QUANTITATIVE APPROACH TO HOSPITAL RESILIENCE BASED ON SYSTEM DYNAMICS: CASE OF SRI LANKA

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DECLARATION

I declare that this is my own research thesis, and this thesis does not incorporate without acknowledging any material previously published submitted for a degree or diploma in any other university or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgment is made in the text.

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ABSTRACT

Past records depict that both the intensity and frequency of climatic-related hazards are increasing devastatingly. Although the number of deaths caused by these extreme events has been comparatively less recently, the economic losses have increased considerably. The complexity of the world with interconnected infrastructure systems has been the main catalyst of these huge losses. COVID-19 and concurrent hazards have set out a perfect example that shows hazards no longer affect discreet parts of the system but render the failure of the whole system. Out of critical infrastructure sectors, damages on health systems have attracted global concern more as the impacts on the health sector can cascade further to socio-economic aspects as well. Therefore, currently, health is considered an important part of disaster risk reduction. Sri Lanka, as a tropical country, experiences climatic-related hazards more frequently. Although Sri Lanka has a disaster management mechanism and public health system, a limited number of evidence exists on integrated systemic risk management mechanisms in the country. Most of the existing emergency and disaster management mechanisms have a hazard-by-hazard approach and fail to incorporate synergized impacts of compound hazard events. The levels of integration of public health and disaster risk management aspects into each other still needs to be enhanced. In a context where systems thinking approaches are more promoted in disaster resilience, this study aims at providing a framework for assessing the public health system disaster resilience for multi-hazard contexts amidst biological hazards. In this regard, this study has followed multiple steps to evaluate the existing health disaster management approaches in the country. Initially, a desk study was conducted to identify key drivers of effective response mechanisms for pandemics, which can affect the capacities of integrated disaster risk management approaches. It was followed by a stakeholder analysis, which used Social Network Analysis (SNA) to identify the stakeholder behaviour in the country for multi-hazard preparedness planning. Furthermore, field data collection was conducted under three phases, including forty-one key informants representing the sectors that are related to disaster management in the country. Qualitative information from this step was analysed using systems thinking and cascading effects were modelled for early warnings, evacuation, shelter management, and hospital functionality. Since functional continuity of healthcare facilities was identified as a key driver of multi-hazard preparedness and response mechanisms, this study presents a model that captures interdependencies within a hospital during a hybrid hazard scenario. As the final outcome, the study presents a framework for enhancing public health systems resilience for multi-hazard contexts. The developed framework was tested for its applicability at the community level in Sri Lanka, through scenario workshops. Along with these outcomes, the study further presents a set of gaps that needs to be immediately addressed based on lessons from recent multi-hazard scenarios amidst the COVID-19 outbreak in Sri Lanka

Keywords: Public Health Systems; Multi Hazards; Biological Outbreaks; Multi-Sectoral; Systems Thinking; Cascading Impacts

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Description
ADB	Asian Development Bank
CBO	Community Based Organizations
CDC	Centres for Disease Control
CI	Critical Infrastructure
CIDA	Construction Industry Development Authority
CRED	Centre for Research on the Epidemiology of Disasters
DDMCU	District Disaster Management Coordination Unit
DES	Discreet Event Simulation
DGHS	Director General of Health Services
DM	Disaster Management
DMC	Disaster Management Centre
DPRD	Disaster Preparedness and Response Division
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
EMS	Emergency Medical Services
EOC	Emergency Operation Centre
EOP	Emergency Operation Procedure
EW	Early Warning
GHSI	Global Health Security Index
GN	Grama Niladhari
HCWs	Health Care Workers

HEDM	Hospital Emergency and Disaster Management
HEDRM	Health Emergency and Disaster Risk Management
HSI	Hospital Safety Index
IOM	International Organization of Migration
JEE	Joint External Evaluation
LA	Local Authority
LKR	Sri Lankan Rupees
MHEW	Multi-Hazard Early Warning
MOH	Medical Officer of Health
MOHSL	Ministry of Health Sri Lanka
NDRSC	National Disaster Relief Service Centre
NEOP	National Emergency Operation Procedures
NGO	Non-Governmental Organizations
NTI	Nuclear Threat Initiative
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
PAHO	Pan American Health Organization
PHI	Public Health Inspector
PHM	Public Health Midwife
PPE	Personal Protective Equipment
RDHS	Regional Director of Health Services
SAR	Search And Rescue
SD	System Dynamics

SFDRR	Sendai Framework for Disaster Risk Reduction
SHI	Safe Hospital Initiative
SLR	Systematic Literature Review
SNA	Social Network Analysis
SOP	Standard Operation Procedure
UN	United Nations
UNDP	United Nations Development Programme
UNDRR	United Nations Office for Disaster Risk Reduction
UNICEF	United Nations International Children's Emergency Fund
USD	United States Dollar
WHO	World Health Organization

1 INTRODUCTION

1.1 Problem Identification

A total of over one million deaths were recorded between the years 2000 and 2019 due to various hazard occurrences worldwide, with an average of 60,000 deaths each year. The interruptions caused by these events had an impact on more than 4 billion people. During the relevant time period, total economic losses due to catastrophes were estimated to reach 2.97 trillion US dollars (CRED and UNDRR, 2020). Although the COVID-19 was the most deadly danger in 2020, 15,080 people died as a result of climate-related catastrophes that year (CRED and UNDRR, 2021). In parallel with those disasters, 1.73 million deaths during the year 2020 were reported due to the pandemic (WHO, 2020a). As the climate change advances, many climate-related concerns are anticipated to become more frequent and intense (Zscheischler et al., 2020). For instance, the number of flood events has shown an increase of nearly 130% during the last two decades. Even in 2020, the number of hazard events is higher than the average number of hazard events during the last two decades (CRED and UNDRR, 2020). Since the incidence of hazards, mainly climatic-related hazards, is increasing, the likelihood of hazards overlapping in spatial and temporal dimensions has also increased. Especially the potential of biological and natural hazards to overlap and heighten the severity of impacts was proven a long time back. (World Health Organization. Regional Office for South-East Asia, 2017).

Currently, the frequency of biological hazards has been increasing due to international travel in bulk volumes, growing resistance to antibiotics, and more human to animal contact (Kostkova et al., 2014). Throughout the world's history, biological hazards in the form of pandemics and epidemics have been posing massive devastations on humankind from time to time (Jarus, 2020; Walsh, 2020). Biological risks can result in significant, broad spikes in morbidity and death, as well as disproportionately greater mortality in particular communities (Madhav et al., 2017). In addition to health crises, indirect health impacts of these biological hazards have the potency of increasing morbidity and mortality further due to the cascading nature of risk (Falcone and Detty, 2015). For instance, pandemics can render short-term and long-term disruptions to the economy such as acute fiscal shocks (Achonu et al., 2005). Furthermore, biological outbreaks, especially pandemics create bleak effects on the society with severe social and political consequences such as clashes between citizens, population displacement, poverty, social unrest, and discrimination (Price-Smith, 2009).

As mentioned earlier, although the deaths caused by climate-induced hazards are found to be lower in 2020 compared to COVID-19, the presence of concurrent hazards during a pandemic cannot be overlooked. Prevention measures for COVID-19 have hampered response procedures for other concurrent hazards, and other way (Quigley et al., 2020). When containment mechanisms like social distancing are disrupted, infection and death rates become more unclear (Normile, 2020). The impacts of simultaneous hazards during COVID-19 highlighted the necessity for being proactive and taking early actions to reduce vulnerabilities for compound events (UNDRR and OCHA, 2020). Due to the COVID-19 crises' effects and concurrent climate-related hazards, the development of reliable Multi-Hazard Early Warning (MHEW) platforms with a clear knowledge of risk has become imperative (Rogers et al., 2020). Furthermore, concurrent hazards associated with COVID-19 have highlighted the systemic character of risk, in which the pandemic's health impacts have cascaded into negative socio-economic consequences, destroying not just isolated sections of a system but also leading to the entire system failure.

This situation happens since human communities have become complex systems that consist of several interconnected systems and infrastructures that support human wellbeing. In the present world, people depend on Critical Infrastructure (CI) systems such as electricity, water, energy, health services, etc. which are highly interconnected (Randil et al., 2022). Due to complex interdependencies among such systems, impacts on one system can trigger adverse impacts on other connected systems as well. Therefore, the resilience of such CI systems stands paramount in the present world. The term resilience has been given several definitions throughout history. However, it can be defined as the ability of a CI system to resist, absorb and recover to normal operation from the impacts of a hazard (Rehak et al., 2018). The process of ensuring the resilience of CI systems consists of several steps such as examination of the existing conditions of CIs, management of vulnerabilities, and enhancement of capacities, which spread through a wider spectrum of sectors.

Out of CI systems that are imperative to day-to-day activities in a community, ensuring the resilience of the public health system is considered significant since the public health systems have been vested with a responsibility of taking care of the health and well-being of people on a day to day basis and victims when a disaster strikes (UNDRR, 2011; WHO and PAHO, 2015). Damages of a hazard event on the health system can pose impacts that spread across areas such as physical infrastructures, socio-economic, and environmental since a health system can be identified as a collection of several sub-systems (Thomas et al., 2020). For instance, structural and non-structural damages to a hospital during any disaster can greatly threaten its functionality. Damaged hospital buildings can lead to the establishment of temporary medical structures which pose a whole new set of challenges (Alpert et al., 2018; Bitterman and Zimmer, 2018). The impacts of disasters on health systems can be long term and the intensity of damages can increase with time. For instance, Waddell et al., (2021) reveal that the most severe health impacts of hurricanes peak within six months following hurricanes. Furthermore, several health impacts such as chronic diseases, and mental impacts can continue for years. Therefore, the process of strengthening the health system resilience should consider the resilience and safety of all of its sub systems as well.

Currently, the existing resilience assessment frameworks for health systems assess resilience or preparedness focusing on one particular hazard type, especially biological hazards (Nuclear Threat Initiative and Johns Hopkins School of Public Health, 2019; WHO, 2019). Although there are frameworks that incorporate an all-hazard approach, these do not adequately address the impacts of compound hazard events and associated cascading impacts on the public health system. Since recent hazards have emphasized the need for the extensive use of Multi-Hazard Early Warning systems to be proactive for compound hazard events, the coordination between public health and MHEW systems has become paramount as well (UNDRR and OCHA, 2020). Even before COVID-19, global Disaster Risk Reduction (DRR) frameworks highlighted the need for integration of public health into DRR for enhancing the preparedness for biological hazards and possible cascading threats and building resilient health systems.

Sri Lanka has universal healthcare coverage which consists of both preventive and curative healthcare facilities, ranging from the national to community level. Ensuring the health and well-being of the community both in general and during a disaster situation is one of the key objectives in the healthcare sector (Senanayake et al., 2017). In parallel, a decentralized disaster management mechanism is in function, focusing on twenty-two possible hazards that can occur within the country (Siriwardana et al., 2018a). However, recent studies that were carried out in the advent of COVID-19 have revealed that the emulation of integrated risk management approaches between health and disaster management sectors still needs to be improved vastly in Sri Lanka (Amaratunga et al., 2020b; Fernando et al., 2021). Therefore, there exists a great research opportunity to evaluate the resilience of health systems taking the impacts of multiple hazard events amidst a biological outbreak. Especially the resilience of components within public health systems to impacts of compound hazard events should be evaluated.

1.2 Research Problem

The healthcare system, including hospitals, could be identified as a complex system, with all the stakeholders such as medical staff, administrative staff, supportive staff, patients, the general public, etc. (Devmini Kularatne et al., 2019). In a broader view, public health systems consist of sub-systems such as health governance, finances, health workforce health information systems, and health services (World Health Organization, 2010). The health sector is considered one of the most crucial critical infrastructure sectors that decides the level of human health and well-being both in general and during disaster events. Therefore, ensuring the resilience of public health systems, especially for multi-hazard contexts, has drawn significant attention over the recent years with the advent of climate change.

Historical reports evidence that biological outbreaks can last for a long period of time. During these outbreaks, the whole health system gets overwhelmed due to the direct health impacts and associated cascading impacts of the biological hazards (Jayasekara et al., 2021). In such a context, the presence of another hazard can severely affect the health sector which has been already put under enormous pressure. COVID-19 and concurrent hazards, as the most recent experience by the time of this study, demonstrated the need for being resilient to multi-hazards events that can concur with long-lasting biological outbreaks. For instance, the overwhelmed capacities in hospitals, due to both COVID-19 and concurrent hazards, called for the need for restructuring of healthcare facilities for future pandemics.

In Sri Lanka, severe damages to the health sector due to disaster events have been recorded in recent years. For instance, floods caused major damage to the healthcare service system recently since they have occurred more frequently (Farley et al., 2017; Ministry of Disaster Management et al., 2017). The 2017 floods caused a loss of 631 million LKR to the healthcare service system of our country (DPRD, 2017). Identifying this issue, the Ministry of Health, Sri Lanka has implemented several initiatives for enhancing the health emergency and disaster preparedness. However, the presence of COVID-19 became an eyeopener for addressing the synergized impacts of compound hazards amidst a biological outbreak that can last for a long period with adverse impacts on the health sector.

Accordingly, identifying and prioritizing key drivers in responding to biological outbreaks, stakeholder coordination in preparedness planning for multi-hazard contexts, mitigating impacts of biological outbreaks on response capacities for other hazards, and functionality of healthcare facilities including hospitals can be identified as the major areas that need attention within existing disaster preparedness and emergency plans. This study takes the COVID-19 outbreak as a case study and attempts to explore the aforementioned areas in the Sri Lankan context. Furthermore, the study introduces a framework that provides the opportunity to evaluate the public health system resilience to multi-hazard contexts amidst a biological outbreak in the country.

1.3 Research Objectives

The main objective of this research is to develop an assessment framework for public health system resilience to multiple hazard events amidst biological outbreaks in Sri Lanka. The overall research study can be categorized into the following sub-objectives.

1. To identify the key actors/ drivers of public health system resilience to biological hazards associated compound events
2. To identify the compound impacts of multi-hazard scenarios on public health systems taking COVID-19 as a case in point

3. To develop a framework for public health system resilience for multiple hazards scenarios during a biological outbreak and test its practical applicability in the Sri Lankan context

1.4 Research Significance

This research directly contributes to the Disaster Risk Reduction (DRR) and disaster management of the public health system in Sri Lanka under the context of resilience to multiple hazard events. Firstly, the study identifies the key drivers and actors in resilience to biological hazards and associated compound hazard events. Utilizing an analysis of data from the global context on preparedness for biological hazards and response to COVID-19, the study presents a key set of performance enhancers in resilience for biological hazards and associated compound events. Furthermore, Social Network Analysis (SNA) is used in the study for the identification of stakeholder behavior in relation to preparedness and response mechanisms for multiple hazard events in Sri Lanka. This step compares the stakeholder network in two cases; 1) pandemics and epidemics only and 2) multiple hazard scenarios during biological outbreaks and identifies the gaps and strengths in relation to stakeholder behavior in public health system resilience in the country.

The study draws on field data collection, taking COVID-19 and concurrent hazards as a case in point, to investigate what Sri Lankan public health sector infrastructures lack in disaster management activities for concurrent hazard events. The analysis has revealed a set of challenges and strengths in the public health systems, including the disaster management sector, for multiple hazard contexts during biological outbreaks. Furthermore, a conceptual model of hospital functionality for a compound hazard event amidst a biological outbreak is developed within this study. This model takes into account the dynamic interactions between subsystems of a hospital. It provides the basis for the optimization of hospital functionality. The model can be further developed to determine the conditions which cause the optimal functionality of a hospital for multiple hazard scenarios during a biological outbreak.

As the main outcome of this study, a framework has been presented that can assist in enhancing the resilience of the public health system in the country for multiple hazard events. This framework constitutes of three stages that compromise seven major elements namely, Governance and leadership; Health finances; Health information systems; Risk Communication; Health services delivery; Health workforce; and Medicines, vaccines, and equipment. The study provides a set of guiding questions to explore the level of resilience in each major area of the health system, thus setting the ideal conditions for each indicator under the above-mentioned elements. After one round of amendments based on experts' comments, the applicability of three elements, Health information systems; Risk Communication; and Health services delivery is tested and confirmed at the community level.

The developed public health systems resilience framework could be used as a primary assessment that identifies the weakest areas to be addressed in sub-systems of the public health sector and based on these results, further analysis could be carried out. As a future research opportunity, the interactions between the public health system's sub-elements can be incorporated into this framework. Furthermore, this framework could be further improved by incorporating the level of likelihood, vulnerability, and capacity to develop a comprehensive resilience index, which is beneficial for enhancing the effectiveness of the disaster risk reduction process in the public health system of the country.

1.5 A Summary of Research Methodology

The methodology of this study consists of six major steps. As the first step, an initial desk study was conducted to identify key areas of public health system preparedness for biological hazards. Under this step, relationships between preparedness parameters and response parameters during COVID-19 and using statistical methods a set of performance criteria based on the preparedness level of countries. Following the initial desk study, a stakeholder analysis was conducted to identify and analyze stakeholder networks related to preparedness activities against biological hazards and possible compound hazard events. Social Network Analysis was utilized in the stakeholder analysis. As the next step, field data collection was carried out to identify key drivers of public health disaster management for multi hazard events in the country. In this regard, three sets of key informant interviews were carried out targeting different groups of key informants.

Two systematic literature reviews were conducted to identify key concepts of hospital functionality during compound hazard events. During the next step, causal loop diagrams and Stock and Flows were used for the conceptual modelling of the hospital functionality during a multi-hazard scenario amidst a biological outbreak. As the next step, the framework for public health systems was developed and presented to a set of experts. Finally, the amended framework was then tested for its applicability at the ground level through scenario workshops. In this regard, community-based action plans were developed for multi-hazard scenarios. These action plans were evaluated next for the inclusivity of indicators of the developed framework with the action plans.

1.6 Structure of the Thesis

Chapter 1 discusses the identification of the research problem, research objectives, and major steps completed during the research methodology.

Chapter 2 is a comprehensive literature review related to the study. Firstly, the importance of disaster resilience of critical infrastructures, public health system resilience, and hospital resilience were discussed along with the importance of global health security for pandemics. Furthermore, the review has elaborated on gaps pertaining to integrated systemic risk management in the existing disaster management mechanism in the country. Finally, the review discusses the importance of systems thinking within disaster management mechanisms especially related to public health systems.

Chapter 3 of this thesis brigns up the major steps of the methodology of the research study. An initial desk study was conducted on the relationships between pandemic preparedness and response mechanisms for COVID-19 using Spearman Correlation Analysis and Mahalanobis Distance Discriminant Analysis methods. Secondly, a stakeholder analysis in relation to preparedness planning for selected hazard events was carried out using Social Network Analysis. This method was used to model stakeholder networks for different hazard scenarios and stakeholder behaviour have been compared and analysed. In the next step, a field data collection was conducted qualitatively through forty-one key informant interviews at three stages. Data was analysed using a systemic risk approach and cascading effects were modelled using causal loops. Lastly, the causal loops and stock and flow diagrams were used to conceptually model the system of a hospital during a hybrid hazard scenario and identify possible interdependencies.

Chapter 4 presents the results of the methodologies described above. Accordingly, this chapter highlights the importance of preparedness parameters for effective response mechanisms against a biological outbreak. Furthermore, the behaviour of stakeholders networks related to preparedness activities against multi hazard scenarios amidst a pandemic was discussed thoroughly within this chapter. Moreover, the chapter presents the practical conditions that observed during concurrent hazards amidst COVID-19 in Sri Lanka. In addition to that the conceptual models of interdependencies within a hospital system were presented within this chapter. Finally, the chapter consists of the developed framework of the public health systems resilience for multi hazard scenarios amidst a biological outbreak.

Chapter 5 discusses the process carried out for verifying the applicability of the presented framework at the ground level health systems action plans. In this regard, scenario workshops were carried out with the participation of both experts and ground level practitioners.

Chapter 6 and 7 include the conclusion and references respectively, and thereafter the Annexes.

2 LITERATURE REVIEW

2.1 Disaster Resilience

Despite the source of climate change, its impacts have been widely discussed as one of the massive challenges facing the world today (Li et al., 2019; Dessler, 2011). Evidence shows that climate change has been detrimental to both physical and mental health. For instance, climate change is closely associated with the increasing frequency and intensity of weather events such as floods and cyclones. These events have resulted in the increased emergence and resurgence of water-borne, vector-borne diseases and other communicable diseases such as cholera, dengue, malaria, leptospirosis, and diarrhoea (Watts et al., 2019; Fredrick et al., 2015; Lin et al., 2012). Moreover, the social impacts of climate change could range from direct loss of lives, livelihood, and property to an increase in poverty and inequality (Leal-Arcas, 2012). Therefore, it is evident that extreme events induced by climate change have been disrupting the communities devastatingly.

The count of climate related disasters has increased five times over the 50 years due to climate change and more extreme weather conditions. World Meteorological Organization (WMO) has recently revealed that, over the last 50 years, a climatic-related disaster occurred every on average. It is estimated that climatic-related disasters have caused 115 deaths and damages of around 202 million US dollars daily (WMO, 2021). According to United Nations Officer for Disaster Risk Reduction (UNDRR), 1.23 million deaths and over 4 billion victims have been recorded within the last two decades. Damages of around 2.97 trillion USD were reported within this period. This is a considerable increase compared to the period of two decades from 1980 to 1999 (CRED and UNDRR, 2020). Considering the period from 1970 to 2019, Tables 2.1 and 2.2 presents the top 5 climatic-related disasters ranked according to deaths and economic losses respectively. The information on disaster damages presented in these two tables shows that although the death tolls of recent extreme events are comparatively low, four out of top five disasters with the highest economic loss occurred within the last five years.

