospital District, the First Affiliated Hospital of Zhengzhou University, is one of the worst affected areas due to its low elevation. At 19:00 on 20 July, the hospital with more than 9,000 patients suddenly lost power, and dozens of surgical operations were interrupted. With more than 600 patients still in the intensive care unit, the hospital urgently activated standby power generations to maintain the care for all critically ill patients. However, the general ward lost support.

Fig. 2 Flooding a) on the street, b) in the subway and c) hospital in Henan rainstorm (Sina 2021; Sohu 2021).

Rainwater and river water rushed into the outpatient area and ward buildings, resulting in the interruption of almost all facilities, including electricity, water, medical equipment and communications, and the rapid depletion of medical supplies. Zhengzhou Fuwai Central China Cardiovascular Hospital was also isolated in the flooding. Several kilometers of roads outside the hospital were flooded, with the deepest point being nearly 3 meters. Water poured into the first floor of the clinic building, leaving the hospital operating without electricity and water, and only relying on small generators. Until the early morning of 21 July, no medical supplies could be delivered to the hospital.

The two key activities by government departments are forecast and emergency response. Fig. 3 demonstrates the forecast, warning, and emergency response by government sectors in this rainstorm according to news reports (Baidu 2022a, 2022b).

The community engagement is based on information dissemination and donation. For information dissemination, on the 21st, CCTV (China Central TV) News opened the "Henan Rainstorm Emergency Mutual Aid Platform" to provide an information relief channel for the people affected by the rainstorm in Henan(CCTV 2021b). Tencent Maps launched the "Zhengzhou Rainstorm Mutual Aid Map" with package "Charity Rescue Hotel Map"(Tom 2021), which can provide services of querying local water accumulation of urban roads for local citizens to avoid risks and also contains the latest mutual assistance points in Zhengzhou to show the assistance addresses, contact numbers, and trapped situation reported by Zhengzhou citizens themselves. There are also other online platforms such as Eleme, Kuaishou and Qunar that exchange mutual assistance information for the affected people (Cqnews 2021). However, due to the power and internet outages in many places, some help information and rescue information cannot be released smoothly and timely. On the other hand, various companies have made many donations through charitable organizations for emergency procurement of disaster relief materials, post-disaster reconstruction, and post-disaster sanitation and epidemic prevention. According to statistics published in public reports, the amount of funds raised across the country has reached nearly 2 billion yuan as of 12:00 on the 22nd (Daily 2021). As of 15:00 on the 24th, a total of 395 enterprises and individual entrepreneurs had donated 3.571 billion yuan in funds and materials (Tencent 2021).

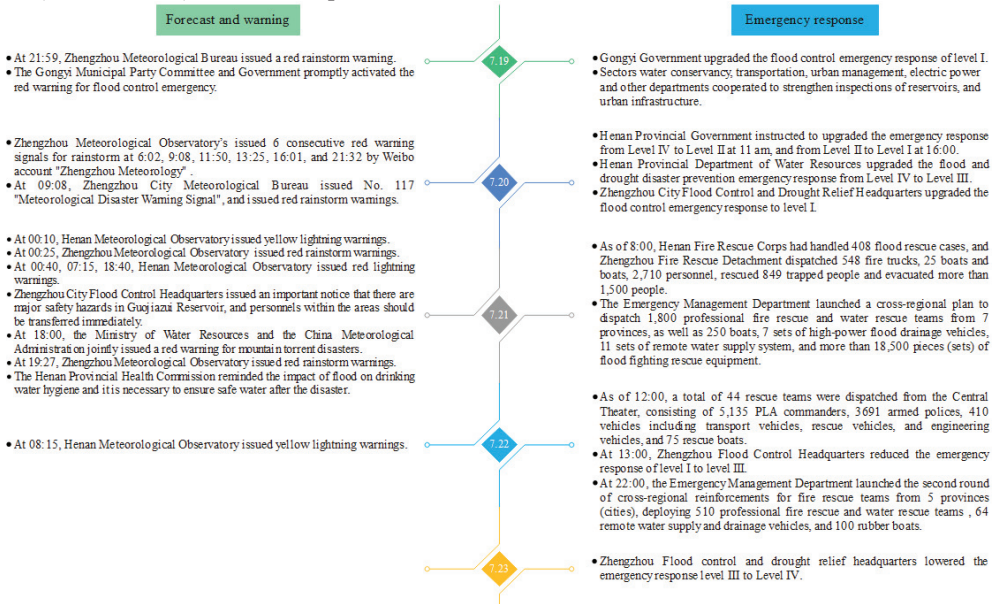

Fig. 3 Government participation in the forecast, warning, and emergency response in Henan rainstorm.