Table 2-1: Top 5 disasters ranked based on reported deaths

Disaster type	**Year**	**Country**	**Deaths**
Drought	1983	Ethiopia	300,000
Strom (Bhola)	1970	Bangladesh	300,000
Drought	1983	Sudan	150,000
Strom (Gorky)	1991	Bangladesh	138,866
Strom (Nargis)	2008	Myanmar	138,366

Table 2-2: Top 5 disasters ranked based on reported economic losses

Disaster type	**Year**	**Country**	**Economic loss (USD billion)**
Strom (Katrina)	2005	Ethiopia	163.61
Strom (Harvey)	2017	Bangladesh	96.94
Strom (Maria)	2017	Sudan	69.39
Strom (Irma)	2017	Bangladesh	58.16
Strom (Sandy)	2012	Myanmar	54.47

Earthquakes and tsunamis cannot be neglected because of devastations incurred as natural hazards although those are not considered climatic-related hazards. During the last decade, earthquakes have accounted for 8% of natural disasters (CRED and UNDRR, 2020). Illustrating the damage caused by tsunamis, around 280 billion USD economic losses have been reported during the period from 1998 to 2018. The number of deaths caused by tsunamis has surpassed 250,000 (UNDRR, 2018a). Although the frequency of these two hazard types is not high compared to climatic-related hazards such as storms and floods, the gravity of damages is considerably high. For instance, the Great East Japan Earthquake and Tsunami in 2011, have together accounted for economic losses of over 228 million USD and around 19,000 deaths (UNDRR, 2018a). It is evident that natural hazards have become a global concern because of these increasing damages. Furthermore, it has been shown that around 19 percent of the Earth's surface area and more than half of the world's people are vulnerable to minimum of one catastrophe.

The impacts of disasters can be categorized as direct and indirect. These impacts deviate between immediate and delayed damages due to a disaster. During a disaster, physical or structural impacts induced by the disaster, such as destroyed infrastructure systems, are considered direct impacts (UNDRR, 2018b). On the other hand, indirect impacts include delayed and longer-term social and economic losses. For instance, damages to health and education can be considered as delayed impacts of disasters (Doktycz and Abkowitz, 2019). Many of the losses induced by disasters are unquantifiable (Figure 2.1 depicts a graphical representation of categories of disaster impacts). These impacts have become intangible mainly because of the cascading nature of the disaster impacts, which is a result of interdependencies among systems. For instance, critical infrastructure systems such as energy, water, health, transportation, etc. are highly interconnected. Most of the time, capturing the holistic picture of losses is difficult due to the complexity of the interdependencies (Kelly, 2015). Therefore, as the intensity and frequency of disasters, especially climatic-related disasters, are increasing it is necessary to ensure the safety and functionality of these interconnected complex systems in order to minimize highly intangible disaster losses.

Figure 2.1: Visualisation of damages caused by disasters

(Developed by author)

2.2 Linkages Between Disaster Risk Reduction and Health

2.2.1 Trends in disaster management in the global context

The Sendai Framework for Disaster Risk Reduction (SFDRR) which is the contemporary global policy framework for disaster management, has facilitated a quantum shift in disaster discourse and practice from disaster response to disaster risk reduction through preparedness, prevention, and mitigation (UNDRR, 2015). DRR is "a policy perspective to prevent new and reduce existing disaster risk and manage residual risk, all of which contribute to strengthening resilience and therefore to the achievement of sustainable development" (IOM, 2019, p. 50). SFDRR as the successor of the Hyogo Framework for Action, which is the global blueprint for DRR efforts between 2005 and 2015, while shifting focus from managing disasters to managing risks, addresses a wider scope of hazards including natural, man-made as well as technological and biological hazards. It's worth noting that, in addition to natural hazards, the SFDRR recognizes biological hazards like epidemics and pandemics as a primary emphasis area in disaster risk management.

Health is a key aspect of SDFDRR. This is evident through the fact that four of the seven global targets of SFDRR are directly linked to health, focusing on population wellbeing, reducing mortality, early warning, and ensuring the safety of health facilities and hospitals (UNDRR, 2015). Further, Djalante et al. (2020) in a recently invited report discuss the applicability of certain DRR strategies and mechanisms as outlined in SFDRR to strengthening disaster management activities for biological hazards like the recent COVID-19 pandemic. The authors emphasize the possibility of leveraging existing disaster risk governance structures that constitute multi-stakeholder engagements and regional-level disaster coordination mechanisms to manage potential health emergencies. Further demonstrating the coverage of a wide array of hazards, SFDRR advocates a multi-hazard approach to the management of disaster risk while encouraging the participation of stakeholders from all levels and sectors of society (UNDRR, 2015).

Out of 17 sustainable development goals adopted by all UN member states in 2015, as part of the 2030 Agenda for Sustainable Development, Sustainable Development Goal 3: 'Good Health and Wellbeing' focuses on ensuring healthy lives and promoting wellbeing for all at all ages. Target 3 D of said goal: ‘strengthen the capacity of all countries, in particular developing countries, for early warning, risk reduction and management of national and global health risks’, enunciates global steering towards leveraging DRR to achieve sustainable health outcomes (United Nations, 2020). Similarly, depending on a risk management approach, the Health Emergency and Disaster Risk Management (HEDRM) Framework introduced by the WHO (2019) provides guidelines for minimizing health risks and impacts of crises and catastrophes. Rather than simply responding to a disaster, the HEDRM focused on controlling health risks and strengthening community and country resilience. (WHO, 2019).

2.2.2 Critical infrastructure resilience to disasters

Critical infrastructures are considered imperative assets and systems for a community. These assets provide services essential for day-to-day human life such as food, energy, water, transport, communications, health, and finance (US Department of Homeland Security, 2013). There are several different definitions given for critical infrastructures in different countries. These definitions vary based on sectors that are considered critical infrastructures in different countries. Table 2.3 presents a summary of sectors that are considered critical infrastructures in a selected set of countries. The damages to these CIs, especially due to natural hazards such as storms, earthquakes, floods, and tsunamis have rendered devastating effects on communities throughout history (Pescaroli and Alexander, 2016). Furthermore, the performance of CI systems has been degraded by manmade hazards as well (Muller, 2012). Therefore, these consequences have called for the need for resilient CI systems for natural and manmade hazards (Rus et al., 2018).

There are several definitions proposed for the resilience of CIs. For an instance, The American Society of Mechanical Engineers characterizes resilience as a system's capacity to withstand external and internal interruptions while continuing to perform its function or, if the function is severed, quickly resuming it (National Infrastructure Advisory Council (US), 2009). Another definition was proposed by the United Nations: "Resilience is the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner including through the preservation and restoration of its essential basic structures and functions"(Harrison and Williams, 2016; Kusumastuti et al., 2014). Despite the availability of several definitions, the interest in resilience assessment of CIs has been increasing collaterally with the increase in the frequency of hazards (Rus et al., 2018). In this context, several various frameworks have been developed to assess the resilience of CIs (see Table 2.4 for a few of the proposed frameworks).

Table 2-3: CI sectors in different countries

Critical Infrastructure sector	**Australia**	**Canada**	**India**	**United Kingdom**	**United States (FEMA)**
Energy	√	√	√	√	√
Food and Agriculture	√	√		√	√
Water and Wastewater	√	√		√	√
Transportation	√	√	√	√	√
Health	√	√	√	√	√
Banking and Finance	√	√	√	√	√
Telecommunication	√	√	√	√	√
Government		√	√	√	√
Manufacturing and industry		√	√		√
Safety		√			
Laboratories	√				
Chemical	√				√
Defence	√		√		√
Commercial facilities					√
Dams/Irrigation					√
ICT	√	√		√	√
Nuclear					√
Emergency services	√	√		√	√
Number of sectors	**12**	**12**	**12**	**10**	**16**

Table 2-4: A selected set of frameworks/tools available for assessing CI resilience

Type of CI system	**Remarks**	**Reference**
Highway bridge networks	A methodology has been proposed for assessing time-dependent expected losses of bridge networks. The risk associated with bridge deterioration has been assessed using this methodology	(Saydam et al., 2013)
Energy Infrastructure	This framework consists of five evaluating indicators has been proposed after reviewing 30 energy infrastructure models.	(Wang et al., 2019)
Airports	This study has incorporated a mathematical model and solution methodology embedded within decision support to address the problem of assessing the resilience of airport runways and taxiway networks for meteorological hazards.	(Faturechi et al., 2014)
Tunnels	The resilience of segment lining systems in the Shanghai metro tunnel system has been characterised by incorporating the functionality curves. These curves have been described using data measured by a detailed monitoring program.	(Huang and Zhang, 2016)
Water supply System	This study proposes a method to assess hard and soft infrastructure systems by modelling the complexity of their interactions. In this regard, graph theory approach and social network analysis were adopted for the purpose.	(Pagano et al., 2018)
Power systems	An indicator-based assessment framework has been proposed under four dimensions, technical, organizational, social, and economic. This framework allows owners, operators, policy makers, etc. to ensure the longevity of power systems.	(Mazur et al., 2019)

Bridges	This study proposes a method based on a three-level hierarchical structure called a bridge resilience measure matrix (BRMM). At the first level resilience is assessed using a Bridge Resilience Index (BRI). The concept of 4Rs (Robustness, Redundancy, Resourcefulness, and Rapidity) is used at the second while resilience is assessed under the dimensions, technical, organizational, social, and economic at the third level.	(Patel et al., 2020)
Healthcare infrastructure	A detailed, indicator-based (57 indicators) assessment tool has been presented. The approach consists of mapping resilience, resilience stress-testing, visualization, and resilience limits of healthcare infrastructures	(Jovanović et al., 2020)

Although there are various assessment frameworks, indicators that are used for assessing CI resilience can be categorized under technical, organizational, social, and economic dimensions commonly (Guo et al., 2021). Under technical resilience, the safety of design and construction (Bruneau et al., 2003), maintenance (Labaka et al., 2015a), robustness (Mazur et al., 2019; Pagano et al., 2018), recoverability (Splichalova et al., 2020), and redundancy (Gu et al., 2020) are assessed by these assessment frameworks. Organizational resilience also plays a vital role in overall CI resilience. Accordingly, governance, adaptability, coordination, and emergency management contribute to organizational resilience vastly (Labaka et al., 2013a, 2013b; Rehak et al., 2018; Sapeciay et al., 2017). Although social resilience is not vastly addressed in existing frameworks, since CI has a major impact on social behaviour, the resilience of CIs should be assessed by considering aspects such as community awareness and preparedness (Labaka et al., 2016). Last but not least CIs should be assessed for resilience using economic factors such as emergency financing and contingency reserves as well (Labaka et al., 2015b). Accordingly, it is a requirement to consider all these dimensions when assessing CI resilience, rather than focusing on technical and organizational resilience

2.3 Public Health Resilience

2.3.1 Impacts of disasters on health systems

Healthcare systems, including hospitals, could be identified as complex systems, with all the stakeholders such as medical staff, administrative staff, supportive staff, patients, the general public, etc. Throughout history, disasters have been affecting the health sector in terms of deaths, injuries, health infrastructure damages, food insecurity, destruction of water supply systems, and transport facilities (Giorgadze et al., 2011). Most of the immediate losses of disasters, such as deaths, injuries, direct losses to health infrastructure, loss of healthcare delivery, etc. depend on the nature of disasters. Furthermore, the health sector must bear a significant percentage of long-term damages caused by disasters. These long-term impacts include loss of healthcare facilities, disruptions to public health campaigns, loss of laboratory facilities, etc. (Goyet et al., 2006). Although food insecurity due to impacts on agriculture and supply chains, and damaged water supply systems are not direct damages to the healthcare sector, those can have a synergized impact on health after being combined with direct health infrastructure damages. Figure 2.2 presents a summary of healthcare sector losses due to a selected set of major disasters from the past.

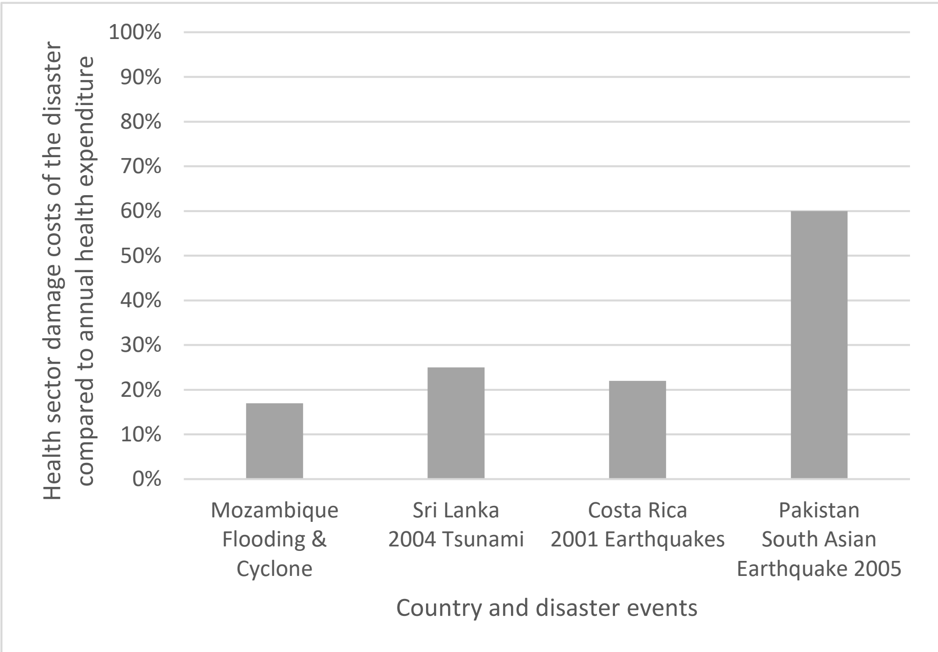

Figure 2.2: Comparison of health sector damage cost of major disasters with annual health expenditure

It is evident that disasters can pose a significant burden on the health sector by means of both direct and indirect damages. As shown in Figure 2.2, damages to the health sector have become a severe challenge for authorities since they have added an extra burden in monetary terms finally. Since it is the paramount duty of the health sector to ensure the well-being of victims, even after severe damages, recovery of damaged health facilities and services becomes the priority (GFDRR et al., 2017). Due to severe damages to the health sector, the recovery phase can be delayed, thus long-term impacts can occur due to this reason. For instance, in 2001 earthquakes in El Salvador damaged nearly nineteen hospitals (63% of total healthcare facilities). Out of them, six hospitals were completely destroyed. Since the damage caused by earthquakes was severe, even after three years healthcare facilities could not function as it was before the earthquakes (PAHO/WHO, 2010). Furthermore, biological outbreaks such as Ebola and COVID-19 have also overwhelmed the healthcare sector severely (Elston et al., 2016; Moynihan et al., 2021). Therefore, it is evident that inadequate resilience in the health sector can lead to long-term crises in any community.

Although there can be vast devastations in the health sector, induced by hazards, adequate resilience enhancement measures can reduce such devastations considerably. For instance, due to massive damages caused by earthquakes and cyclones in the health sector in the American region, WHO has implemented an initiative named, Safe Hospitals to ensure the safety of hospitals which play a major role as CIs within a health system (WHO, 2015). Under this initiative, hospitals were assessed for their safety and necessary measures were taken to improve the safety against identified hazards. This initiative resulted in a considerable reduction in damage to healthcare facilities in the said region. For instance, Table 2.5 presents a comparison of damages caused by two earthquakes, which are similar in magnitude, occurred in Mexico. Accordingly, there is a considerable decrease in damages due to the 2017 earthquake, that occurred after the implementation of the Safe Hospitals Initiative in Mexico (PAHO/WHO, 2020). Hence, it is evident that the resilience of the health sector to disasters can be achieved with adequate measures. In this regard, health sector resilience should not only be perceived as a health concern but also, a socio-economic concern that demands multi-disciplinary collaboration.

Table 2-5: A comparison of damages to hospitals, caused by two earthquakes in Mexico

Damage category	**1985**	**2017**
Buildings with structural collapses	50	No structural collapses in hospitals 7 structural damages
Lost beds	5286 (out of 17,695)	952 (out of 34,022)
Deaths inside health care units	Over 1,000	None
Cost of losses	US $ 9 billion (2017)	US $ 6 million

2.3.2 Resilience of public health systems

Recent calamitous events such as natural hazards, civil conflicts, communicable disease outbreaks, etc. have highlighted the need for improving disaster preparedness and response mechanisms within the health sector (Barasa et al., 2018; Bozorgmehr et al., 2020). For instance, it has become high time to investigate on what are the lessons that we can get from health sector responses to COVID-19 and other hazards that occurred in parallel (Legido-Quigley et al., 2020). The concept of resilience can be used as an answer to this need. In 2014, European Commission has identified resilience as an objective of health systems (European Commission, 2014).

Following the definitions given for CI resilience, public health system resilience can be identified as the ability of a health system to resist, absorb, accommodate to, and recover from impacts of a hazard. Currently, broader definitions are available for resilience covering risk (exposure) mitigation. However, WHO defines Health Systems resilience as the ability to prepare for, manage (absorb, adapt and transform) and learn from shocks (Thomas et al., 2020). Accordingly, a shock can be defined as a sudden and extreme event that impacts a health system. These shocks include natural hazards such as the 2004 Indian Ocean Tsunami, hurricanes, and earthquakes, public health emergencies, political conflicts, civil wars, etc. However, due to the adaptive nature of health systems, resilience is not only about absorbing a shock and adapting to it, but also about how the health system transforms the shock and moves to a better stage then functions smoothly (Abimbola and Topp, 2018; Blanchet et al., 2017).

A health system cannot be considered in isolation as one element and it consists of sub-systems such as healthcare facilities (hospitals, nursing homes, primary care units, etc.), health professionals, information systems, public health programs, financial resources, etc. (Burton et al., 2018; Martínez-García and Lemus, 2013). WHO presents six system building blocks namely, service delivery, health workforce, health information systems, essential medicines, financing, and leadership/governance (World Health Organization, 2010). Accordingly, *leadership/governance* and *health information systems* which are considered cross-cutting blocks provide the base in terms of policy, regulations, and plans required for other sub systems. *Health workforce* and *Financing work* as the inputs of the health system while *service delivery* and *essential medical products* are the outputs of the system. Therefore, the process of ensuring resilience of the health systems to shocks should focus on resilience of the whole network of sub systems.

Health resilience is considered a key aspect of DRR practices in general. Bangkok Principles for the International Conference on the Implementation of the Health Aspects of the SFDRR 2015-2030, place paramount importance on building the resilience of health systems (UNISDR, 2016). However, ensuring disaster resilience of health systems cannot be solely done by health officials and needs a multi-sectoral approach. The SFDRR emphasizes opportunities for leveraging multi-stakeholder engagements and regional-level disaster coordination mechanisms to manage potential health emergencies. Furthermore, the Bangkok Principles stress the need for developing multi-sectoral policies and integrated plans that address health emergencies and other health sector aspects while simultaneously advocating the active representation of health officials in DRR committees and platforms (UNISDR, 2016).

It is evident that health system disaster resilience has a vast range that should be achieved through multi-sectoral approaches. There are several frameworks, assessment tools, etc. which guide achieving different statuses such as health resilience, health security, health disaster emergency preparedness, etc. (See Table 2.6 for a comparison of selected frameworks available for health systems resilience). For instance, the Health Emergency and Disaster Risk Management (HEDRM) Framework devised and published by WHO (2019), sets guidelines for mitigating health risks in emergencies and disasters having a risk management approach as a base.

It considers the necessity of building community resilience for health emergencies rather than being reactive only after a crisis occurs. Furthermore, the Global Health Security Index (GHSI) assesses the health security of countries against biological hazards taking dimensions in a vast range (Nuclear Threat Initiative and Johns Hopkins School of Public Health, 2019).

Table 2-6: A selected set of frameworks available for health systems resilience/safety

Name of framework	Developers	Focused hazards	Main dimensions of health systems
Health Emergency and Disaster Risk Management Framework	World Health Organization	All hazards	• Policies, Strategies, and Legislation • Planning And Coordination • Human Resources • Financial Resources • Information And Knowledge Management • Risk Communications • Health Infrastructure and Logistics • Health And Related Services • Community Capacities for Health EDRM • Monitoring And Evaluation
Public Health System Resilience – Addendum	United Nations Office for Disaster Risk Reduction	All hazards	• Governance • Disaster scenarios • Finances • Land use/building codes • Ecosystem services • Institutional capacity • Societal capacity • Infrastructure resilience • Disaster response • Recovery/building back better

Global Health Security Index (GHSI)	Nuclear Threat Initiative & Johns Hopkins Bloomberg School of Public Health	Biological hazards	• Prevention • Detection & reporting • Rapid response • Health system • Compliance with international norms • Risk environment
Monitoring The Building Blocks of Health Systems	World Health Organization		• Service delivery • Health workforce • Health information systems • Access to essential medicines • Financing • Leadership/ Governance
Joint External Evaluation Tool (JEE)	World Health Organization	Biological hazards	• Prevention • Detection • Respond • Other IHR related hazards and Point of Entry (POE)

2.3.3 Resilience of hospitals

2.3.3.1 Definition of hospital resilience

Healthcare facilities have a vital role in ensuring the health system resilience in a disaster since all around the world, hospitals are considered the most important service units, and those are expected to perform at the operational level even immediately after a disaster (WHO and PAHO, 2015). During disasters, people tend to turn over to hospitals seeking medical attention as well as a refuge (Kularatne et al., 2018). Therefore, hospitals are supposed to remain functional and safeguard the patients, healthcare workers, and visitors in any kind of emergency. During disasters, a hospital has to provide 'lifeline' services to minimize the impact of disasters on communities (Barbara et al., 2006). Therefore, the concept of hospital disaster resilience to identify priorities has become a major concern recently in parallel to the increased impacts and frequency of disasters (Cimellaro et al., 2010a; Cristian, 2018; Zhong et al., 2014).

In the present world, hospitals have been identified as one of the critical components of community resilience to disasters. For instance, paragraphs 30(c) and 33(c) of Sendai Framework for Disaster Risk Reduction (SFDRR) 2015-2030 elaborates on the necessity to strengthen disaster resilience of public and private investments through DRR and prevention in terms of structural, non-structural, and functional elements of the critical infrastructure systems such as hospitals (UNDRR, 2015).

A hospital can be identified as a complex adaptive system that consists of several subsystems (Mahajan et al., 2017). A complex adaptive system includes a set of individual agents which are interconnected and have unpredictable behaviours (Holden, 2005). Although the term 'resilience' in these complex systems is considerably discussed in the research, resilience assessment is yet to be explored and make usable (Hosseini et al., 2016). There are quantitative, qualitative and semi qualitative methods used in evaluating the resilience of complex infrastructure systems. Interviews, surveys, and frameworks are a few strategies used in qualitative and semi qualitative approaches. Illustrating quantitative approaches, both general measures (ex; probabilistic and deterministic approaches) and structural-based models (ex; optimization models, simulation models) are utilized in quantitative methods (Garrido-Píriz et al., 2021; Hosseini et al., 2016).

2.3.3.2 *Assessment of hospital resilience*

Concerning the healthcare sector, Zhong et al., 2014 stressed the need for measuring hospital resilience separately using several concepts such as hospital safety, cooperation, recovery, emergency plans, business continuity, and critical care capacity. The overall resilience level of a hospital can be determined through the combination of these variables. The output indicates the ability of the hospital to function during a disaster and its cascading impacts (Zhong et al., 2014). Table 2.7 presents details on a set of selected frameworks that are available to measure hospital resilience.

Table 2-7: A selected set of frameworks available for hospital resilience

Assessment tool/study	**Developer**	**Remarks**	**Reference**
Hospital Safety Index	World Health Organization	The safety level of hospitals are assessed based on three areas namely, structural, nonstructural, and emergency management	(WHO and PAHO, 2015)
Hospital Safety and Health Management System- Self Assessment Questionnaire	Occupational Safety and Health Administration (OSHA)	This contains 53 questions under 6 categories. Marks are allocated under four options	(OSHA, 2013)
Health Care Facility Design Safety Risk Assessment Toolkit	Agency for Healthcare Research and Quality	This tool targets 6 areas of safety; infections, falls, medication errors, security, injuries of behavioural health, and patient handling And also, the tool addresses more than 200 potential environmental concerns.	(AHRQ, 2017)
Medication safety self-assessment tools	Australian Commission on Safety and Quality in Health Care	This is specifically developed to help the health care facilities initiate an active and system-based approach towards medication safety.	(ACSQHC, 2015)
Hospital Emergency Readiness Overview (HERO) survey	(Kollek and Cwinn, 2011)	This tool evaluates the readiness of the hospital for chemical, biological, radiological, or nuclear hazards.	(Kollek and Cwinn, 2011)

Mass Casualty Disaster Plan Checklist	Higgins et al, 2006	This tool evaluates the preparedness of the hospital for mass casualty events.	(Higgins et al., 2006)

In general resilience assessment approaches can be classified into two major categories named, qualitative and quantitative approaches. Qualitative assessment approaches are based on the experience, judgments, and opinions of experts or evaluators (Gregg, 2006). Quantitative approaches utilize tangible facts and associated data (Messier, 2014). There are two subgroups under quantitative approaches named, general resilience assessment approaches and structural-based assessment approaches (Hosseini et al., 2016). There are assessment approaches that fall in between qualitative and quantitative assessments and can be identified as semi-quantitative assessment approaches. Qualitative models provide the basis for these approaches. But discreet tools such as Likert scales or percentage rankings are involved in semi-quantitative approaches (Garrido-Píriz et al., 2021). Figure 2.3 illustrates the classification of assessment approaches used in the present study. Furthermore, assessment approaches identified during the review were categorized into these groups.

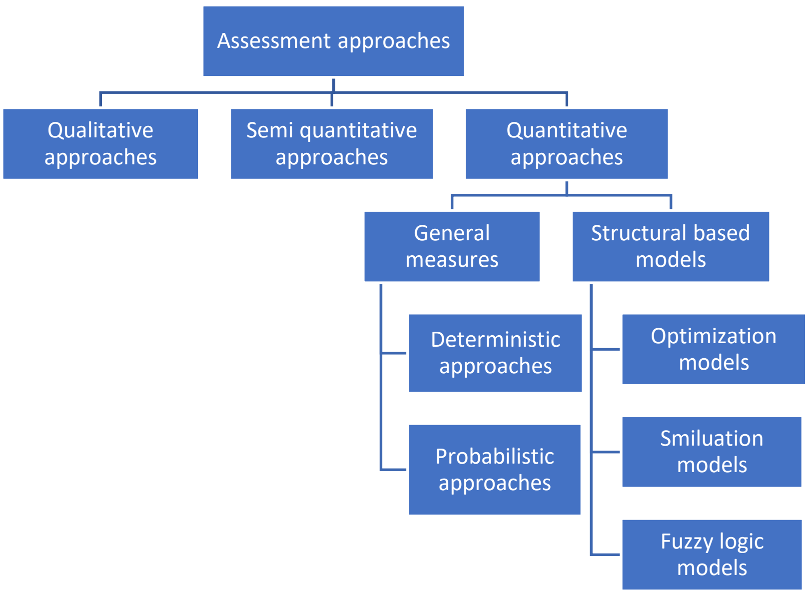

Figure 2.3: Classification of hospital resilience assessment approaches

It is important to note that there is a slight variation in the concepts used in assessing hospital resilience in these three types of approaches. Hospital safety and hospital disaster preparedness are the most common concepts used in both qualitative and quantitative approaches.

2.3.3.2.1 Hospital safety

The Hospital Safety Index (HSI), developed by the World Health Organization, is the most common assessment tool used in studies to assess hospital safety. The Ministry of Health and Medical Education in Iran, for example, has required the use of the index to evaluate more than 900 institutions. Furthermore, the HSI has been used in 28 Latin American nations and territories, with 8 of them establishing national safe hospital initiatives (Sunindijo et al., 2020). The HSI evaluates hospital safety under three criteria named: structural safety, non-structural safety, and hospital emergency disaster management. Since this is an indicator-based approach it allows the evaluators to assign scores to areas of hospital safety based on given measuring criteria by inspection (WHO and PAHO, 2015). The stability of structural elements of hospitals is critical in ensuring the overall safety of the hospital. Determining the structural safety needs specific geological assessments of the ground foundation of hospital buildings (Yari et al., 2021). However, the data and resources required for such assessments are limited in most cases (Devmini Kularatne et al., 2019).

Although the failure of non-structural elements of the hospital does not have a significant impact on the stability of the building structure, it can affect the safety of people and equipment inside the hospital; thus affecting the whole functionality of the hospital (A. R. Raeisi et al., 2018). An inadequate level of non-structural safety can render heavy costs to healthcare facilities. Providing adequate supports, anchors, storage, and maintenance stands paramount in ensuring the non-structural safety of healthcare facilities (Radovic et al., 2012; Sunindijo et al., 2020). Under the non-structural safety, fire safety in hospitals can be identified as a major concern in most situations (Ebekozien et al., 2020). Because by nature, hospitals are highly susceptible to fire hazards due to the high usage of oxygen, large electrical networks, presence of flammable chemicals, etc. (Loria et al., 2012). In the setting of a healthcare facility, compliance to safety measures in ensuring non-structural safety should be the all-inclusive responsibility of stakeholders of hospitals.

2.3.3.2.2 Hospital emergency management and preparedness

The level of readiness of a healthcare facility and its workers is critical in guaranteeing the facility's efficiency, especially in the event of a crisis. Vulnerability, disaster response capability, communication facilities, key supplies, transportation availability, mortuary capacity, responder willingness, future demands, and other factors all play a role in hospital disaster preparedness (Munasinghe and Matsui, 2019). In general, building components, patients, hospital beds and medical equipment, hospital staff, basic lifelines, and services are a few vulnerable components that should be looked into when ensuring hospital preparedness (Koneshwaran et al., 2021; Mulyasari et al., 2013).

Module 4 of the Hospital Safety Index is often used in evaluating hospital disaster management and preparedness. For instance, Hospital Emergency and Disaster Management (HEDM) was introduced by (Mojtahedi et al., 2021) incorporating the indicators under the above-mentioned module. Command and control, response and disaster recovery planning, safety and security, communication and information management, logistics and evacuation, human resources, finance, patient care, and support services, and decontamination and security are the main areas that are evaluated under the hospital preparedness (Janati et al., 2018; Mojtahedi et al., 2021). Under each of the categories listed above, many factors must be guaranteed. Gender, lack of safety, the danger of being affected, inadequate coordination and communication, gruelling workload, and caring for family dependents are only a few factors that might influence human resource readiness (Abdul-Razik et al., 2021).

A high level of planning is required in the preparedness stage for a hospital to respond to a disaster effectively. Although required facilities and resources are in place, disaster response strategies may fail due to the lack of integrated cooperation. Therefore, preparedness plans should be enriched with developed procedures which can eliminate publications and enhance the efficient use of resources (Abdul-Razik et al., 2021). For strengthening the disaster preparedness level of a hospital, (Beyramijam et al., 2019) have proposed four key activities; (1) Preparing disaster preparedness policies, (2) Planning response to emergencies and disasters, (3) Training employees, and (4)

Monitoring and evaluation of results. In the long-term run, it is necessary to measure and compare the own performance of a hospital against disasters and analyse the most effective strategies for enhancing the level of hospital disaster preparedness.

2.3.3.2.3 Hospital recovery capacity

The measurement associated with assessing the hospital recovery phase is the hospital's functionality after the occurrence of a disaster. As shown in Figure 2.4 an immediate functionality reduction can be observed just after the occurrence of the hazard event. The recovery stage is time-dependent and can be expressed as a function of direct losses, available resources, and independencies (Hassan and Mahmoud, 2019). Mainly quantitative approaches have focused on assessing the hospital's functionality considering the hospital as a dynamic system. The recovery capacity of a hospital can be assessed based on the variation of functionality over time (Bruneau and Reinhorn, 2007).

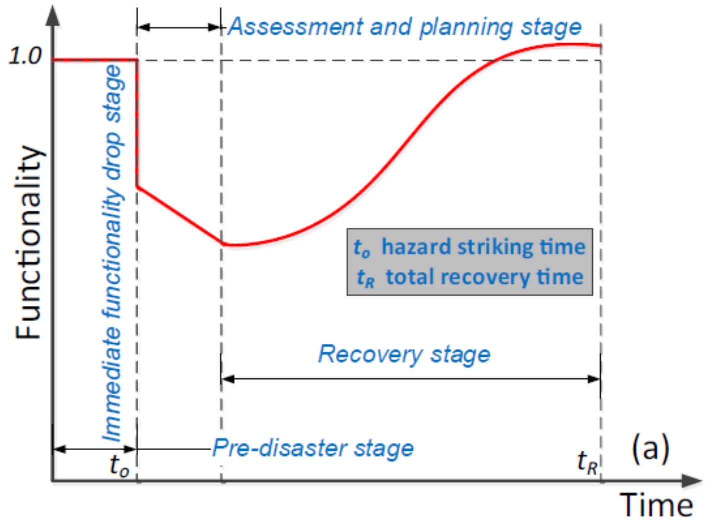

Figure 2.4: Variation of hospital functionality over time

(Developed by author)

The definition of hospital functionality can have several variations. For instance (Hassan and Mahmoud, 2019) have defined the hospital functionality in relation to damages to the structural and non-structural components and contents. In this study, the authors have incorporated a fault tree in quantifying the functionality of a hospital after an earthquake event. A fault tree comprises the impact of several subcomponents and their correlations to the overall functionality of the hospital (Yu et al., 2019).

Furthermore, several indicators are used in assessing the hospital's functionality. Waiting time of patients, the number of patients in the backlog, patients' satisfaction, available beds, staff burnout, and economic loss are several key indicators that have been incorporated in quantifying the hospital functionality over the recovery stage. There are several occasions where these indicators are interconnected as well. For instance, the waiting time of patients to be treated is interconnected with the number of patients in the backlog. An overcrowded backlog leads to an increase in the patients' waiting time. Furthermore, it can affect patient satisfaction as well in addition to the quality of care at the hospital. Despite the indicator, the process of quantifying functionality needs several parameters such as flow of staff allocation, triage, medical procedures, resources allocation, the flow of patients, status of critical lifelines, etc. (Li et al., 2019; Pianigiani and Viti, 2021; Pishnamazzadeh et al., 2020). Hospital recovery is a complex and dynamic process because the number of resources and time recovered for a component of the hospital system to recovery varies from one to another (Khanmohammadi et al., 2018). It is necessary to identify the contribution of recovery of several different components to the functionality (Shang et al., 2020). Therefore, the assessment approaches that aim at quantifying hospital functionality should be able to incorporate the dynamic interdependencies of subsystems in a hospital and their contribution to the overall functionality.

2.4 Pandemics and Compound Risks

2.4.1 Impacts of pandemics

Centres for Disease Control (CDC), US defines an epidemic as a sudden increase in the number of infected cases of a disease over the normally expected rate among a certain community. If an epidemic spreads over a large scale such that cases are reported in several countries or continents, that event can be considered a pandemic (CDC, 2012). Specially pandemics, which are considered large-scale outbreaks, can pose severe impacts on a community. According to evidence from the past, the frequency of pandemics increases considerably at the moment due to reasons such as urbanization, environmental pollution, global travel, migration, etc. (Jones et al., 2008). Therefore, there is a dire need for expanding and enhancing existing policies and plans to improve the capacity of health systems.

Currently, the International Health Regulations (IHR) 2005, functions as the guiding document for global pandemic preparedness (WHO, 2008). As a common practice countries have developed their pandemic preparedness plans adhering to IHR [2005] and updated those plans based on lessons learned from past pandemics (Droogers et al., 2019). Although these improvements were in place, the COVID-19 pandemic has revealed there are significant gaps in current global pandemic preparedness (Sirleaf and Clark, 2021). Even before the COVID-19 pandemic started, global health security for pandemics was experiencing severe challenges and gaps. For instance, many countries were unable to fulfil the requirements for complying with IHR (Fischer and Katz, 2013). Furthermore, gaps in facilities for basic medical care, rapid detection and contact tracing, stringent decisions for isolation, community preparedness for pandemics, etc. were highlighted during past pandemics (Moon et al., 2015). However, pandemic preparedness cannot be neglected, and it should be continuously improved since the impacts of pandemics have a vast range from health impacts to socio-economic impacts.

2.4.1.1 Health impacts

Pandemics can pose severe widespread impacts on human health as well as economic, social, and political impacts. Direct impacts of pandemics can be identified as health impacts that arise in terms of morbidity and mortality. For instance, over 50 million deaths were caused by the Spanish Flu which occurred in Spain in 1918 (Johnson and Mueller, 2002). Furthermore, since 1981 HIV/AIDS pandemic has caused more than 35 million deaths (WHO, 2021). The history of pandemics depicts that, pandemics have affected the younger population who are more capable of contributing to the economy several times. For instance, the H1N1 pandemic which originated in China in 1977 mostly affected people over 20 years old. (Ghendon, 1994). Furthermore, these infectious diseases can give long-term illnesses to people who recovered from them (Ex; Zika virus).

Furthermore, indirect health effects induced by pandemics might exacerbate morbidity and mortality. For instance, medical services can be severely affected by pandemics due to the loss of both human and physical resources. During the COVID-19 pandemic, infections among healthcare workers became a severe challenge for maintaining medical care delivery at hospitals (Heneghan et al., 2020). Furthermore, since healthcare workers were severely infected during the Ebola outbreak 2014-2016, the number of deaths increased drastically due to limited care for infected patients (Sochas et al., 2017). Although healthcare workers do not die because of infections, their potential in delivering the service is affected due to these diseases.

In addition to that, the diversion of resources in the health sector to tackle the pandemic can decrease the focus on other important processes such as child immunization, non-communicable diseases, etc. (UNDP, 2014). Furthermore, the number of non-infected patients who routinely visit for treatments in hospitals reduces considerably due to the fear of infections. Due to this reason, although direct deaths of pandemics do not increase, the indirect deaths caused by lack of proper treatments can increase drastically (Barden-O'Fallon et al., 2015).

2.4.1.2 Economic impacts

There can be both short-term fiscal impacts and long-term economic impacts due to pandemics. Short-term shocks mainly occur due to the need for allocating more resources for curtailing the outbreaks at the initial stages. For instance, the main concern of authorities will be diverted towards contract tracing, establishing quarantine centres, constructing new healthcare facilities, deploying additional personal protective equipment, medical supplies, etc. These activities require a significant amount of additional resources that eventually increase the health expenditure of a country (Barden-O'Fallon et al., 2015; Herstein et al., 2016). Furthermore, pandemics can impose challenges on tax revenues in countries. For instance, the capacity of the Liberian government to collect tax revenues was limited during the Ebola outbreak in 2014-2016 (Shang et al., 2021).

The long-term economic impacts of pandemics are not easily quantifiable. Reductions in the labour force due to infections and mortality are a major reason behind long-term economic impacts. Furthermore, there are behavioural changes that resulted from the fear of infections (Jonas, 2014) World Bank has predicted that there could be a reduction of roughly 5 percent in global Gross Domestic Product (GDP) due to a severe pandemic (Burns et al., 2006). Economists have estimated that COVID-19 has caused a loss of 3.4 percent in global GDP (Szmigiera, 2022).

2.4.1.3 Social impacts

Social impacts of pandemics spread across a vast range starting from social discrimination to civil conflicts between citizens. (Price-Smith, 2009). Most importantly, due to high mortality communities can collapse drastically. For instance, many indigenous communities in the Americas were severely affected due to deaths caused by smallpox (Diamond, 2009). These shocks can ultimately cause social instability as well. Furthermore, pandemics can change demographic variations as well. For instance, the fear of infection and insecurity provoke people to migrate in large numbers (Barrett and Brown, 2008).

Furthermore, the impacts of pandemics can cause severe political tension as well. For instance, political tension in Guinea and Liberia was aggravated during the Ebola outbreak in 2014-2016 due to the lack of public trust in politicians. These conflicts have hindered public health efforts taken to mitigate the outbreak (ICG, 2015). In addition to that, pandemics can create social problems for minorities within society. There is a high potential for these marginalized groups to be stigmatized for infections and possible consequences (Fraser et al., 2004).

Therefore, it is evident that pandemics and epidemics can create severe devastations across all dimensions starting from health to socioeconomic aspects. However, it is important to note that these impacts can be severely aggravated if any other hazards concur with the pandemic.

2.4.2 How pandemics can affect the healthcare system; experience from COVID-19

During COVID-19 the whole healthcare system in the world was overwhelmed since the number of infected cases has been rising significantly. As shown below healthcare facilities, mainly hospitals have had several responsibilities in regard to responding to the pandemic (Abir et al., 2020).

1. Treating infected COVID-19 patients including patients with severe symptoms and mild symptoms, asymptomatic patients, and suspected cases
2. Continuing treatments for non-COVID-19 infected patients
3. Preventing the virus transmission to healthcare workers (HCWs) and other patients

4. Ensuring the hospital safety from other natural and manmade hazards

However, fulfilling these responsibilities became challenging to the healthcare administration since the whole global healthcare system lacked enough evidence-based measures and scientifically validated information on the virus (Capolongo et al., 2020). Table 2.8 details the main challenges that healthcare facilities faced during the pandemic.

Table 2-8: Challenges faced by hospitals during the COVID-19 pandemic

Challenge	**Remarks**	**Reference**
Inadequate bed capacity	Hospital bed capacity became inadequate because of the sudden inclines in COVID-19 infected patients. Especially, hospitals ran out of enough ICU beds to treat critically ill COVID-19 patients who require weeks of treatment. The shortage of ICU beds has amplified the fatality rates, especially in countries recognized as underdeveloped and with fragile healthcare systems. There is a vast difference between available ICU bed facilities in developed and underdeveloped countries. For instance, New York City had 1,600 ICU beds alone, while there were only 2,000 ICU beds in the whole of sub-Saharan Africa excluding South Africa. Shortages in ICU facilities can lead to major ethical dilemmas as well because of the inability to provide treatment for the whole group of severely ill COVID-19 patients.	(Ma and Vervoot, 2020; Vincent and Creteur, 2020)
Lack of medical equipment	During treatments for COVID-19 infected patients, the requirement for ventilators turned out to be considerably high. Ventilators are required in assisting critically ill patients' breathing since the COVID-19 virus attacks the lungs of infected patients causing breathing difficulties. Therefore, the inadequate number of available mechanical ventilators in healthcare centres emerged as a severe risk. This shortage has increased the death rates during the early stages of the pandemic in countries where COVID-19 cases went considerably high.	(Iyengar et al., 2020).
Lack of PPE	Lack of Personal Protection Equipment (PPE) has affected the safety of HCWs. Especially, the shortage of gloves, hand sanitizers, shields, and respirators has increased the number of COVID-19 cases and deaths among HCWs. One of the major reasons for the shortage of PPEs was the impact of the pandemic	(Bradhser and Adherman,

	on PPE manufacturers. For instance, China was the producer of almost half of the facemasks needed for the whole world, was severely affected during the early stages of the pandemic, and manufacturing and exporting facemasks were paused.	2020; Jacobs et al., 2020)
Inadequate supply of medicines	The impacts of COVID-19 have severely affected supply chains for medicines. Especially medical supplies such as pharmaceuticals, testing materials, and laboratory and intravenous kits were severely hindered during the COVID-19 crisis. Restrictions imposed on international traveling were one of the major reasons, but it was not the only reason for the breakdowns in medical supply chains. Lack of laborers in factories due to migration and domestic travel bans, poor coordination among authorities, financial barriers, etc. have worsened the impacts on the supply chains of medical equipment.	(Mirchandani, 2020; Sharma et al., 2020).
Loss of healthcare workers	Early statistics from the WHO have depicted that a considerable number of HCWs have tested positive for COVID-19. For instance, some countries have reported a percentage of over 30% of HCWs being infected by the virus. In addition to COVID-19 infections, the pandemic has posed significant mental stress on frontline HCWs. Inside COVID-19 treatment facilities, frontline HCWs are supposed to work for long hours with the fear of uncertainty and exposure to the virus. Mostly in developing and underdeveloped countries, transportation facilities for HCWs were affected during lockdown periods and it increased their mental stress further. In addition to that, HCWS had to experience verbal harassment, discrimination, and physical violence during COVID-19.	(Pappa et al., 2020; WHO, 2020b, 2020c)

Healthcare-associated infections	Since hospitals became overcrowded with COVID-19 infected patients, hospitals turned into red spots of the virus causing healthcare-associated infections. For instance, during the second wave of COVID-19 in the United Kingdom, infections within healthcare facilities have risen considerably due to the increased hospitalization rates.	(Heneghan et al., 2020; Kim et al., 2020)
Breakdowns in non-COVID-19 treatments	Due to the fear of COVID-19 infections, the number of non-COVID-19 patients who are reaching the hospitals for treatments has decreased considerably. In most cases, this has led to deaths at home without getting proper treatments for diseases such as heart problems and cancers.	(Baral, 2020; Hurdle, 2020)
Impacts on the mental well-being of patients	Uncertainty about COVID-19 has affected the mental well-being of both COVID-19 patients and non-infected patients.	(Jakovljevic et al., 2020)
Impacts of concurrent hazards during the pandemic	Hazards would not stop occurring since COVID-19 is already there. Therefore, although the hospital system has been already overwhelmed by the pandemic, hospitals were supposed to cope with the impacts of concurrent hazards that occur amidst the pandemic. For instance, several hospitals in Croatia were evacuated due to an earthquake with a magnitude of 5.3 Mw. Furthermore, a fire that broke out in an ICU ward has killed 10 COVID-19 patients in a Romanian hospital.	(Čivljak et al., 2020; NDTV, 2020)

The impacts of the pandemic have made evident the systemic nature of risks and hazards no longer affect a discreet part of a system but affect the whole system. If a system is considered, several subsystems are interconnected and depend on each other. Therefore, an effect on one element of a system will weaken the connected elements, which will eventually lead to the dysfunctionality of the whole system. These failures can be identified as a series of cascading events. During the review of literature, it was evident that increased hospitalization rates due to the COVID-19 pandemic have triggered a series of disruptive events within the hospital system. Studying these cascading impacts is beneficial for identifying the components of the hospital which are affected step by step and educating decision-makers on necessary measures for resilience enhancement. During the present study, considering the insights from the review, cascading events inside a healthcare facility were modelled as shown in Figure 2.5.