3. Influencing Factors

The healthcare system resilience is investigated at three phases including preparedness, response, and recovery.

In the preparedness phase, works including infrastructure construction, warnings, and developing a plan for disaster management have great impacts on healthcare resilience. Based on the performance of reservoirs and rescue in Henan Rainstorm, there are still shortcomings in water conservancy facilities, which means that urban drainage capacity could hardly adapt to urban development. This is one of the main reasons why flooding has hampered rescue efforts. The lower level of the infrastructure, the less resilient the system is reacting to sudden natural disasters. As early as in 2016, Zhengzhou was selected as the provincial pilot of sponge city construction in Henan Province (Observer 2021). Compared with traditional engineering planning, sponge city construction is a systematic engineering focusing on solving urban water problems through urban planning and construction control system. It has good "flexibility" and "resilience" in adapting to environmental changes and coping with natural disasters. When it rains, sponge city absorbs water, stores water, seeps water and cleans water, and after which when it is needed, the stored water was "released". However, the Henan rainstorm is sudden and extremely heavy rainstorm, which has exceeded the capacity of sponge city to cope with. In addition, the construction of a more perfect drainage system is the fundamental solution to water logging.

The rainstorm disaster exposes the inaccuracy of weather forecast and the problems in the disaster warning system. According to the news in Fig. 3, the meteorological bureau of Henan Province issued warnings for many times, and it is not right to underestimate their functions. However, on the other hand, the inaccuracy of forecast and warning is undeniable that contributes to the untimely emergency response. The forecasted rainfall amount of the previous red warnings is much larger than the actual value, so that the warnings did not attract sufficient attention at the start of rainfall. However, the forecasted rainfall warning issued at 16:00 on 20 July was very small so that the actual rainfall amount quickly exceeded by more than twice (Zhang et al. 2021).

In the case analysis on Henan Rainstorm, we could evaluate the reliability of flood fighting infrastructure and the perfection of warning system to some extent. As for the emergency plan, we are currently unable to obtain more relevant information, as some documents are not published. Even so, high attention is regarded necessary to be paid to the importance of emergency plan when improving resilience of healthcare systems. We have summarized several aspects of the emergency plan. Healthcare systems are vulnerable to equipment damage, power outages and Internet outages in a disaster. Earthquakes, for example, can also lead to massive power outages in hospitals, causing casualties (Hassan and Mahmoud 2019). A good emergency plan also contains how to organize the emergency organization and management system, emergency rescue support system, comprehensive coordination of mutual support system, well-trained emergency team and so on.

For hospitals, we found that it is important to ensure the reliable performance of various supporting systems (i.e., water supply, electricity, and communication systems) in the response stage to maintain the normal operation of inpatient buildings, operating rooms, and emergency rooms. Another influencing factor is the accessibility of hospitals from different directions during a disaster (Chand and Loosemore 2015; Afsaneh, Kahnali, and Heyrani 2020), which requires more volunteers to be mobilized and different transportation modes to ensure unimpeded access to hospitals for supplies and personnel.

Governmental participation is important to preserve healthcare system resilience. In this case, the government contributes to the urban infrastructures, posts the warning information, guides the emergency policies, determines the stock and supplies of medical and emergency stuff, and provides financial support.

Community engagement improves the responsiveness of healthcare systems. Corporate donation accelerates the recovery of the healthcare system to normal operations after natural disasters. In this disaster, we also find that there are diverse methods to release and

receive information, which can facilitate the rescue operations. But there are still some obstacles in releasing information due to widespread blackout and internet outages. In addition, some problems emerged that people who do not use internet are still struggling with seeking for help, and there is a gap between the requestor and rescuer grasping the mutual aid information of different mutual aid channels.

The speed and level of recovery are also metrics to evaluate the resilience. The human team and financial resources involved in post-disaster reconstruction affect the speed of healthcare system recovery, and the damage degree of system affects the level of system recovery. Learning lessons from accidents and boosting catastrophe awareness is also a way to improve resilience. The First Affiliated Hospital of Zhengzhou University organized a seminar to promote the early warning of the heavy rain on August 22. Based on the experience of "7·20 Henan Rainstorm", the conference put forward suggestions that power, lighting, and water supply, as well as generators should be guaranteed. The division of responsibilities for logistics and security section officials has also been clarified. Other lessons from historical accidents can be reflected in the updating of emergency plans.