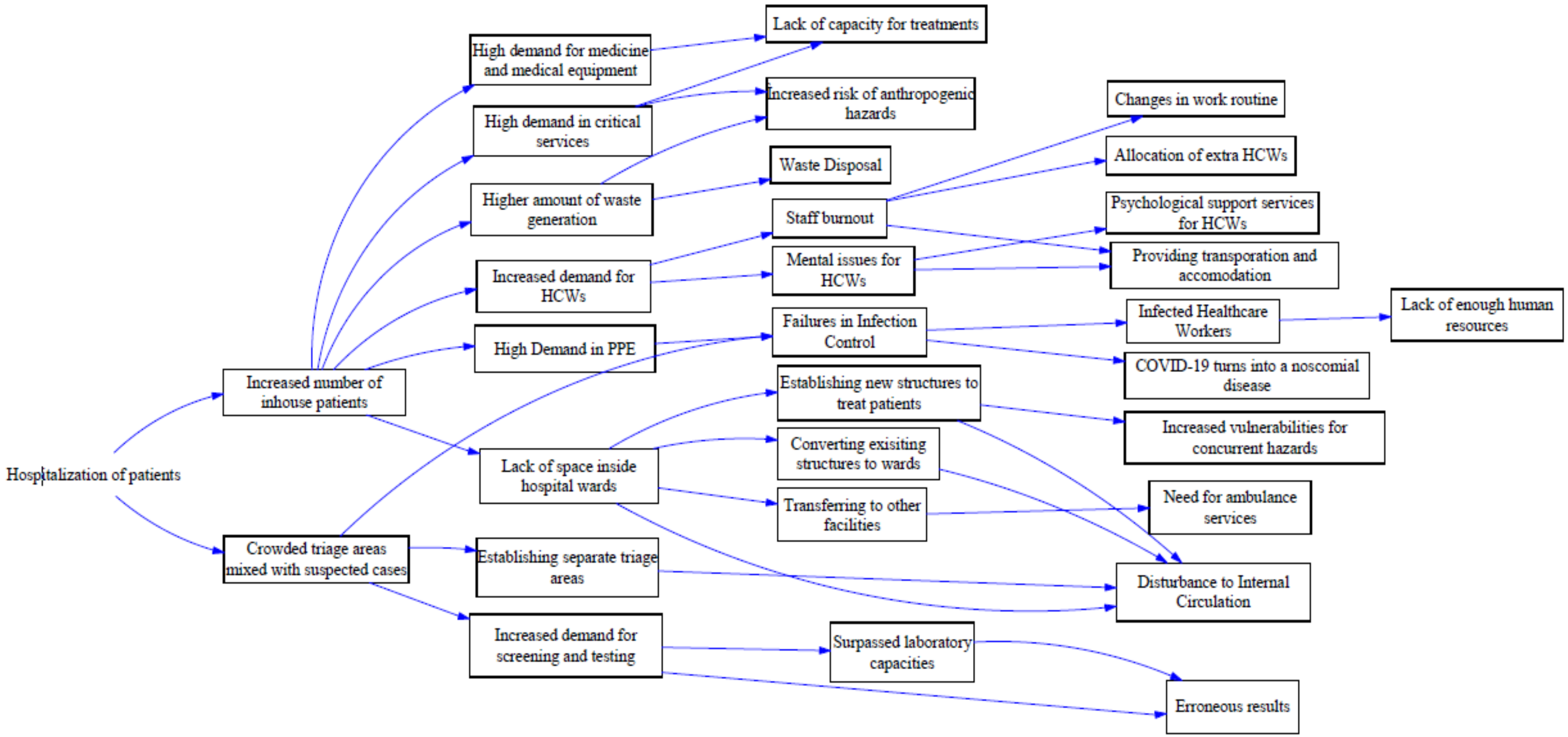

Figure 2.5: Representation of identified cascading events inside a hospital during COVID-19 *(Developed by author)*

2.4.3 Multi-hazard scenarios featuring pandemics

Multiple hazards can be defined as hazardous events where natural, man-made, or biological hazards overlap in time and space (Adapted from Quigley et al., 2020). In general, if two or more hazards are occurring simultaneously those hazard events can be referred to as multi-hazard scenarios (Ex: floods and landslides amidst COVID-19). Currently, natural hazards have concurred and interacted with the impacts of the COVID-19 outbreak and disrupted response measures for COVID-19 and vice versa. Apart from COVID-19, 389 climate-related hazards were reported during the year 2020, and these events have claimed 15,080 lives around the world (CRED and UNDRR, 2021). The impacts of compound hazard events during a pandemic were not a new experience to the world. Throughout history, biological outbreaks have started following natural disasters such as floods, hurricanes, earthquakes, etc. For example, 922 people died of pneumonia, strokes, and myocardial infarctions after the Great Hanshin-Awaji Earthquake in Kobe and Osaka (Takeyoshi et al., 2001). In Sri Lanka, leptospirosis outbreaks have increased in the Medirigirya area after the high occurrence of floods (Wijerathne and Senevirathna, 2018). Furthermore, cascading impacts followed by major disaster events pose severe disruptions to society.

2.4.4 COVID-19 and concurrent hazards

Recently, a perfect example of a multiple hazard scenario was reported in Honduras. Two hurricanes affected the country during the COVID-19 pandemic. The time gap between these two hurricanes was not more than two weeks. According to reports, these hydrometeorological hazards have affected more than 3.5 million people in Honduras (Zambrano et al., 2021). Furthermore, Vanuatu experienced a category 5 cyclone named, Harold, with high winds of 200km/h which caused severe devastations. The same cyclone affected the Fiji Islands with power outages, fallen trees, and flooding. More than 1,500 victims were sheltered in 52 emergency shelters (WMO, 2020). Table 2.9 presents a summary of selected concurrent hazards that occurred amidst COVID-19 in 2020 and 2021.

Table 2-9: A summary of selected hazards that occurred during COVID-19 in 2020 and 2021

Location	**Year**	**Type of hazard**	**Impacts**	**Reference**
Croatia	2020	Earthquake	• It was a Mw6.4 magnitude earthquake • Seven deaths were reported • Infrastructure systems and buildings, including the major hospital and a number of other healthcare-related facilities in the region, have been severely damaged.	(International Medical Corps, 2020)
Samos Island	2020	Earthquake	• The northern coast of Samos Island was hit by an earthquake of a magnitude of Mw7.0 hit. • It has killed two people and injured 19 others on Samos Island.	(Kiratzi et al., 2021)
Philippines	2020	Typhoon	• The typhoon *Vamco* has killed at least 42 people and caused extensive flooding in the Philippines	(Gomez and Favila, 2020)
Haiti, Dominican Republic and Puerto Rico	2020	Strom	• In Haiti, the Dominican Republic, and Puerto Rico, Tropical Storm Laura killed at least 23 people, created landslides, and cut off remote settlements.	(Brackett and Childs, 2020)

India and Bangladesh	2020	Cyclone	• In India and Bangladesh, Cyclone Amphan claimed more than 85 deaths, wreaking havoc on low-lying areas with massive devastation of houses, crops, and infrastructure.	(Slater, 2020)
Afghanistan	2020	Floods	• Flash flooding in Afghanistan killed 150 people in a remote area. • According to reports, flooding has destroyed over 100 homes in the area.	(India Today, 2021)
Guatemala	2020	Hurricane	• Mudslides caused by Hurricane Eta caused nearly 150 deaths or missing people. • In the central mountains of the country around 150 homes were buried due to massive landslides.	(CBS News, 2020)
Indonesia	2021	Volcano eruption	• At least 34 people were killed by a volcano that erupted on the Indonesian island of Java. • Nearly 5,205 people had been affected by the eruption. Furthermore, it caused 3,697 displaced from their homes • Temporary tents were set up at 19 places around the Pronojiwo, Candipuro, and Pasirian sub-districts.	(Suhartono, 2021)
India and Nepal	2021	Flash floods	• More than 180 people have died due to flash floods caused by heavy rains in Nepal and India.	(BBC News, 2021)

			• Large numbers of people have been evacuated, and over 1,600 homes have been burned or damaged.	
Indonesia and Timor-Leste	2021	Cyclone	• Cyclone Seroja has killed around 222 people in Indonesia and Timor-Leste. • Furthermore, it has affected over 600,000 civilians while displacing nearly 20,000 people. • According to reports, nearly 2,000 buildings including a hospital were affected by heavy rains and winds.	(Alexander, 2021)
Germany	2021	Floods	• Floods caused by heavy rain which lasted nearly for a week killed almost 200 people and injured nearly 700 people. • Damages to infrastructure have severely affected the disaster response services. For instance, at least 80 train stations were not operating, and many railway lines were out of service. It affected the supplies of resources required for relief services.	(Fitzgerald et al., 2021)

2.4.5 Impacts of concurrent hazards

Multiple hazards emerging at the same moment can harm a community in a synergistic way. Climate-related hazards which wreaked havoc during COVID-19, have made it impossible to respond to many catastrophes at the same time. When a country's disaster management officials are dealing with multiple crises at the same time, reaction efforts for one disaster can exacerbate the effects of another. (UNDRR and OCHA, 2020). For example, adopting social distancing restrictions to limit COVID-19's severe consequences may have an impact on countermeasures for a simultaneous catastrophe such as a tsunami or flood. Emergency response coping capacities were harmed during the COVID-19 epidemic, despite the fact that the occurrence of a second calamity compounded the difficulties (Chondol et al., 2020).

As a result of social distancing and movement limitations during COVID-19, opportunities for safe evacuation were limited. As a result, it was expected that large-scale evacuations in the event of a simultaneous hazard scenario would result in a significant rise in pandemic morbidity and mortality (Collins et al., 2021). Most of the time, public places such as schools, religious places, etc., are converted into disaster shelters, and the local authorities are vested with the responsibility of managing those places. However, spaces in shelter sites have become insufficient to maintain social distancing during the COVID-19 pandemic. When shelter sites are crowded with less ventilation and lack proper healthcare facilities, it can increase the risk of COVID-19 transmission inside the shelter sites (Vikas, 2020). Furthermore, severe challenges associated to shelter sites for numerous catastrophes include the requirement for hygiene and safety materials, special arrangements and segregation of people at increased risk of COVID-19, and extensive loss of social infrastructures (Mohanty et al., 2021; Potutan and Arakida, 2021).

Because of the COVID-19 pandemic, natural and other disasters will not stop continue to arise. Even though natural hazards affect all, the impacts are uneven and cause more adverse effects on certain communities. Though COVID-19 does not discriminate, its impacts and response measures vary (Nordling, 2020). Devakumar et al., (2020) stress the fact that the access for marginalized groups to healthcare facilities was limited by policy responses taken during the pandemic. Concurrent hazards events, such as natural hazards during a biological outbreak, can exacerbate existing socioeconomic weakness in a community. These combined effects can have a negative influence on already marginalized and adversely impacted communities (Chen and Cook, 2020; UNDRR and OCHA, 2020). Travel bans and quarantine regulations, for example, caused an insufficient supply of food and relief materials for natural disaster victims in India and Bangladesh (Suri, 2020). Furthermore, these impacts have highlighted the consequences of neglecting vulnerable communities in disaster preparedness and response planning. For instance, a significant number of people in India are excluded from social resilience measures due to reasons such as lack of proper identification (UNDRR and OCHA, 2020).

The combined effects of pandemics and nature induced disasters, and other emergencies can wreak havoc on a country's health system that is already under pressure. Natural hazards can cause direct damage to the built environment of hospitals or indirect damage by disrupting support services (Hassan and Mahmoud, 2019; Khanmohammadi et al., 2018). Even without the presence of damages to the hospital, its functionality can be affected by a surge in the number of patients (Hassan and Mahmoud, 2020). Furthermore, man-made hazards such as fires also substantially impact the safety of occupants, infrastructures, and functionality of hospitals (Chowdhury, 2014). Meanwhile, biological outbreaks disrupt hospital functionality by the increasing rate of hospitalization (Ehelepola and Wijesinghe, 2018). Hariri-Ardebili, (2020) demonstrates that a hospital's loss of capability becomes quick after simultaneous dangerous occurrences such as natural hazards and pandemics.

Withstanding the combined impacts of concurrent hazards constituted a huge issue for the global healthcare system during the COVID-19 pandemic. For instance, hospitals in the capital of Croatia were evacuated during the earthquake in March 2020 (Čivljak et al., 2020). Furthermore, 25% of healthcare facilities in the Northern province of Vanuatu were destroyed by the cyclone Harold that hit the Asian pacific region amidst the COVID-19 pandemic (WMO, 2020). In Japan, more than twenty hospitals were flooded or had no electricity and water during the heavy rains in June 2020 (Al Jazeera, 2020). Multiple disasters striking at the same time have highlighted the urgent need for a multi-hazard strategy for DRR that takes into account the systemic and cascading characteristics of risks.

2.4.6 Strategies for battling multi-hazard contexts

The effects of simultaneous hazards that concurred COVID-19 have proven that a hazard-by-hazard strategy for DRR, including high-level disaster preparedness, has to be changed to a multi-hazard approach. Establishing methods to identify, quantify, manage, or eliminate systemic risk while maintaining a thorough awareness of cascading threats has become a difficult task (UNDRR, 2020a). Governments have a huge role in this regard to make complicated and highly compromised judgments that take into account the necessity to mitigate the effects of multi-hazards and cascade impacts (Filippelli, 2020). Processes for addressing the impacts of multiple concurrent hazards require changes to international and national policy to better prevention, preparedness, mitigation, response, and rehabilitation (Cardil and de-Miguel, 2020). According to Rogers et al. (2020), government and decision-makers should have an equal focus on both low probability and high impact events and high probability, relatively minor but media relevant events. If not, the catastrophic impact of low likelihood events such as multiple extreme hazards can be neglected at the planning stage. Revision of Standard Operation Procedures (SOPs) and contingency plans and repositioning and strengthening emergency supply chains are a few measures that can enhance multi-hazard preparedness. In regard to MHEW systems, there should be redesigns in policies related to preparedness and response planning for multiple hazards informed by scientific insights, especially during biological outbreaks such as the COVID-19 pandemic.

Hazard monitoring, forecasting, and predictions, an element of an MHEW system, have a crucial role in mitigating the impacts of multiple hazards. For instance, accurate forecasting and prediction methods enable the relevant authorities to plan response mechanisms ahead of another disaster that occurs during a pandemic (Quigley et al., 2020). In this regard, modelling techniques such as System Dynamics, Discrete Event Simulation (DES), dynamic models, etc. can be used to forecast changes in the spread of a pandemic and identify the possible catastrophic scenarios created by the occurrence of other natural or man-made hazards (Moodley et al., 2021). Moreover, there should be adaptions in early warning systems to include information on physical distancing and preventive behaviours during evacuations (UNDRR and OCHA, 2020). Disaster risk communication has the potency of supporting the preparation of multi-hazard scenarios during the pandemic. In this regard, local governments, community-based organizations, and humanitarian agencies have a significant role in identifying possible hazards and overlapping events, strategies to keep communities safe from multiple hazards, and possible ways for crafting and disseminating messages (MacClune et al., 2020).

In order to reduce the catastrophic risks of simultaneous hazards and pandemic cascading effects, a multi-sectoral approach must be emulated. The engagement of key stakeholders is critical in improving resilience in the face of hypothetical multi-hazard scenarios, such as a Tsunami during a pandemic (UNDRR, 2020b). Countries should have a sound legal basis to avoid power struggles between government departments and ensure coordination arrangements in disaster management mechanisms (Haigh et al., 2018; UNDRR and OCHA, 2020). The Bangkok Principles for the Sendai Framework's health components underline the importance of incorporating health into disaster management strategies and practices (UNISDR, 2016). Coordination between health authorities and disaster management institutions is thought to be important. The COVID-19 pandemic's negative cascading effects underscored the importance of adhering to these guidelines (UNDRR, 2020c). Furthermore, capabilities of local actors to access resources easily should be strengthened since they are the first to respond to a disaster (UNDRR and OCHA, 2020). During the evacuation and shelter management process, collaboration with relief services and the private sector and the continuation of the supply of emergency services to victims play a key role in avoiding further cascading impacts. Likewise, preventing the impacts of compound hazards and cascading effects need to be achieved through steps such as strengthening risk governance and multi-institutional coordination, rearranging policies on preparedness and response planning, strengthening early warning systems and risk communication, and enhancing capacities and engagement of local authorities and relief services.

2.5 Context of Sri Lanka

2.5.1 Disaster management in Sri Lanka

Following the 2004 Indian Ocean Tsunami and the extensive devastation it wreaked, the necessity for a methodical approach to disaster management became apparent, prompting the appointment of a Parliament Select Committee on Natural Disasters (2005) to make recommendations (Siriwardana et al., 2018b). The recommendations were given in the committee report, and in May 2005, the government passed the Sri

Lanka Disaster Management Act, which established a legislative structure for disaster management in the country. Several regulatory organizations and policy structures were established within the legal provisions of the stated legislation to control and implement DRM operations in the country (Disaster Management Ministry, 2014). The Sri Lanka Disaster Management Act No. 13 of 2005 included provisions for the establishment of the National Council for Disaster Management (NCDM) and the Disaster Management Centre (DMC) as the executing agency of the NCDM. Being the central authority for executing a countrywide Disaster Risk Management program, it is important to be noted that the DMC has the right to gain the assistance of 'mandated national agencies' to carry out activities related to Disaster Risk Management. The said Act has made legal provisions for a set of technical agencies to forecast and issue early warnings related to impending disasters to the DMC. These early warnings are disseminated to the grass-root level using the national early warning system (Disaster Management Centre, 2014a).

It is important to note that the current institutional framework for Disaster Risk Management (DRM) encourages a decentralized approach to DRM, in which the national government is responsible for disaster response in the first instance, but subnational in the second instance. The goal of replicating a decentralized [or decentralized] approach to DRR is to ensure that all levels of government and diverse stakeholders are involved in the disaster risk reduction and management process. It is the responsibility of the authorities to collate the relevant Disaster Management Plans within respective areas including provisions for the establishment of Disaster Management Committees in the area (Disaster Management Centre, 2014a; Siriwardana et al., 2018b).

At the national and regional level, technical agencies generate Early Warnings based on hazard monitoring and forecasting and support the DMC with technical assistance for preparedness and response planning activities. In addition to these agencies, ministries in charge in the NCDM, tri forces, police, Non-Government Organizations, Community Based Organizations, etc. are involved in the DRM activities in the country. These agencies are planning, implementing, and coordinating DRM activities as per the disaster management plans and programs at different administrative levels (Disaster Management Centre, 2015).

The existing institutional framework for disaster management in Sri Lanka considers health as a major aspect of DM mechanisms. According to the National Disaster Management Act and Disaster Management Plan, the Ministry of Health is vested with the responsibility of managing emergencies and disasters that can threaten the health and well-being of the community. For instance, the risk of epidemics like Dengue and Hepatitis and pandemics such as SARS, Avian Influenza, and the current COVID 19 pandemic must be handled through a mechanism driven by the health sector, with the Ministry of Health, Nutrition, and Indigenous Medicine playing a prominent role. (Disaster Management Centre, 2015; DPRD, 2018).

However, the existing disaster management mechanism in the country does not adequately consider the integrated disaster management approaches which are promoted at the global level currently. The systemic nature of risks in the present world has called for countries to shift from traditional risk by risk perspective to integrated systemic risk approaches. Interactions of hazards, especially extreme events, with systems that are complex, interdependent, and highly interconnected by means of social, economic, technical, and environmental pave the way for systemic risks (United Nations Office for Disaster Risk Reduction, 2019). COVID-19 has set an example of how hazards can affect the whole system rather than posing challenges to discreet parts of the system (UNDRR, 2020c). Improving disaster and emergency risk management to include systemic risk and resilience, removing barriers for a whole of society involvement, and equipping the community to go beyond traditional DM methods can be identified as several approaches to reshape the existing disaster management practices (Australian Institute for Disaster Resilience, 2021). Although Sri Lanka has started several initiatives such as interdisciplinary approaches to strengthen hospital safety (Hasalanka et al., 2021; D. Kularatne et al., 2019), biological hazard preparedness in the construction sector (CIDA, 2020), and community-based risk management mechanisms, these approaches are still to be developed vastly.

2.5.2 Public health system in Sri Lanka

Mainly the public health sector in Sri Lanka contains two branches namely curative health services and community (preventive) health services. The curative health sector varies from primary health care units to specialized hospitals while the community health services pay attention to the preventive side of the people. These services are responsible for focusing on child and maternal health, as well as communicable diseases. Both of these health services have had their relevant health units delegated from the national to the local level. In the context of curative health services, teaching hospitals, provincial hospitals, specialized hospitals, and some base hospitals and district hospitals function under the central government. The provincial government manages the remaining district and base hospitals, divisional hospitals, and Primary Medical Care Units (Ministry of Finance, 2016). According to Health Facility Survey (2015), altogether 1085 healthcare institutions provide the service under Curative health care (Ministry of Health and Indigenous Medical Services, 2015).

Though there are only 21 teaching hospitals functioning, they have the highest bed strength: 29% out of the total hospital beds (Ministry of Health and Indigenous Medical Services, 2015). The main functions of preventive health care and the responsible institutions for the respective function are shown below in Table 2.10. In regards to preventive healthcare institutions, the central government regulates the Family Health Bureau (FHB), Health Promotion Bureau (HPB), Epidemiology Unit, and specialized campaigns while the Medical Officers of Health (MOHs) and provincial public health programs function under the provincial government (Medcalf et al., 2015).

Table 2-10: Responsible agencies in preventive health services and their functions

Function	**Responsible Agency**
Disaster preparedness and response	Disaster Preparedness and Response Division (DPRD)
Communicable Disease Prevention and Surveillance	Epidemiology Unit Special Campaigns – Dengue, Malaria
Immunization	Epidemiology Unit
Maternal & Child Health Care Services	Family Health Bureau
Health Promotion and Education	Health Promotion Bureau

Non-Communicable Disease Prevention	NCD Unit, Ministry of Health
Environmental and Occupational Health	E & OH unit, Ministry of Health

Public health services in the country are provided under the purview of the Minister of Health at the Ministry of Health, Nutrition, and Indigenous Medicine. The Minister of Health is assisted by the Deputy Minister of Health while on an administrative level; the Secretary of Health is assisted by the Additional Secretary and Senior Assistant Secretary.

Separate ministries of health have been formed at the provincial level in each of the nine provincial councils, demonstrating this. The Provincial Directors of Health Services (PDHS) are in charge of these ministries. Each province is organized into administrative districts, with Regional Directors of Health Services (RDHS) in charge of health services. There are currently 26 Regional Directors of Health Services (RDHS) in the country (Epidemiology Unit, 2012). The organizational structure of RDHS at the district level can be shown in Figure 2.6 (Senanayake et al., 2017).

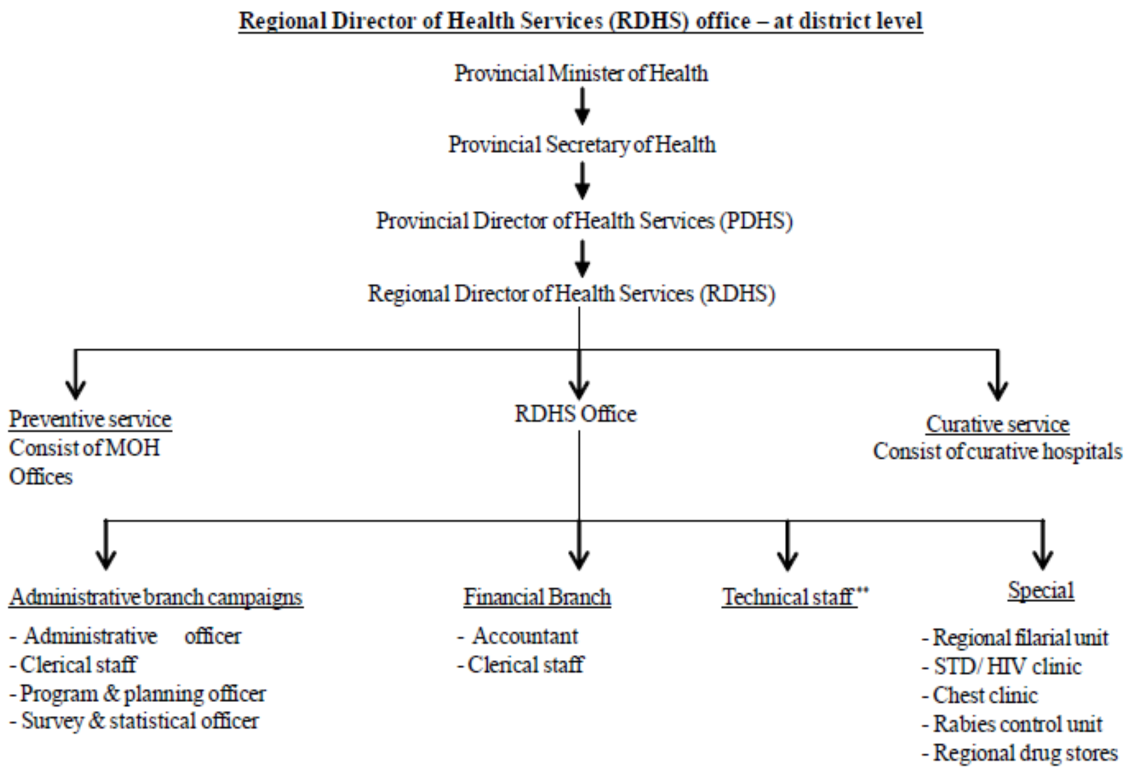

Figure 2.6: Organizational structure of Regional Director of Health Service Office

Medical Officers of Health (MOHs) handle public health services in smaller regions inside each district. MOHs are in charge of providing preventive and promotional health services in their administrative regions (Epidemiology Unit, 2012; Medcalf et al., 2015). The MOH engages in health promotion activities which include activities like executing awareness-raising programs (pertaining to epidemics like Dengue and Leptospirosis) and carrying out dental clinics in the division's schools and offices The organizational structure of the MOHs at the divisional level is shown below in Figure 2.7 (Senanayake et al., 2017).

Each MOH area is divided into smaller sub-units, each of which is controlled by a Public Health Inspector (PHI) who is in charge of tasks like sanitation, disease prevention, and promoting nutrition and hygiene in the sub-unit. A PHI area is further broken into areas with populations ranging from 3000 to 4000 people. This division is made to allow local Maternal and Child Health (MCH) operations to be carried out under the guidance of a Public Health Midwife (PHM) (Epidemiology Unit, 2012).

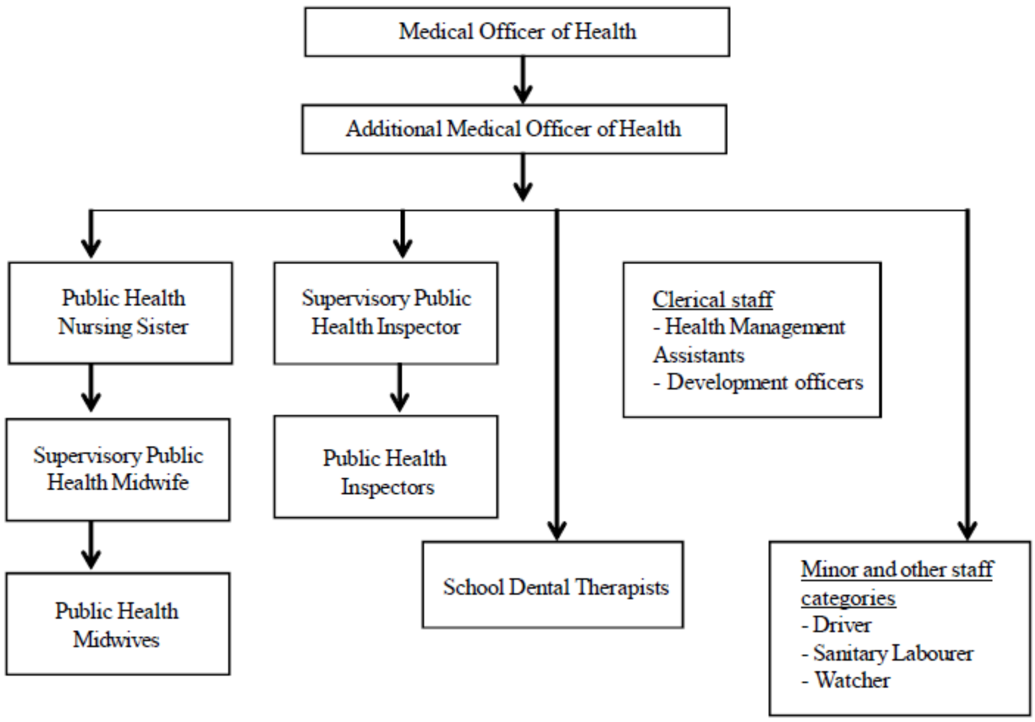

Figure 2.7: Organizational structure of MOH Office

2.5.3 A snapshot of COVID-19 and compound hazard scenarios in Sri Lanka

Sri Lanka has taken precautions to prevent the entry of coronavirus into the country in the third week of January 2020, far before the first imported case of COVID-19 was discovered on the 27th of January (Embassy of Sri Lanka Indonesia, 2020; Epidemiology Unit, 2020). Travelers arriving from Iran, South Korea, and Italy have been sent to the quarantine center in Batticaloa since the first week of March. By the 5th of April, the Sri Lanka Army had 37 quarantine centers, the Sri Lanka Air Force had two, and the Sri Lanka Navy had one (Ministry of Health and Indigenous Medical Services Sri Lanka, 2020). The Sri Lankan government implemented many preventive and control steps after the first Sri Lankan tested positive for COVID-19. Within a week, schools and universities were shuttered, and an emergency curfew was enforced on parts of the island where there was a high danger of transmission. Furthermore, the government imposed an island-wide curfew in the third week of March in response to the rising number of COVID-19 cases (Fernandez, 2020)

Within the first wave of the COVID-19 outbreak in the country, Sri Lanka reported a total of 3396 cases with a death toll of 13 (Rodrigo, 2020). The second wave of COVID-19 in Sri Lanka started after a cluster was detected in early October. Two major clusters were detected in an apparel factory and a wholesale fish market (PTI, 2020). The third wave of COVID-19 in Sri Lanka officially began in mid-April and daily new cases rose to 2,500. Amidst the rapid increase in the number of infected cases, the nationwide lockdown imposed by the Sri Lankan Government lasted until the 1st of October 2021 (Kotelawala, 2021; PTI, 2021). By the end of 2021, Sri Lanka has reported 587,596 COVID-19 cases with a death toll closer to 15,000 (Worldometer, 2021a). Apart from the pandemic, several natural hazards affected the country severely.

Normally, Sri Lanka experiences rain from a variety of sources, including monsoonal, conventional, and depressional rain (Department of Meteorology, 2019). Monsoonal showers and depressions in the Bay of Bengal have caused heavy showers in Sri Lanka during the COVID-19 outbreak. Sri Lanka experienced the first season of heavy showers which concurred with COVID-19 in May 2020. These heavy rains caused a rainfall of over 200 mm within 24 hours in some areas of the country. During the heavy rains in Kegalle District, which was the most adversely hit district, over 2000 people were killed and 400 homes were damaged. Affected houses and victims were primarily caused by high winds and landslides (Flood List, 2020a). Furthermore, severe rain and flash floods in Sri Lanka in August 2020 destroyed houses and affected over 1,500 people in the districts of Kandy and Kegalle, according to the DMC (Davies, 2021).

Heavy rains fell over the country from December 2 to 5 as a result of monsoonal showers and a cyclone in the Bay of Bengal. These heavy rains have wreaked havoc on Sri Lanka's northern region (IFRC, 2020). DM officials made preparedness measures ahead of Cyclone Burevi, and residents were moved to safety centers in the Northern and Eastern regions (Flood List, 2020b). Due to the formation of winds in the South-West monsoon in 2021, the Southwestern part of Sri Lanka had more than 300mm of rain in less than 24 hours. The DMC reported that severe rains hit 84 divisions in 10 districts for a month commencing on May 2nd, 2021. During that time, a total of 245,212 affected people were reported, with 14 deaths. Furthermore, two people were missing at the time of reporting owing to flooding and power outages (DMC, 2021). Since the country's DM mechanism was put to the test for several hazard scenarios within the period of the third wave of the COVID-19 pandemic in 2021, the country's readiness and abilities to respond have been put to the test. In order to respond to these concurrent threats, the country's Disaster Management and Public Health sectors have to work together.

2.6 Systems Thinking as an Approach for Measuring Public Health System/Hospital Resilience

2.6.1 Definition of a system

Miller (1995) has defined a system as a set of interacting units that have relationships among them. Although there are several definitions for a system, they do not deviate significantly. Accordingly, a system can convert the input to a particular output where the magnitude of the output depends on the input (Simonovic, 2010). Based on the interlinks between inputs and outputs there are two types of systems named, Open systems and Feedback systems. In open systems, the output does not impact the input while the inputs are changed according to the outputs in feedback systems (See Figure 2.8). It is important to note that a system may consist of people and physical elements. Furthermore, there can be physical, social, technological, economic, biological, and political components inside a system that increases its complexity of the system (Bala et al., 2017).

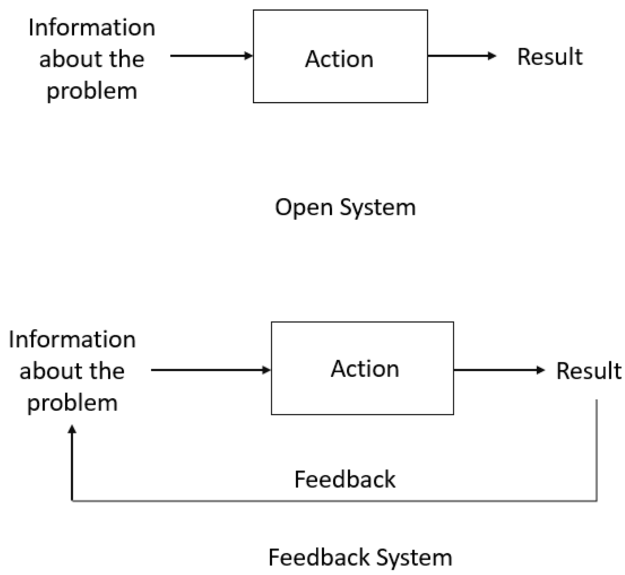

Figure 2.8: Visualisation of types of systems

It cannot be denied that, at present, people highly depend on critical infrastructure systems such as water, energy, health services, telecommunication, etc. (Randil et al., 2022; Turoff et al., 2016). Furthermore, interdependencies among these CI systems have grown rapidly due to reasons such as globalization, and technological advancements (Arnold and Wade, 2015). At present, the world consists of networks of systems that are complex and highly interconnected. Therefore, an extreme event that affects one component in a system can severely impact other components which are connected to each other, thus posing severe devastation on the whole system and affecting the community (Helbing et al., 2006). Since elements that are at risk of disasters connect to each other and are not in isolation, the use of *Systems Thinking* in disaster risk management is highly beneficial (Simonovic, 2015). Systems thinking can be used as a rigorous approach for determining plans and mechanisms for disaster management in relation to large-scale complex systems.

The term *Systems Thinking* refers to systems of thinking about the system in general. Out of the available definitions for systems thinking, Sweeney and Streman have defined systems thinking as representing and accessing the dynamic complexity of a system both graphically and textually (Sweeney and Sterman, 2000). Despite the availability of various definitions, the process of systems thinking involves identifying interconnections, understanding the dynamic behavior of systems components, systems structure as a cause of that behavior, and the idea of seeing systems as a whole rather than parts (Arnold and Wade, 2015).

It is important to note that different dimensions such as dynamic thinking, structural thinking, and operational thinking, which the systems thinking approach includes, are highly beneficial for managing the complexity of disaster management (Simonovic, 2010). Complex activities such as devising and testing emergency plans, resource prep-positioning, risk assessments, recovery of the built environment, and damage assessments, which are performed in disaster preparedness and recovery stages can be more streamlined with the use of systems thinking (Chandana and Leung, 2010; Simonovic, 2015). Furthermore, the systems thinking approach allows for capturing a holistic view of vulnerabilities before a disaster and damages after a disaster. Traditional approaches which have a risk-by-risk perspective do not adequately capture all the possible paths of vulnerabilities and indirect damages after a disaster occurs. Therefore, among highly interconnected complex systems, this approach allows witnessing the big picture since the ability to see the world as a complex system is the essence of systems thinking (Mavhura, 2017; Sterman, 2002). However, to be successful in the systems thinking approach, it is necessary to understand the characteristics of complex systems.

2.6.2 Characteristics of complex systems

There is no hard and fast rule between simple and complex systems. The complexity of a system results from the interdependencies between components in a system. In a complex system most importantly there are a large number of elements that are interconnected to each other. If these elements are considered individually, those may be simple. However, the larger the number of elements in a system, the more difficult it is to understand the system (Cilliers, 2005). The presence of a large number of elements alone does not make a system complex. For example, due to the presence of a high number of sand particles, a beach cannot be introduced as a complex system. Within a system, elements interact with each other and these interconnections are dynamic (Cilliers, 2002).

It is important to note that, complex systems are inherited with interconnections that are integrated to gain feedback from previous interactions. Therefore, the effect of any activity within a given system can become feedback (Northrop, 2010). Furthermore, interconnections between system's elements are non-linear. It indicates that a small change in a particular element can cause a large result finally and vice versa (Cilliers, 2002). Accordingly, the systems thinking approach defies the belief that the sum of the performance levels of elements in a system is equal to the performance of the whole system. In addition to that, interactions exist within a short range of elements. Most of the time information required for a particular element is received by a neighboring element. Because of this, characteristic individual elements do not take into account the functions of the whole system but respond to information that is available to those (Cilliers, 2005).

Moreover, complex systems showcase adaptive behaviors. These behaviors are modified by the system itself based on the state of and predictions of the environment (Northrop, 2010). In general, complex systems consist of history since they require a long history to function. Therefore, most of the time information on history is stored by a complex system. Accordingly, the present behavior of a complex system is connected with its past behavior (Ladyman and Wiesner, 2020). Interactions between elements in a complex system decide its behavior mainly. However, due to this interconnectedness, if a particular element of a system is affected by a disaster, the effects can cascade into other layers of elements as well. Therefore, in using the systems thinking approach in disaster risk management it is important to understand how do disaster effects cascade within a complex system.

2.7 Summary

This chapter presents the literature review conducted covering the resilience of public health systems during a multi-hazard context, especially amidst a biological outbreak. Accordingly, the chapter identifies the gaps in the Sri Lankan context in relation to health emergencies and disaster management mechanisms for multi-hazard events. Furthermore, the chapter presents the need for considering the health sector as a system in exploring and enhancing its resilience in multi-hazard contexts.

3 RESEARCH METHODOLOGY

3.1 Identification of Key Drivers in Biological Hazard Preparedness

Since biological outbreaks can pose severe impacts over a long period, it is necessary to identify what are the areas to be prioritized in mitigating the possible impacts. Therefore, this step attempts to identify the key drivers in biological hazard preparedness. In this regard, relationships between parameters on pandemic preparedness and performance in COVID-19 were explored using Pearson's correlation method incorporating a database of 145 countries. In addition to that, based on identified relationships, a set of key performance criteria that are specific to the COVID-19 context were determined by using the Mahalanobis distance discrimination method.

3.1.1 Global Health Security

3.1.1.1 Global preparedness for biological outbreaks

"Global Health Security" is described by the WHO as the prevention, identification, and response to naturally occurring biological diseases (World Health Organization, 2015a). WHO's International Health Regulations (2005) serve as international legislation that aids in improving the health security of a country (WHO, 2008). Most countries evaluated their prior performance and changed their nationally developed preparedness and response plans in light of the lessons learned during pandemics (Droogers et al., 2019; Oshitani et al., 2008). For instance, the Ebola in Africa in 2014-2016 prompted the United States to improve healthcare facility preparation (Bell et al., 2016). Evaluating global and national preparation in a structured manner is crucial within the framework of upholding the health security around the globe since it allows for the identification of sections that are not well prepared (Oppenheim et al., 2018). Table 3.1 presents a summarized description of tools that are in use for assessing levels of compliance with IHR (2005).

Table 3-1: Tools available for assessing Global Health Security

Name	Developers	Remarks	References
Self-Assessment Annual Reporting (SPAR)	World Health Organization (WHO)	This tool used self-reported documents of a country to evaluate the preparedness	(World Health Organization, 2018a)

Joint External Evaluation (JEE) Tool	World Health Organization (WHO)	JEE assesses health security based on three sectors namely, prevention, detection, and response. These three areas consist of 49 indicators under 19 technical areas. The assessment process takes place every 4-5 years	(World Health Organization, 2017)
Global Health Security Index (GHSI)	Nuclear Threat Initiative (NTI) and the John Hopkins Centre for Health Security (JHU)	There are three new areas introduced in GHSI in addition to the three Sections in JEE, Accordingly, this tool evaluates the health system, compliance with international norms, and overall risk environment additionally. There are 84 sub-indicators in this tool, listed under 6 main categories.	(Nuclear Threat Initiative and Johns Hopkins School of Public Health, 2019)

3.1.1.2 Global Health Security Index (GHSI)

GHSI has been designated as a prominent significant comprehensive tool of assessment for national health security in over 190 nations, pushing them to make measurable improvements in individual health security of countries at the national level and to improve global readiness for virus outbreaks. The GHSI differs from the JEE in that it includes additional factors under health system resilience, conformity with international norms, and risk environment when assessing a country's projected level of preparation. As a result, the GHSI has six primary categories with a total of

34 components (presented in Table 3.2). During the process of evaluation, this assessment tool considers a wide variety of topics that impact the global health security. For instance the tool includes, the hospital bed capacities as well as the performance of the government (Nuclear Threat Initiative and Johns Hopkins School of Public Health, 2019).

Table 3-2: Subindexes available for assessment in GHSI

Indicator	**Description**	**Countries with the highest scores**
Overall GHSI index	The overall score of 6 categories	United States, United Kingdom, Netherlands
Prevention sub-index	Preventing the emergence of pathogens	United States, Sweden, Thailand
Detecting and reporting sub-index	Early detection and reporting for epidemics of potential concern	United States, Australia, Latvia
Rapid Response sub-index	Responding rapidly and mitigating the spread of an outbreak	United Kingdom, United States, Switzerland
Health System sub-index	Resourcefulness and robustness of the healthcare system in treating diseased people and preventing disease spread to healthcare workers	United States, Thailand, Netherlands
Compliance with International norms sub-index	Measures taken by the government to improve health capacity, financial plans to close gaps, and adherence to global norms	United States, United Kingdom, Australia
Risk Environment sub-index	The overall risk environment encompasses political hazards as well as the country's vulnerability to biological outbreaks.	Liechtenstein, Norway, Switzerland

The findings of this tool show that there is no country that is geared to resist pandemics. Accordingly, there are deficiencies that must be filled in all 195 countries. Based on the results of the GHSI, these countries are divided into three groups: most prepared, more prepared, and least prepared. Only 13 states are deemed to be the most prepared for a worldwide biological disease, with 109 countries falling into the more prepared group and 73 countries falling into the least prepared category.