4. Resilience Framework

Based on what we have discussed above, a framework is proposed as shown in Fig.4.

In a natural disaster, hospitals are both rescuers and victims. It can be concluded from the above that for hospitals and medical institutions, absorbability (ability to withstand sudden disasters), adaptability (backup facilities to provide services) and recoverability (quick recovery from sudden disasters at a reasonable cost) are important in assessing resilience.

Hospitals and medical institutions should make credible and implementable emergency plans before disasters to withstand sudden shock. A satisfactory emergency plan has detailed requirements for the standards of infrastructure and stand-by. Solid basic power supply and power backup system is important to improve the coping capacity of hospitals and ensure the normal operation of medical equipment, so did other medical infrastructures and internet supply systems. The emergency plan should also emphasize how to organize rescue and self-rescue teams during disaster, and how to cooperate with professional emergency rescue teams, as well as the quality of the logistics support team.

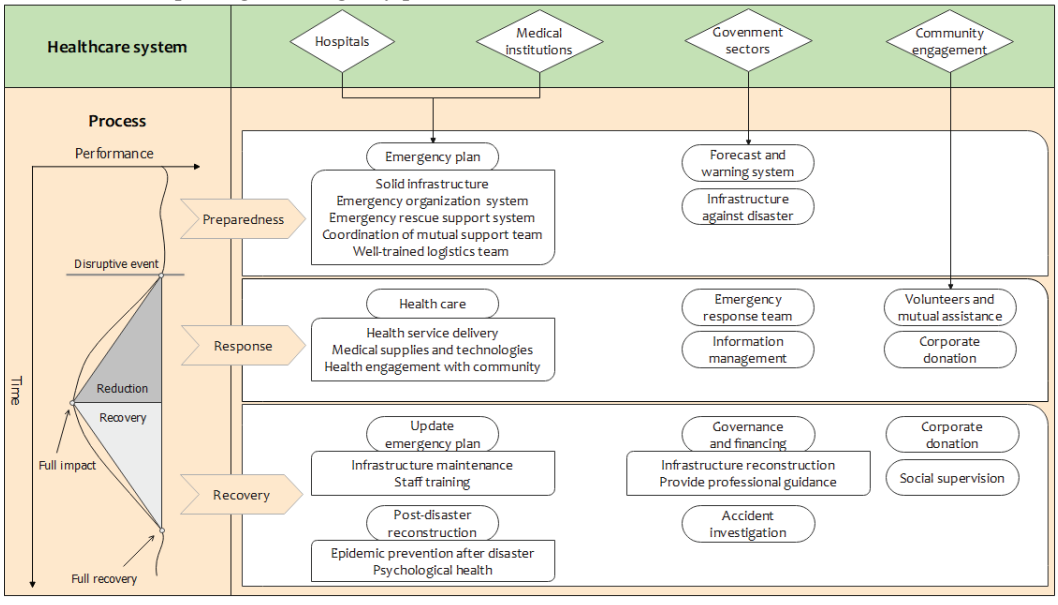

Fig. 4 Resilience framework for healthcare systems in natural disaster.

In the response phase, health service delivery and medical supplies are the most important and indispensable tasks for hospitals and medical institutions. For example, ambulance services can handle and quickly transfer patients with various illnesses and injuries during disasters. Hospitals and medical institutions can also organize to distribute basic emergency medical kits in communities and to disseminate basic medical precautions for self-rescue in disasters.

A hospital needs to restore the original function level before the disaster, including hospital facility, hospital's staff availability, hospital's space availability, hospital's supplies availability, housing functionality level, etc. Hospitals and medical institutions should update emergency plans based on historical accident experience, timely replacement and maintain infrastructure, as well as strengthen staff training based on disaster experience. Hospitals and medical institutions can also publicize the significance of post-disaster epidemic prevention and provide essential medical supplies to communities. Besides, normally the post-disaster epidemic prevention cannot be ignored, especially when floods and waterlogging can easily accelerate the spread of the virus. Many people have psychological stress response after the accident, which may even affect their immunity. Medical institutions can establish professional psychological intervention teams to make efforts to personnel psychological counseling. Personnel psychological counseling includes not only people injured or affected by the disaster but also the helper such as the emergency team. Team activities of psychological intervention after disaster interventions might particularly refer to a set of micro-governance interventions proposed by Gilson et al(2020).