3.1.2 Global response against COVID-19

Since the virus started in Wuhan, Hubei, the Chinese government's timetable of retaliatory measures began with the publication of the virus's genetic data. Subsequently, travel restrictions were enforced in 16 cities across Hubei province, impacting over 50 million people (Shih, 2020). Transportation activities were, without a doubt, cancelled right away. The corresponding actions were funded with a total of 145 million dollars. Furthermore, the Chinese authorities paid significant concerns on healthcare services. In Wuhan, two hospitals with over 2000 bed capacity were built quickly to supplement existing facilities (Khan et al., 2020). Furthermore, scientists got together and initiated necessary activities to design quick diagnostic kits and develop a vaccine right away (Hui et al., 2020).

Even before the first confirmed cases, countries surrounding mainland China took the first steps. Governments took standard precautions such as installing temperature screening devices at point of entries with necessary quarantine facilities. The ultimate purpose of these containment methods was to increase social distance and pace down the spread of the virus. One of the most notable features observed in most Western Pacific countries is the application of lessons learned from earlier pandemics, particularly SARS (2003). Hong Kong's government, for example, made quick steps to enhance the domestic production of hand sanitizers and facemasks (Po-Wei et al., 2020).

Preventing and mitigating the impacts of the outbreak became no longer limited to the healthcare or administrative sectors. It was thought to be a multi-sectoral approach that linked several industries (Xiao and Torok, 2020). When a country's administration is taking and prioritizing decisions about responsive measures, the advice of public health specialists has become critical. In this regard, the behavior of complicated social structures should be taken into account when developing decision-making models (Johns Hopkins University, 2020). In order to slow down a biological breakout, considerable changes in societal behavior were required (Stuart et al., 2020). As a result, officials in the country made decisions about travel bans, border controls, the capability of countermeasures, and the continuing key services based on the suggestions of experts in interrelated sectors including health, finance, and academics.

Many issues have been raised about whether the actions taken by the majority of the nations which were most badly affected, were successful in suppressing the outbreak as anticipated. There were significant disparities across the countries in the statistics provided under several performance metrics. Table 3.3 lists six parameters that have shown significant changes.

Table 3-3: Parameters to evaluate the performance of response mechanisms against COVID-19

Indicator	**Description**
Number of days taken to go for lockdown	Number of days between the detection of first confirmed patient and imposing domestic travel restrictions
Tests per million	The number of diagnostic tests performed per million.
Cases per million	Number of confirmed patients per million inhabitants
Case fatality rate	The ratio between the total deaths and total confirmed cases.
Recovery case percentage	The ratio between total recoveries and total confirmed cases
Active case percentage	The ratio between total active cases and total confirmed cases

The number of days that governments took to declare a lockdown after the detection of first confirmed case might vary due to a variety of factors, the most important of which is decision-making efficiency. Closing of educational institutions, prohibition of public gatherings/events, movie closures, and public transportation closures were among the lockdown measures implemented by governments around the world. These restrictions were established across the country or in certain states or regions. The time gap, in terms of days, between the detection of first confirmed patient and the declaration of travel bans at the domestic level was used as a criterion in this case (Hale et al., 2020a).

3.1.3 Pearson's Correlation Analysis

Data for the thirteen elements presented in Tables 3.2 and 3.3 were acquired from numerous international publications and reports published on COVID-19 conditions and global health security. Each country's ratings for the overall GHS index and sub-indexes were accessible in the final report issued by the GHSI developer (Nuclear Threat Initiative and Johns Hopkins School of Public Health, 2019). The 'COVID-19 government response tracker which was developed by Oxford University, consisted of the dates when domestic travel restrictions were imposed (Hale et al., 2020b). The WHO's daily situation reports from December 31, 2019, to May 21, 2020, were utilized to gather the number of cases and deaths recorded in 145 countries (WHO, 2020d). Population data required to determine the parameter 'cases per million' were observed from 'Latest United Nations Population Division estimates' (United Nations, 2017). Individual country COVID-19 situation reports and the worldometer website, which was refreshed using individual country reports, were used to derive statistics on recoveries, active cases, and tests completed per million (Worldometer, 2021b).

For this study, data were collected from 145 countries, taking into account the availability of data for all of the above-mentioned factors. However, it is unclear whether the precise number of cases and deaths has been included in the reports, as most governments are now examining their numbers of confirmed cases and deaths. The IBM SPSS Statics 2013 program was used to run Pearson's correlation analysis on the acquired data set to discover the correlations between each parameter from the two contexts. Pearson's correlation strategy was chosen for the analysis to explore the connections between these parameters in a more meaningful manner since it provides information about the size of the correlation and the direction of the relationship.

3.1.4 Mahalanobis distance discrimination method

Discriminant analysis techniques vastly contribute to research problems that need to separately identify which population a particular sample would belong to, based on certain characteristics (Mahalanobis, 1936). Accordingly, the Mahalanobis distance between a sample (y) and a population (G) can be presented as shown in equation (1),

$$d^2(y,G) = (y-\mu)'V^{-1}(y-\mu) \text{ --------------------------- Eq. (1)}$$

where Mahalanobis distance is represented by *d(y, G),* the mean of the population is represented by *μ,* and the covariate matrix is represented by *V.* According to the Mahalanobis distance discrimination method, the sample to which a sample *y* belongs can be determined by calculating the Mahalanobis distance from each population to sample *y* and selecting the minimum distance. However, this method is valid only for populations in which mean values are significantly different and have a normal distribution.

During this step, it was attempted to determine the level of preparedness that a country belongs to using the identified relationships previously in this study. Accordingly, four parameters were selected, days took to declare a lockdown, cases per million, fatality rate, and tests per million. During the analysis, three populations were identified based on overall GHSI, most prepared, average prepared, and least prepared. Mean values of each parameter were determined under each of these populations. During the next step, data collected under each parameter were divided into four areas based on the mean values of populations as shown below in Table 3.4.

Table 3-4: Identification of different areas for calculating Mahalanobis distances

	Most Prepared	**Average Prepared**	**Least Prepared**
Area I			
Area II			
Area III			
Area IV			

During the next step, Mahalanobis distance was calculated from the sample to each of the three populations of countries under the four areas presented above. Accordingly, in Equation 02, d_i represents Mahalanobis distance between a population and sample, y is the mean of the sample, and μ and σ represent the mean and standard deviation of the population respectively. Finally, the minimum Mahalanobis distance was used for the prediction.

$$d_i = \left| \frac{y - \mu_i}{\sigma_i} \right| \text{ ----------------------------- (02)}$$

It is important to note that the Student–Newman–Keuls test has indicated that differences between means of selected parameters in populations in each case are statistically significant (P<0.05).

3.2 Identification of Stakeholder Behaviour in Preparedness Planning for Multi-Hazard Contexts in Sri Lanka

The presence of a biological outbreak, which can last for long periods does not stop the occurrence of other hazards. Especially, due to the increasing frequency and intensity of climatic-related hazards, the likelihood of biological outbreaks concurring with climate-induced disasters has increased (Normile, 2020; Quigley et al., 2020). In addressing the impacts of such compound events, being proactive stands significant (Rogers and Tsirkunov, 2010). The pro-activeness of a multi-sectoral approach is directly affected by the level of coordination among stakeholders. Furthermore, effectiveness in the flow of information also affects the functionality of multi-sectoral approaches. Therefore, this step explores the stakeholder coordination related to disaster management mechanisms in a multi-hazard context. For this purpose, Sri Lankan disaster management mechanism was taken into consideration as a case in point. In this regard, this step presents a comparison of results between two case studies: 1) only a biological outbreak and 2) multiple hazard scenarios. The existing national emergency operation plan was used during this step to identify relevant stakeholders for two case studies. Moreover, Social Network Analysis (SNA) was utilized to model and analyze the stakeholder networks. The following sub-sections present these steps in detail with the respective results of the case studies.

3.2.1 Social Network Analysis

John Barned invented the term "Social Network Analysis (SNA)" in 1954 to describe a method that visualises out and assesses formal and informal interlinks for the purpose of determining what helps or hinders knowledge flows between stakeholders. (Landherr and Heidemann, 2010; Serrat, 2017). This visualization tool can be used to help develop network communication behavior (National Research Council, 2009). Though SNA has historically been linked to social sciences, it now collaborates with a wider spectrum of several fields (Perez and Germon, 2016). SNA provides various advantages over other ways of visualizing network behavior, including identifying key units, distinguishing breakdowns information paths, bottlenecks in the flow, and structural flaws (Serrat, 2017).

In disaster-related studies, SNA is widely used to analyze linkages between various entities engaged in disaster management operations. Rajput et al., (2020) conducted research on temporal network analysis of inter-organizational contacts on social media during catastrophes, using Hurricane Harvey as an example. The goal of this study was to identify the responsibilities of organizations and situational information communication by analyzing networks of communication between organizations on social media. Based on their interactions on Twitter, online organizational communication networks were mapped and analyzed in this study. SNA was used by Kim and Hastak, (2018) to convert emergency social networking data into catastrophe knowledge and to analyze the accumulated connections of social media users during the disaster response phase. Moreover, a research study conducted in Thailand looked into roles of social networks in disaster preparedness activities for earthquakes at different stages from the local level to the national level of the country (Suwanmolee, 2014). Shehara et al., (2019) employed SNA to evaluate how stakeholders behave in communication networks during the emergency disaster management phases in Sri Lanka. Accordingly, in the present study, centrality parameters were used to identify significant stakeholders in the coordination networks.

Within the process of SNA, networks between actors are represented graphically as a web of nodes that are connected to one another. Centrality is named as a parameter in social networks that signifies the most significant, central, or influential nodes (Das et al., 2018). Various centrality metrics are in use by researchers to depict the dynamics of a communication network. As indicated in Table 3.5, four centrality metrics were selected in the present study to examine the communication networks between stakeholders who are involved in emergency preparedness for biological hazards and related compound hazard occurrences.

Table 3-5: Centrality parameters used for the analysis

Centrality parameter	**Description**	**Justification**
Degree centrality	The number of a network actor’s direct contacts	This parameter is relevant for assessing an actor's ability to communicate directly with other actors in the network.

Closeness centrality	Indicates how closely a member is connected to all other members in the network	This parameter assists in the identification of participants in the network who occupy a central location and can interact with the assistance of a few intermediates.
Betweenness centrality	Evaluate actors who mediate more connections in the network (network controllers)	Based on the position in the network, this parameter reflects the level of control an actor has over the information flow within the network.
Eigenvector centrality	Measures the node influence in a network	This parameter assists in the identification of the communication network's most impactful nodes.

The interconnectivity of nodes in the network is measured using these centrality criteria. As a result of the results obtained for centrality metrics, the most important and impactful players in the stakeholder networks may be recognized. Moreover, the readings related to centrality parameter represent which players in stakeholder networks are inherited with the most power to affect and control the information flow. In order to simulate the network of stakeholders engaged in epidemic preparedness and response operations, the method by which stakeholders are connected to one another must be mapped.

3.2.2 Case study 01: Preparedness planning for epidemics in Sri Lanka

Under Case study 01, recently released Emergency Operation Procedures (EOPs) were referred to identify stakeholders pertaining to preparedness and response planning for biological hazards in Sri Lanka. Under the leadership of the National Disaster Management Council, the Disaster Management Centre (DMC) of Sri Lanka has published the National Emergency Operation Plan (NEOP) (2015). (NDMC). In the event of an outbreak, NEOP defines stakeholders as those who are engaged in conducting emergency operations (Disaster Management Centre, 2015). These key stakeholders who are responsible for emergency preparedness and response activities are shown in Table 3.6.

Table 3-6: Stakeholders who are responsible for carrying emergency preparedness and response activities for epidemics

Stage of the epidemic	Stakeholders
Before	Disaster Management Centre (DMC), Divisional/ District Secretary (DDS), Air Ports (AP), Local Authorities (LA), District Disaster Management Coordination Unit (DDMCU), Public Media Institutions (PMI), SL Army (SLA), SL Police(SLP), SL Airport, and Aviation Services Pvt. Ltd (SLAAS), Ministry of Health (MOH), Hospitals (HP), Public Health Inspector (PHI), Ministry of Mass Media Information (MMMI), General Public (GP), Ministry of Local Government and Provincial Councils (MLGPC), Grama Niladhari Divisions (GND),
During	Disaster Management Centre (DMC), District Disaster Management Coordination Unit (DDMCU), General Public (GP), Local Authorities (LA), Ministry of Health (MOH), Public Media Institutions (PMI), SL Airport, and Aviation Services Pvt. Ltd (SLAAS), Public Health Inspector (PHI), Air Ports (AP), Hospitals (HP), Ministry of Mass Media Information (MMMI), Grama Niladhari Divisions (GND), SL Police(SLP), Ministry of Local Government and Provincial Councils (MLGPC), Divisional/ District Secretary (DDS), National Water Supply and Drainage Board (NWSDB), SL Army (SLA),

For the purpose of modeling the stakeholder network pertaining to biological outbreak emergency preparedness and response activities, the stakeholder agencies that are linked to one another must be mapped. Therefore, the relationships between stakeholders were discovered using emergency operations protocols, key informant feedback, and desk research. The interactions between the stakeholders/units were identified by including the actions allocated at each phase of an epidemic (see Table 3.7 for interrelationships).

Table 3-7: Interrelationships between stakeholders

Before an epidemic			During an epidemic		
ID	Label	Actors connected with	ID	Label	
1	DMC	2, 4, 5,6,11,12,15,16	1	DMC	2, 5, 6, 11, 12, 15, 16, 17, 18
2	MOH	2, 3, 4, 5, 9, 8, 12	2	MOH	1, 3, 8,9, 11, 12, 17
3	HP	2	3	HP	2
4	DS	1, 2, 5, 13	4	DDS	5, 12, 13
5	DDMCU	1, 2, 4	5	DDMCU	1, 4
6	GP	1, 7, 9, 12, 13, 14, 15, 16	6	GP	1, 7, 9, 14, 15, 16, 17,
7	PMI	6	7	PMI	6
8	SLAAS	10	8	SLAAS	10
9	PHI	6	9	PHI	6
10	AP	8	10	AP	8
11	MMMI	7	11	MMMI	7
12	MLGPC	6, 13	12	MLGPC	4, 13, 18,
13	LA	14	13	LA	4, 12, 14,
14	GN	6	14	GN	6, 13
15	SLA	6	15	SLA	6
16	SLP	6	16	SLP	6
			17	NWS&DB	6
			18	NGO/INGO	1,12

3.2.3 Case study 02: Preparedness planning for multiple hazard scenarios

Case Study 02 has tried to recognize and assess stakeholder networks pertaining to possible multi hazard events in Sri Lanka during an epidemic or pandemic. Floods, cyclones, landslides, droughts, vector-borne diseases, and coastline erosion are named as most common hazardous events in the hazard profile of Sri Lanka (Tissera, 1997). Tsunamis are not a common hazard, but the damage they may cause is significant. Most importantly, Tsunamis have the highest risk index out of all types of hazard events (8.9 out of 10) in Sri Lanka (Amaratunga et al., 2020c). Hydrometeorological risks such as cyclones, floods, and landslides all can strike the country at the same time. (Abeysinghe et al., 2021). Therefore, considering hazard profile of the counrty, the study has selected four hazard scenarios as shown in Table 3.8.

Table 3-8: Possible multi hazard events identified

Scenario No.	Biological Hazards	Landslides	Floods	Cyclones	Droughts	Tsunamis
I	√	√	√	√	-	-
II	√	√	√	√	-	√
III	√	-	-	-	-	√
IV	√	-	-	-	√	

The same process followed in Case study 01 was used for identifying relevant stakeholders for the selected multi-hazard scenarios. Accordingly, Table 3.9 presents a summary on key stakeholders who are responsible for carrying out emergency disaster management activities for selected hazard scenarios.

Table 3-9: Identification of stakeholders pertaining to individual hazards

Type of hazard	Stakeholders
Biological hazards	Disaster Management Centre (DMC), Divisional/ District Secretary (DDS), Ministry of Health (MOH), Public Health Inspector (PHI), Ministry of Local Government and Provincial Councils (MLGPC), SL Army (SLA), District Disaster Management Coordination Unit (DDMCU), Grama Niladhari Divisions (GND), Public Media Institutions (PMI), SL Airport, and Aviation Services Pvt. Ltd (SLAAS), Air Ports (AP), Ministry of Mass Media Information (MMMI), Hospitals (HP), Local Authorities (LA), SL Police(SLP, General Public (GP),
Landslides	SL Police (SLP), Disaster Management Centre (DMC), Public media institutions (PMI), SL Army (SLA), National Building Research Organization (NBRO), Ministry of Mass Media & Information (MMMI), General public (GP), Ministry of Education (MOE), Department of Meteorology (DOM), Schools (SCH), Divisional Secretary/District secretary (DDS), Road Development Authority (RDA), District Disaster Management Coordination Unit (DDMCU), Provincial RDA (PRDA), Local authorities (LA), Grama Niladhari (GN), Hospitals (HP), Ministry of Provincial Council and Local Government (MPCLG), SL Navy (SLN), Ministry of Health (MOH), Sri Lanka Transportation Board (SLTB)
Floods	DMC, GP, MMMI, Department of Irrigation (DOI), SLA, SLP, DPL, GN, Ministry of Agriculture (MOA), Mahaweli Authority Sri Lanka (MASL), PMI, DDMCU, CEB, DOM, SLP, DDS

Droughts	Department of Irrigation (DOI), SLP, GP, DMC, DOM, Ministry of Agriculture (MOA), Mahaweli Authority SL (MASL), Ceylon Electricity Board (CEB), SLA, MMMI, PMI, District Police (DP), MPCLG, GN, DDMCU, SLA,
Tsunami	DMC, DOM, DDMCU, GP, SLP, Geological Survey & Mines Bureau (GSMB), IOTWC (Indian Ocean Tsunami Warning Centre), NARA (National Aquatic Reservation Authority), SLA, SLN, MOE, SCH, RDA, HP, PMI, SL Airport and Aviation Services Ltd (SLAAS), SL Ports Authority (SLPA), PRDA, JMA, PTWC (Pacific Tsunami Warning Centre), MOH, Coast Conservation Department (CCD), SLTB, Meteorology Climatology and Geophysical Agency (BMKJ), Indian National Centre for Information Services (INCOIS), Joint Australian Tsunami Warning Centre (JATWC), Regional Integrated Multi-Hazard Early Warning Systems (RIMES), California Integrated Seismic Network (CISN), Coast Police Stations (CPS), LA, Minister, Deputy Minister (DM), Secretary (SEC), Non-Governmental Organization (NGO), International NGO (INGO), Fishing community (FC), Department of Fisheries (DOF), Office of the Chief Defense Staff (OCDS), National Disaster Relief Services Centre (NDRSC)

Even though the followed document, National Emergency Operation Plan, provides EOPs for every hazard identified by the National Disaster Management Act separately, there are no preparation procedures provided on multi-hazard events. Therefore, a combination of stakeholders with respected to each individual hazard in the multi-hazard scenario was taken into consideration for recognizing and shortlisting stakeholder agencies for the selected hazard events. For instance, for Scenario III, stakeholder agencies who are coming under both biological outbreaks and tsunamis were considered combinedly.

As the next step links between the identified stakeholders were established. The NEOP contains essential guidelines for responsible entities to follow during immediate preparation and response planning, including how to coordinate with other stakeholders. As a result, if the NEOP specifies that one agency obtains information from and collaborates with another, a connection, also known as a link, has been formed between these two organizations. The NEOP specifies two-way interaction among stakeholders in each of its directions. Therefore, links between actors in the networks were considered undirected and unweighted (see Annex B for identified links). After identifying the nodes and links, communication networks were modeled using the Gephi open-source software and centrality parameters were determined.

3.3 Identifying the Practical Conditions at the Ground Level in Responding to Multi Hazards Amidst a Biological Outbreak

This step of the present study has attempted to investigate how public health authorities in Sri Lanka have been engaged in disaster management activities pertaining to concurrent hazards amidst COVID-19. In this regard, data were collected in the form of key informant interviews which were participated by professionals who are actively engaged in disaster management mechanisms in the country. Key informant interviews were conducted under three phases with three different sub-objectives. This chapter details the process of conducting key informant interviews and analysis of data using thematic analysis, causal loop diagrams, and descriptive epidemiology.

3.3.1 Key Informant Interviews

The study has adopted a qualitative approach since it allows to gather in-depth knowledge on research objectives (Polit and Beck, 2017). Battling with hazard events that occurred during the pandemic was a first-hand experience for disaster management stakeholders. Therefore, utilizing a qualitative research method was beneficial to explore individuals' experiences of the challenges and impacts on response mechanisms for multiple hazard scenarios during COVID-19 (Mohajan, 2018). The target population of the data collection was the officials who have been actively engaging in disaster preparedness and response activities during hazards that occurred amidst the COVID-19 pandemic in the country. Therefore, this study has been informed by data gathered through in-depth interviews with key informants who represent the disaster management sector, public health sector, and non-government organizations in Sri Lanka. Key informant interviews were conducted in three phases. Table 3.10 presents a summary of details of the phases of key informant interviews. Due to the restrictions imposed to curtail the COVID-19 pandemic in the country, interviews were conducted through online platforms.

Table 3-10: A summary of key informant interviews

Phase No.	Objective	Time period	No. of key informants
01	To investigate the role of public health authorities in disaster preparedness and response mechanisms including biological hazards	July 2020 – Sept 2020	08
02	To identify the impacts of biological hazards on disaster risk management activities for other hazards	May 2021 – Aug 2021	25
03	To investigate the involvement of the public health sector in a Multi-Hazard Environment	Sept. 2021 – Nov 2021	08
Total			**41**

3.3.2 Phase 01

As described in Table 3.10, the first phase of interviews was carried out to observe the role of public health actors in disaster preparedness and response mechanisms including biological hazards. Furthermore, the focus was extended to the factors that affect effective response mechanisms for biological outbreaks. Key informants were selected from both the disaster management and public health sectors. Table 3.11 presents the details of agencies/institutions that were represented by the key informants. Semi-structured interviews were conducted using a predefined questionnaire. Questions were guided to key informants under three main areas namely, stakeholders of biological hazards preparedness planning, response mechanisms against pandemics and epidemics, and early warning mechanisms for biological hazards (Please refer to Annex A.1 for the questionnaire). All the interviews were recorded using forms of electronic media and transcribed for the purpose of analysis.

Table 3-11: Institutions/agencies of key informants

Disaster Management Sector	Public Health Sector
Disaster Management Centre	Disaster Preparedness and Response Division
District Disaster Management Coordination Unit	Quarantine Unit
Emergency Operation Centre	Epidemiology Unit
	College of Community Physicians
	National Dengue Control Unit

3.3.3 Phase 02

Since the impacts of COVID-19 have hindered the disaster management activities for other hazards that occurred simultaneously, the second phase of interviews focused on investigating how the preparedness and response mechanisms for compound hazard events were affected by COVID-19. As mentioned in Table 3.10, twenty-five key informant interviews were conducted with professionals who were actively engaged in battling compound hazard events during COVID-19. For the purpose of determining the key informants, the current National Early Warning System (NEWS) in the country was followed (Disaster Management Centre, 2015). Accordingly, professionals were selected from agencies that are involved in the early warning system. Figure 3.1 presents a summary of agencies that are represented by the key informant interviews during phase 02.

At the initial stage, a pilot study was conducted with two key informants to validate the suitability of the questionnaire (Please refer to Annex A.2 for the initial questionnaire). According to the feedback taken from the pilot study, the initial questionnaire was customized since several questions were not applicable to all the key informants. Therefore, four separate interview guides were developed for disaster management authorities, technical agencies, search and rescue teams, and non-governmental organizations (Please refer to Annex A.3 for the questionnaires). Although there were four types of interview guides, questions were formulated under three main areas namely, early warnings, evacuation and search and rescue, and shelter management. As mentioned under phase 01, interviews were transcribed, and key themes were identified during the analysis. The analysis consists of causal loop diagrams and a descriptive epidemiological analysis method.

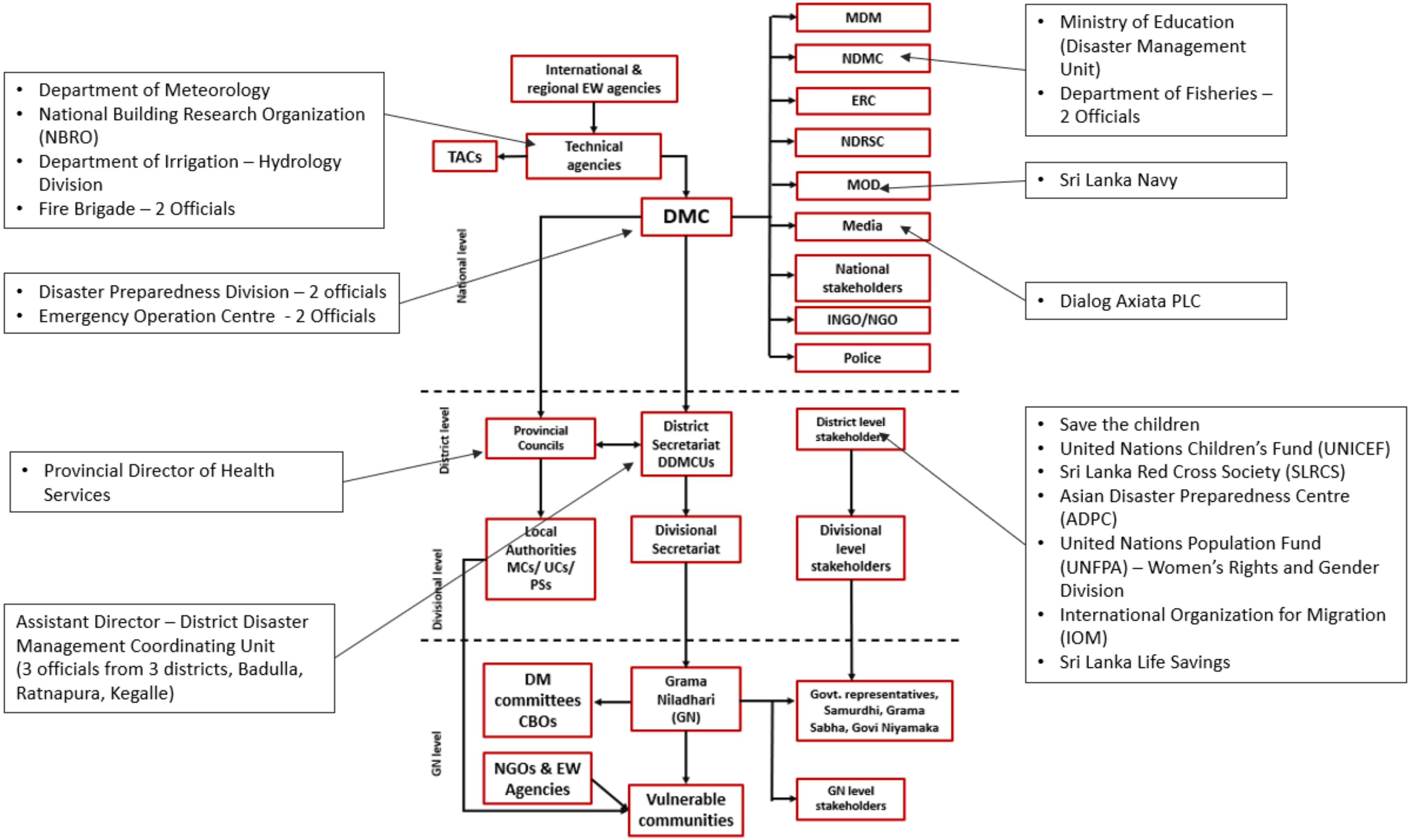

Figure 3.1: Overview of selecting key informants for the phase 02

3.3.4 Phase 03

The third phase of interviews targeted to observe the methods for improving the involvement of the public health sector in disaster management mechanisms in a multiple-hazard context. This phase was enriched by insights from key informants who represented public health authorities. Professionals were selected from both curative and preventive health sectors with equal participation. Two separate interview guides were used during these interviews which were carried out as semi-structured interviews. Accordingly, there were three major sections in the questionnaire that was directed to curative sector health officials. These three major sections were general information, impacts of biological hazards on hospital functionality, and impacts of compound hazards during COVID-19. There have been four main areas namely, risk knowledge, risk communication and dissemination, preparedness and response, and monitoring and forecasting services, in the questionnaire used for interviewing preventive health officials. These two interview guides for preventive and curative sectors are shown in Annexes A.4 and A.5 respectively.

3.3.5 Epidemiological analysis of disaster preparedness and response activities

In general, the descriptive epidemiological analysis covers three dimensions namely, time; place; and person. It is important to note that in epidemiological studies compiling and exploring data by these three dimensions is beneficial in several different ways. Firstly, it allows the researcher to explore data carefully and gives the opportunity to be familiar with the data available. It is important to note that epidemiological analysis indicates what can or cannot be done based on collected data. Furthermore, epidemiological analysis allows the researcher to learn patterns and trends about a particular public health problem. Last but not learns it allows the researcher to identify the areas in the community where the risk is high.

In general, the epidemiological analysis method is used for exploring areas connected to public health concerns such as infectious diseases. However, in this present study, this methodology was tailor-made for the disaster management context. Therefore, impacts and strategies taken to mitigate the compound hazard events that occurred amidst COVID-19 were analyzed using three parameters, time; person; and place. During the process of analysis, the following four major areas in DM mechanisms were considered, risk knowledge; risk communication; preparedness and response planning; and disease surveillance. Accordingly, interventions taken under these areas were analyzed for three different compound hazard events.

1) Southwest monsoon - 2020
2) Cyclone Burevi - 2020
3) Southwest monsoon - 2021

Illustrating how the three parameters were used for the analysis, the following criteria were used for interventions taken under risk knowledge during each compound hazard event mentioned above.

1) Time – To what extent have interventions under risk knowledge been applied at the correct time considering the variation of outcomes of the applications over time?
2) Place – To what extent have interventions under risk knowledge captured geographical variability and applicability?
3) Person – To what extent have interventions under risk knowledge addressed the right audience considering their unique attributes

3.4 Identifying Interdependencies within the Functionality of Healthcare Facilities During Multi-Hazard Scenarios

During the COVID-19 pandemic, the entire hospital system in almost every country was overwhelmed due to the rapidly increased. In general, hospitals are considered complex adaptive systems that consist of different interconnected subsystems (Mahajan et al., 2017). In relation to understanding the resilience of a such system during a disaster situation, the dynamic behavior of hospital sub-systems during the recovery process should be taken into consideration (Cimellaro et al., 2010b). Especially during a public health emergency such as a biological outbreak, the dynamic nature of hospital operations was eminent as a crucial factor that affects hospital functionality. Therefore, this step has aimed at incorporating the dynamic interactions between hospital sub-systems which eventually assist the process of assessing the functionality during a compound hazard event.

3.4.1 Modeling method

Systems thinking can be identified as available method for studying the dynamic behavior of a complex system considering the systems approach. It defies the practice of considering the subcomponents of the system in isolation because a complex system may give a false impression of the dynamic behavior if sub compments are considered in isolation. The results form a analysis that consider isolated sub components can be completely different from the real behavior of the actual system. Therefore, systems thinking takes into consideration all the interacting components that influence the dynamics of a complex system. Accordingly, system dynamics methodology based on the feedback concepts of control theory developed by Forrester (1968) is identified as the most appropriate technique to handle such complex systems to enhance systems thinking and systems learning.

Six basic steps have to be followed in building a system dynamics model. The process starts with identifying the problem. Variables affecting the have to be identified in this stage to develop the dynamic hypothesis explaining the cause of the problem at the next step. The developed dynamic hypothesis can be used to create a basic structure of a causal graph. This casual graph should be augmented with more information before being converted to an SD flow graph. Furthermore, the SD flow graph can be translated into STELLA or VENSIM programs or equations. After formulating the model, it should be further validated before implementation. Figure 3.2 presents a graphical overview of this process (Martinez-Moyano and Richardson, 2013).

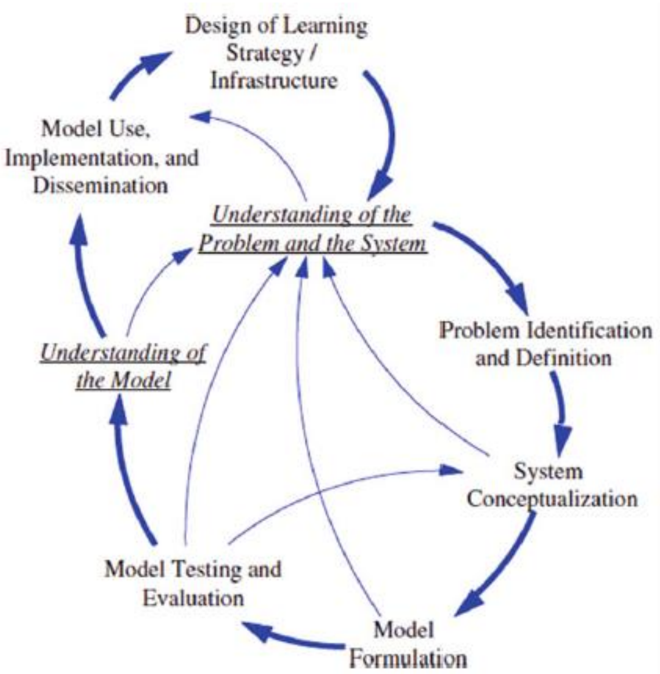

Figure 3.2: A summary on how systems dynamics modelling approach works

The above-explained steps can be identified under three major steps namely conceptualization, dynamic hypothesis formulation, and analysis as shown in Figure 3.3 (Pluchinotta et al., 2018). Out of these steps, this study has drawn on the conceptualization process and stock and flow diagrams to conceptually model interdependencies in the functionality of a hospital.

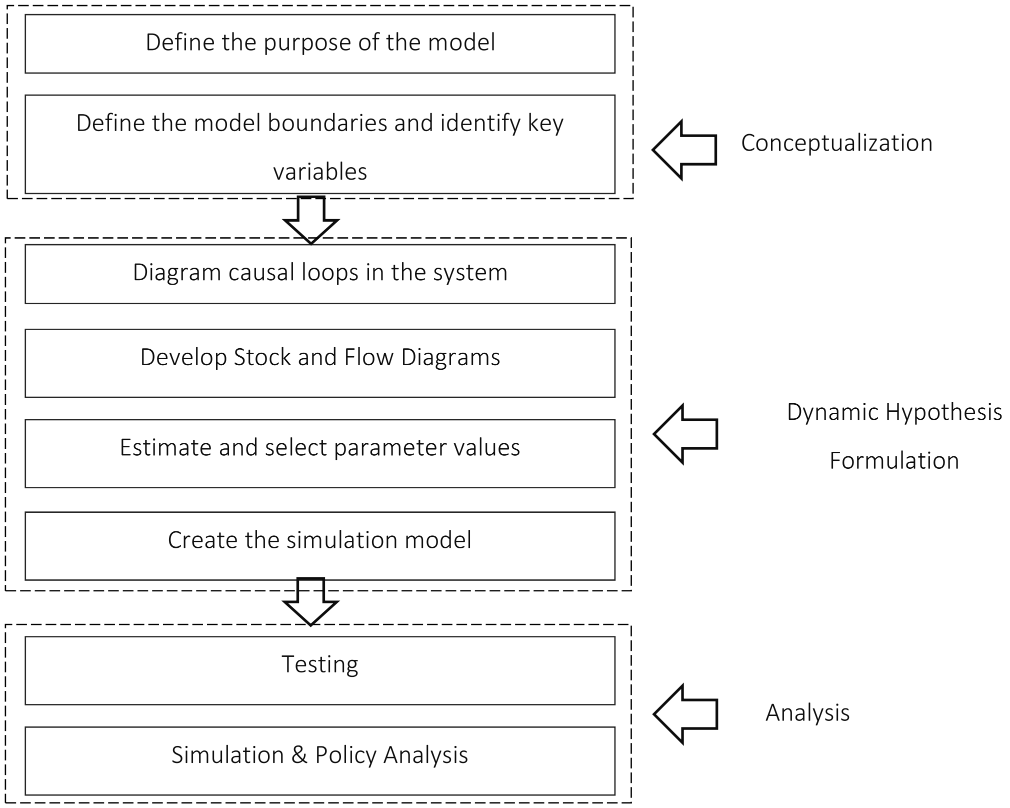

Figure 3.3: Process of developing the SD model for hospital functionality

3.4.2 Conceptualization

The first step under conceptualization is defining the purpose of the model and the boundary of the system. In the next step, the variables of the hospital functionality were determined using insights from two Systematic Literature Reviews (SLRs). The first SLR has drawn on research publications on hospital resilience. Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) guidelines were followed during this SLR to ensure the validity of the review (Moher et al., 2009). The time period taken for extracting research articles was from January 2010 to April 2021. Three databases namely, PubMed, Web of Science, and Scopus were searched for literature using the search string; ("Hospital Resilience" OR "Hospital Functionality" OR "Hospital Safety") AND ("Natural hazards" OR "Manmade hazards" OR "Disasters" OR "Biological outbreaks" OR "Pandemic" OR

"Earthquakes" OR "Floods" OR "Fire" OR "Hurricane" OR "Strom" OR "Cyclone" OR "High wind" OR "Landslide" OR "Cyber-attack" OR "Terrorist" OR "CBRN" OR "Chemical" OR "Radiological" OR "Nuclear"). All the literature reviews were excluded from the review. Journal articles, book chapters, and conference proceedings that are peer-reviewed and published in English were included in the review.

The second SLR has drawn on scholarly articles, global and national reports, policy, and legal frameworks, news items, and internet sources that have focused on challenges and changes to hospitals during COVID-19. In selecting scholarly articles, Google Scholar, ScienceDirect, and Wiley Open Library databases were searched using the search string; “Hospital” AND “COVID-19” AND (“Changes” OR “Operations” OR Challenges”). Google Scholar, Science Direct, and Wiley Open Library have yielded respectively 150,27, and 11 articles published in 2020. In addition to these, another 8 publications were added through the manual search of the literature. After the screening process, 75 sources were retained for this study based.

The insights from the two SLRs were used for identifying key variables that affect hospital functionality during a concurrent hazard event amidst a biological outbreak. After identifying these key variables, findings of both SLRs and key informant interview phase 03 were used to establish the interrelationships between these identified variables. In representing the identified interrelationships causal loops and stock and flow diagrams were used during this step.

Causal loops and stock and flow diagrams can be used to represent conceptual modeling. Figure 3.4 shows a simple single stock model of the population where the flow is only due to birth and death (Bala et al., 2017). Causal loops allow the users to identify the variables in a system and the relationships between them. Furthermore, stocks can be used to represent the variables of the system at any particular time (Güneralp and Seto, 2008; Pluchinotta et al., 2018). Flows represent how stocks change with time (Thompson and Bank, 2010).

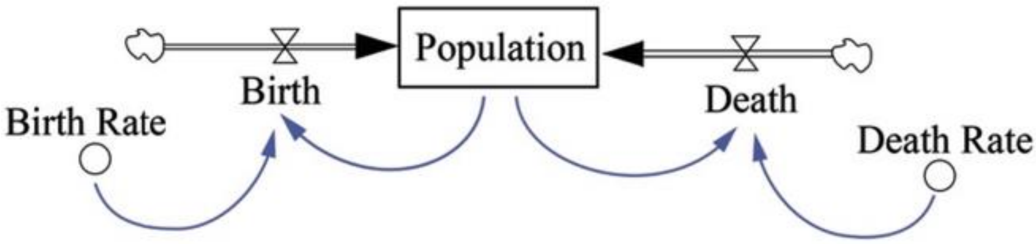

Figure 3.4: Diagram of dynamics in the growth of the population

A combination of causal loop diagrams and stocks and flows are used in this study to represent the interdependencies of hospital sub-systems. These tools represent the basic mechanism of the system to capture the hypothesis about the causes of its dynamic behavior over time. There will be positive or negative relationships between the variables. Accordingly, types of relationships can be described as shown in Table 3.12. In these diagrams, the direction of relationships is represented by the arrowhead. Furthermore, different thicknesses of arrows have been used to represent the strength of the relationships. It is important to note that conceptual modeling also makes it possible to better understand the functioning of the system.

Table 3-12: Types of relationships in the conceptual models

First variable	Connected variable	Type of the relationship
Increase	Increase	Positive
Decrease	Decrease	Positive
Increase	Decrease	Negative
Decrease	Increase	Negative

4 FINDINGS

4.1 Key Drivers in Biological Hazard Preparedness

As mentioned in Section 3.1, data was collected from 145 countries for 13 parameters which were identified from a review of secondary literature. Table 4.1 presents a summary of data collected for a selected set of countries.

4.1.1 Impacts of Preparedness Measures on Effective Response Mechanisms

The correlation analysis results, which were performed to evaluate relationships between the parameters of expected performance levels (preparedness) in global health security and the actual performance in responding to the COVID-19 pandemic, are shown in Table 4.2. This analysis includes data from 145 countries. However, the results have presented several questionable relationships among the selected parameters for the analysis.

i) Number of days taken to impose travel restrictions

The analysis results show a moderate positive relationship between the days taken to go for lockdown from the first confirmed case in countries and the GHS indexes. Days used to limit domestic travel had a modest strength of correlation with the overall GHS Index (rho = 0.564); the preventative sub-index (rho = 0.533); rapid response (rho = 0.537); and the health system (rho = 0.547). These results indicate that countries that have scored high in the GHS indexes have taken more days to go for a lockdown compared to other countries. For example, countries in the top 20 of the GHSI, such as the United States and the United Kingdom, have taken more than 50 days to impose travel restrictions within local areas after the detection of the first case within their borders. It is possible to argue that most prepared countries in global health security are expected to take rapid decisions and go for a lockdown immediately. However, the results present two possible scenarios in relation to this matter. Accordingly, those countries might have been overconfident in their health preparedness and waited for a longer period without any rapid action. On the other hand, these countries might have taken other measures such as mandatory masks, social distancing practices, etc. before imposing lockdown measures. Furthermore, the number of days taken for a lockdown has shown a low positive correlation towards the 'cases per million' (rho= 0.292). This indicates that the delay in taking decisions to impose travel restrictions has caused high morbidity in several cases.