The government mainly provides various kinds of technical assistance, as well as grants. For example, before disasters (including typhoons, hurricanes, rainstorms, earthquakes, etc.), the Meteorological Bureau should make efforts in predictions and warnings. The accuracy and precision of prediction calls for high requirements on the professionalism of the prediction team. If the predicted result is less serious than the actual situation, it will not attract the attention of other sectors and the public, let alone make them actively respond to the disaster. On the contrary, if the severity of the predicted result exceeds the actual value, it may cause excessive human and capital input, which is a waste of resources. At the same time, it will also reduce the public's trust in government departments. In addition, well-built disaster-resistant infrastructure is also closely related to the work of various government departments, such as dams, reservoirs, and urban pipeline networks.

Government can provide professional rescue teams with professional rescue facilities, which are the backbone of reducing casualties and improving the adaptability of the healthcare system to disasters. In addition, as we discussed earlier, the government should undertake information management and launch a unified, centralized, systematic, and user-friendly information collection and distribution channel to avoid information duplication or isolation. After a disaster, the government should provide funding to help rebuild the healthcare system including the urban infrastructure. Another role of government is to do accident investigations. While this may not contribute much to the recovery of the healthcare system in current accident, the lessons learned from the accident investigations can improve the resilience of the healthcare system and its performance level in the next accident.

The community generally does not have much impact on the healthcare system during the preparedness phase, when the public can only receive information, disseminate information, seek shelter, and prepare daily necessary supplies and basic medical supplies to deal with disasters.

During the response phase, community engagement begins to have an impact on the entire healthcare system, through the formation of volunteer teams and the public's spontaneous mutual help. From the perspective of time, since professional emergency rescue teams are unlikely to arrive at the accident site immediately, self-help and mutual assistance within the scope of the disaster becomes very important, which will make the performance level of healthcare system after the shock is higher than the actual level. From the perspective of resources, the self-rescue and mutual rescue of the trapped people also saves

rescue costs. Many companies responded by making donations, from when the healthcare system suffered a disaster until after the disaster. In addition, the other function of community participation, which has not been mentioned in this article, is social supervision. To a certain extent, public supervision and public opinion are also the driving force for the reconstruction of the healthcare system, especially now that the natural disasters are easily become hot topics online.

5. Discussion

This resilience assurance framework can serve as a management reference for the overall development or enhancement of the health system, particularly in the face of natural disasters. This framework can offer criteria and problem-solving ideas from two dimensions to decision-makers and urban managers. Firstly, from the perspective of system composition, which institutions or organizations must be involved when a disaster strikes? Secondly from the time dimension, what should the various components of such systems do in each stage from before the natural disaster to the ends of the disaster?

The proposed resilience assurance framework, however, has several limitations. The first, for example, is that it cannot accurately quantify system resilience or set guidelines for enhancing infrastructure resilience. To strengthen the inherent resilience of the system at the technical level, it is expected to incorporate the contributions (Liu, Zhai, and Yu 2022; Niazi et al. 2021; Liu et al. 2021; Mitoulis et al. 2021) of other scholars. Secondly, in certain countries, the function of the government in the health system is less essential, while in others, the hospital is a for-profit business that overlaps with the role of the community. However, it is challenging for us to have a standard framework that is applicable to every nation, thus when utilizing this framework as an evaluation tool, it should be altered accordingly based on individual circumstances. A potential subject for future research is how to integrate the management and technological influencing factors and guidance strategies.

6. Conclusion

In this paper, we presented a case analysis on healthcare system against Henan rainstorm and a resilience framework of for healthcare systems in natural disaster. We analyzed how the healthcare system performed in this rainstorm disaster according to public reports. Factors that influence the healthcare system resilience were then examined. Based on this, a comprehensive healthcare system resilience framework is presented to state how to improve its resilience from two dimensions: 1) key components of the healthcare system and 2) the phases of resilience process (preparedness, response, and recovery). This approach is broadly applicable and could serve as a paradigm to assess healthcare systems resilience. It may serve as a research basis for resilience engineering and urban public safety, and it is also expected to provide reference for improving healthcare system resilience against natural disasters.

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