Table 4-1: A summary of data collected for the analysis

Country	Overall GHS Index	Prevention sub-index	Detection and Reporting sub-index	Rapid Response sub-index	Health System sub-index	Compliance with International Norms sub-index	Risk Environment sub-index	Days for lockdown from the first case	Tests per Million	Cases per Million	Case-Fatality rate	Recovery case Percentage	Active case Percentage
US	83.5	83.1	98.2	79.7	73.8	85.3	78.2	54	40729	4610	6.00	23.6	70.5
Latvia	62.9	56	97.3	54.7	47.3	51.1	67.2	10	50109	534	2.21	67.7	30.1
Canada	75.3	70	66.4	60.7	67.7	74.7	82.7	53	36524	2143	7.52	51.3	41.1
Germany	66	66.5	84.6	54.8	48.2	61.9	82.3	52	42923	2130	4.61	88.3	7.1
Brazil	59.7	59.2	82.4	67.1	45	41.9	56.2	19	3462	1464	6.49	40.5	53.0
South Africa	54.8	44.8	81.5	57.7	33	46.3	61.8	20	8872	323	1.86	46.8	51.3
Italy	56.2	47.5	78.5	47.5	36.8	61.9	65.5	21	53635	3770	14.24	59.0	26.7
Greece	53.8	54.2	78.4	44	37.6	49.1	58.2	23	13816	274	5.84	48.2	46.0
Ireland	59	63.2	78	45.1	40.2	52.8	77.4	27	59945	4946	6.49	86.3	7.2
India	46.5	34.9	47.4	52.4	42.7	47.7	54.4	52	1973	86	3.49	40.9	56
Chile	58.3	56.2	72.7	60.2	39.3	51.5	70.1	21	22306	2807	1.01	41.66	57.31
Sri Lanka	33.5	24.2	43	26.4	16.9	41.7	56.7	50	2295	49	0.82	57025	41.95
Uganda	44.3	42.7	50.3	56.5	11.6	65.4	35.5	10	1793	6	0	41.25	58.75

Table 4-2: Results of correlation analysis

		1	2	3	4	5	6	7	8	9	10	11	12	13
1	Overall GHS Index													
2	Prevention sub-index	.916**	1											
3	Detection and reporting sub-index	.844**	.717**	1										
4	Rapid Response sub-index	.864**	.742**	.649**	1									
5	Health System sub-index	.922**	.850**	.702**	.778**	1								
6	Compliance with International Norms sub-index	.703**	.597**	.531**	.570**	.572**	1							
7	Risk Environment sub-index	.648**	.616**	.337**	.504**	.627**	.314**	1						
8	Days for locks down from the first case	.564**	.533**	.430**	.537**	.547**	.363**	.344**	1					
9	Tests per M	.304**	.298**	.142	.216**	.330**	.085	.535**	.271**	1				
10	Cases per M	.319**	.305**	.143	.315**	.364**	.028	.490**	.292**	.575**	1			
11	Fatality rate	.398**	.402**	.321**	.299**	.354**	.321**	.290**	.299**	-.005	.170*	1		
12	Recovery Percentage	.037	.023	-.049	-.001	.050	-.043	.309**	-.033	.206*	-.045	-.072	1	
13	Active cases Percentage	-.172*	-.141	-.059	-.144	-.163*	-.062	-.384**	-.043	-.210*	-.015	-.138	-.903**	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

ii) Rates of morbidity and mortality

When it comes to 'cases per million' and 'case-fatality rate,' both have minimal positive correlations with the overall GHSI and other sub-indices. As a result, the case-fatality rate exhibits low positive associations with the overall GHSI (rho=0.398) and the health system sub-index (rho=0.354). Furthermore, the 'cases per million' parameter has a slightly moderate positive relationship to the sub-index of the risk environment (rho=0.49). These relationships stand questionable since countries that are ranked at the top of the list, considered as most prepared, are expected to take relevant actions and control a health emergency effectively. In an ideal situation, these relationships have to demonstrate negative correlations. But the analysis indicates that most prepared countries according to the GHSI have shown higher rates of morbidity and mortality. For instance, countries such as the United Kingdom and the Netherlands have had their case-fatality rates above 10% during the first waves of the COVID-19 pandemic in those countries, even though they are ranked among the most prepared countries by the GHSI.

iii) Testing capacities

A moderate positive correlation (rho = 0.535) can be observed between the 'Tests per million' parameter and the risk environment sub-index of GHSI. Furthermore, the indicator 'tests per million' has a low positive correlation with the health system sub-index (rho=0.33). Indicators under the risk environment sub-index mainly assess the political and security risk; socio-economic resilience; infrastructure adequacy; and environmental and public health vulnerabilities. The capacity of the health system in curative healthcare facilities; medical countermeasures and personnel deployment; healthcare access; infection control practices; and availability of equipment are assessed under the sub-index of the health system (Nuclear Threat Initiative and Johns Hopkins School of Public Health, 2019). The testing capacity of a country can depend on the adequacy of infrastructure, political decision-making and policies on diagnostic facilities, and economic resilience (Torres et al., 2021). Therefore, the observed correlation during the analysis, most prepared countries in risk environment and health systems having higher testing capacities, can be considered an anticipated outcome.

However, the results reveal that preparation in detecting and reporting on the tests conducted by a country has a relatively low impact due to the low positive relationship between the sub-index detection and reporting and the number of tests per million is a low positive correlation (rho=0.142). The sub-index 'Detection and Reporting' assesses the laboratory systems; real-time surveillance and reporting; epidemiology workforce. Therefore, the number of tests per million is expected to increase with the country's performance under detection and reporting. Although the observed results are in contrast with the expected outcome, the findings of the present analysis are supported by the situation in Germany. Despite scoring relatively low in the area of 'detection and reporting,' the country was able to increase the number of tests utilizing the technique named, pool testing) that they have invented newly (Bird, 2020).

4.1.2 Key Performance Indicators for COVID-19 Based on Preparedness Level based on GHSI

4.1.2.1 Overall GHSI with days taken to go for lockdown

Using the methodology described above, the means of the number of days taken to go for a lockdown were calculated (See Table 4.3 for results).

Table 4-3: Means values for each population of countries

Population	Most Prepared	Average Prepared	Least Prepared
Mean	7.9	17.8	37.58

Four areas were determined based on means values as shown in Table 4.4. The minimum values under each area are colored in red. According to the method described above, the following criteria can be observed in relation to the number of days taken to go for lockdown.

Table 4-4: Calculation of Mahalanobis distance for days taken to go for lockdown

	Most prepared	Average prepared	Least prepared
X < 8	1.7084449	1.0386528	0.6701828
8 <= X < 17	1.2828408	0.4041268	0.5142656
17 <= X < 37	0.6964168	0.4701627	2.1462729
37 < = X	0.5558674	2.3371720	5.6313569

- Most prepared countries – More than 37 days
- Average prepared countries – between 8 to 37 days

- Least prepared countries – less than 8 days

4.1.2.2 Overall GHSI with cases per million and case fatality rates

As the first step mean values for cases per million under each population were calculated and the results are shown below in Table 4.5.

Table 4-5: Means values for cases per million under each population of countries

Population	Most prepared	Average prepared	Least prepared
Mean	2195	1220	478

Four areas were determined based on means values as shown in Table 4.6. The minimum values under each area are colored in red. According to the method described above, the following criteria can be observed in relation to the number of cases per million.

Table 4-6: Calculation of Mahalanobis distance for cases per million in countries

	Most	Average	Least
X < 450	1.37806	0.55652	0.20205
450 < =X < 1200	0.36297	0.27921	0.11923
1200 <= X < 2200	0.85460	0.27527	0.76163
2200 <= X	1.03921	1.70869	2.42234

- Most prepared countries – more than 2200 cases per million
- Average prepared countries – between 1200 to 2200 cases per million
- Least prepared countries – less than 1200 cases per million

(Please note that these values for cases per million were extracted from COVID-19 situational reports developed by the WHO)

4.1.2.3 Overall GHSI with case fatality rates

Using the methodology described above, the means of case fatality rates reported in countries were calculated (See Table 4.7 for results).

Table 4-7: Means values for case fatality rates under each population of countries

Population	Most prepared	Average prepared	Least prepared
Mean	2195	1220	478

Four areas were determined based on means values as shown in Table 4.8. The minimum values under each area are colored in red. According to the method described above, the following criteria can be observed in relation to the case-fatality rates.

Table 4-8: Calculation of Mahalanobis distance for case fatality rates in countries

	Most	Average	Least
x < 3	1.264447	0.55889	0.466546
3 <= x < 4	0.907142	0.033516	0.104003
4 <= x < 8.3	0.529439	0.659741	0.707124
8.3 <= x	0.791181	2.849307	2.815905

- Most prepared countries – more than 4%
- Average prepared countries – between 3% to 4%
- Least prepared countries – less than 3%

4.1.2.4 Overall GHSI with tests per million

As the first step mean values for tests per million under each population were calculated and the results are shown below in Table 4.9.

Table 4-9: Means values for tests per million under each population of countries

Population	Most prepared	Average prepared	Least prepared
Mean	2195	1220	478

Four areas were determined based on means values as shown in Table 4.10. The minimum values under each area are colored in red. According to the method described above, the following criteria can be observed in relation to the number of tests per million.

Table 4-10: Calculation of Mahalanobis distance for tests per million in countries

	Most	Average	Least
X < 6500	1.46604815	0.66877209	0.370918
6500 < = x < 22000	0.86612804	0.31339945	0.696276
22000 <= x < 33000	0.34695676	0.00585972	1.619827
33000 <= X	1.68376841	1.19707404	5.23227

- Most prepared countries – more than 33000 tests per million
- Average prepared countries – between 6,500 to 33,000 tests per million
- Least prepared countries – less than 6,500 tests per million

Based on the four analyses conducted above following criteria can be derived for each level of pandemic preparedness (See Table 4.11).

Table 4-11: Summary of parameters based on overall preparedness levels in countries

Preparedness level	**Days took to go for lockdown**	**Cases per million**	**Case fatality rate**	**Tests per million**
Most prepared	more than 37 days	more than 2200	more than 4%	more than 33000
Average prepared	between 8 to 37 days	between 1200 to 2200	between 3% to 4%	between 6,500 to 33,000
Least prepared	less than 8 days	less than 1200	less than 3%	less than 6,500

4.1.3 Summary

This section presents a set of key insights on drivers of preparedness for biological hazards. According to the results, more time is taken by most of the countries which are ranked as most prepared according to GHSI, to declare lockdown measures within the country. This delay stands as a possible reason for the high morbidity and mortality in most of those countries. However, a set of countries that are identified as most prepared and have taken timely measures recorded low numbers in morbidity and mortality. It depicts that even though the health sector is prepared, the timeliness of crucial decisions is also vested with a major responsibility. This scenario further indicates a sort of overconfidence in the countries that are listed as most prepared., with their strength in health infrastructure and technology. Since public confidence in government decisions is high in these most prepared countries, authorities are vested with major responsibilities in making timely decisions. Therefore, it is evident that risk governance stands paramount in preparedness for biological hazards.

4.2 Stakeholder Behaviour in Preparedness Planning for Multi-Hazards Amidst Biological Outbreaks

4.2.1 Case study 01

The relationships identified in Table 3.7 were used to model the communication networks among stakeholders before and during an event of epidemic, using the Gephi open-source software. Accordingly, the communication networks among stakeholders for immediate preparedness and response planning before and during an epidemic are shown in Figures 4.1 and 4.2 respectively. Nodes in the network models represent the stakeholders after being ranked based on the degree centrality value. The varying node sizes represent the degree centrality values of respective stakeholders.

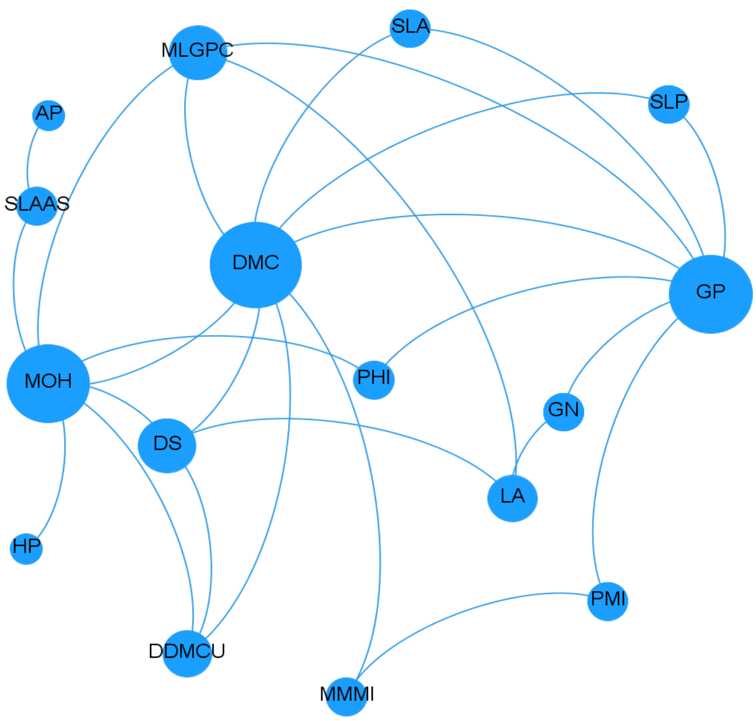

Figure 4.1: Communication network of stakeholders before an epidemic

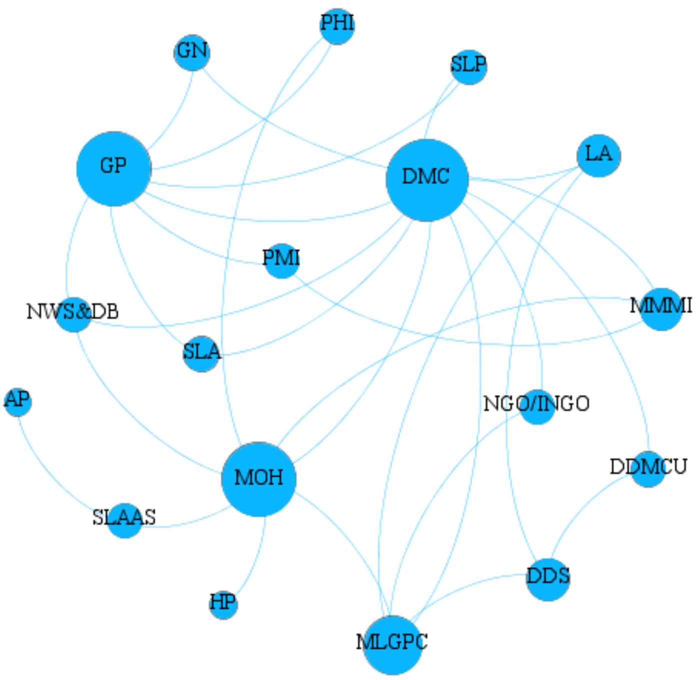

Figure 4.2: Communication network of stakeholders during an epidemic

After modeling the communication networks, values of four centrality parameters for each model were obtained from the analysis. Accordingly, Table 4.12 presents the stakeholders with the highest value under each centrality parameter selected for the analysis.

Table 4-12: Top-ranked stakeholders for centrality parameters

Centrality parameter	Before an epidemic	During an epidemic
Degree centrality	Disaster Management Centre	Disaster Management Centre
Closeness centrality	Disaster Management Centre	Disaster Management Centre
Betweenness centrality	Ministry of Health	Ministry of Health
Eigenvector centrality	Disaster Management Centre	Disaster Management Centre

The results reveal that DMC has obtained the highest values for both degree centrality and closeness centrality parameters. According to these parameters, DMC can be considered the key agency that plays the centralized role in preparedness and response planning for epidemics. Since the degree centrality of DMC is high, it has the highest potential to contact other stakeholders in the network directly. Therefore, the efficiency of the communication network depends on how actively DMC functions within the network of stakeholders in an event of an epidemic.

However, the Ministry of Health, Sri Lanka (MOHSL) has obtained the highest rank in betweenness centrality. Being top-ranked in betweenness centrality, MOHSL has the highest capacity to control the flow of information within the communication network. Since MOH can influence the flow of information their effectiveness related to accuracy, workability, and timeliness of information has a significant impact on the communication network. The results show that DMC and MOHSL are the most important key actors in the communication network of stakeholders who are responsible for emergency preparedness and response planning in an event of an epidemic in Sri Lanka. Furthermore, hospitals in Sri Lanka function under the purview of the MOHSL. Since hospitals are vested with a major responsibility of case management during an epidemic, their position in the communication network of stakeholders should have significant value. During the stakeholder analysis, it was evident that hospitals connect to the network of stakeholders through the MOHSL.

Furthermore, the network models have highlighted the involvement of local government agencies and Non-Government Organizations as well. These agencies have a high potential in addressing possible cascading impacts which can be triggered by the health impacts of the pandemic. Therefore the inclusion of these agencies within the existing plans pertaining to preparedness planning for epidemics can be identified as a positive move. Although local government agencies and NGO/INGOs have the capacity to address possible indirect impacts of the pandemic, the National Disaster Relief Service Centre (NDRSC) is the legally mandated agency for disaster relief services. However, the developed models emphasize that NDRSC is not included within the network of stakeholders who are responsible for preparedness and response planning pertaining to epidemics.

Past studies conducted on stakeholder analysis of preparedness and response planning for hazards and network models have been developed for stakeholder communication during frequent hazard events in Sri Lanka. Figure 4.3 represents the communication network model for emergency preparedness mechanisms during tsunamis (Shehara et al., 2019). According to these models, DMC has the highest rank for betweenness centrality, and the legally mandated technical agencies do not have the highest rank in the respective centrality. However, in contrast, MOHSL has the highest Between Centrality pertaining to epidemics. It emphasizes that the preparedness planning for epidemics in Sri Lanka is mainly a health sector-led process in contrast to other hazards. Accordingly, two main areas are highlighted by the findings of Case study 01, as shown below.

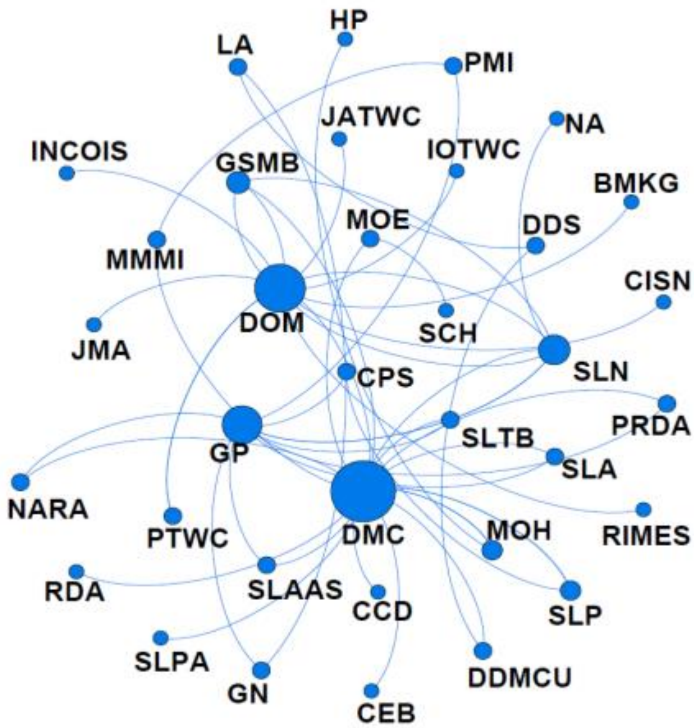

Figure 4.3: Communication Network for Tsunami Early Warning
(Shehara et al., 2019)

1. **Role of health authorities in preparedness planning for epidemics and pandemics**

The findings of the SNA models show that health authorities play a critical role in biological hazard preparedness and response activities in Sri Lanka. Furthermore, the insights from the review of secondary literature have backed up this claim. In most rules enacted under the Quarantine and Prevention of Disease Ordinance No. 13 of

1897, the Director-General of Health Services is designated as the competent authority for enabling the activities pertaining to the prevention of disease transmission. Several agencies under the Director-General of Health Services, including the DPRD, Epidemiology Unit, and Quarantine Unit, play significant roles in relation to preparedness planning for biological hazards.

As identified during the literature review as well, the DPRD serves as the primary authority for coordinating disaster preparedness operations in the case of an outbreak in the country (DPRD, 2018). The Strategic Plan for Health Sector Disaster/Emergency Preparedness, initially issued in 2011 and later adapted by DPRD in 2015, offers a pathway to the health sector in disaster/emergency management, including biological risks. Furthermore, the Ministry of Health of Sri Lanka has advised avoiding disease transmission as one of the duties to be fulfilled during the disaster response phase, in the manual for Public Health Inspectors (PHIs) (Ministry of Health, 2010). Furthermore, the aforementioned document outlines three types of evaluations: rapid reconnaissance, rapid health assessments, and surveys to prevent the spread of diseases (Ministry of Health, 2010).

2. **Engagement of non-health sector stakeholders for preparedness and response planning for infectious diseases**

Epidemics and pandemics must be viewed as more than just health emergencies, and biological hazard preparedness and response should be modeled after a multi-sectoral, whole-of-society strategy. The engagement of local government authorities, tri-forces, media institutions, corporate sector organizations, global development partners, NGOs, INGOs, and community-based organizations in the process makes it more successful. The national action plans emphasize the need of incorporating local government authorities, provincial and district-level administrative officials, tri forces, media institutions, and NOGs/INGOs, as indicated in the stakeholder network diagrams (Figures 4.1 & 4.2). Sub-national administrative authorities in Sri Lanka have been actively involved in handling the crisis' cascading effects, with actions such as providing access to critical services, giving food and dry rations to victims, recommending curfew passes and maintaining social order, etc.

Preparedness activities for pandemics and epidemics can be incorporated into the Business Continuity Plans (BCPs) of private sector organizations and institutions.

Furthermore, private sector organizations have made attempts to include pandemic/epidemic preparedness in their Corporate Social Responsibility (CSR) and sustainability activities. In addition to that private sector organizations and other non-health-related agencies have a major responsibility to integrate pandemic and epidemic preparedness into their occupational health and safety standards. Currently, several organizations have identified the significance of this need and taken necessary actions in this regard. For instance, Construction Industry Development Authority (CIDA), Sri Lanka has recently announced COVID-19 and Dengue Health and Immunity Enhancement Guidelines to be followed in the construction industry (CIDA, 2020).

4.2.2 Case study 02

Following the same method used in Case study 01, details on nodes and links pertaining to four hazard scenarios were used to model the communication networks using Gephi open-source software. Figures 4.4, 4.5, 4.6, and 4.7 depict the communication networks of stakeholders immediately before the event of multiple hazards scenarios I, II, III, and IV respectively. In these visualized models, stakeholders are represented by nodes which are ranked based on the Degree centrality value being represented by the varying node sizes.

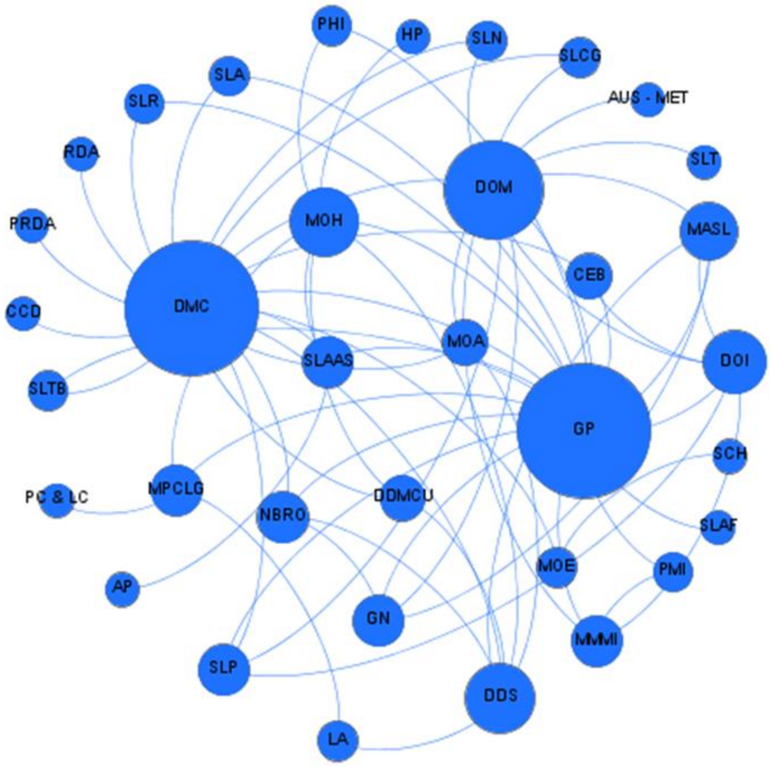

Figure 4.4: Communication network diagram of stakeholders pertaining to hazard scenario I

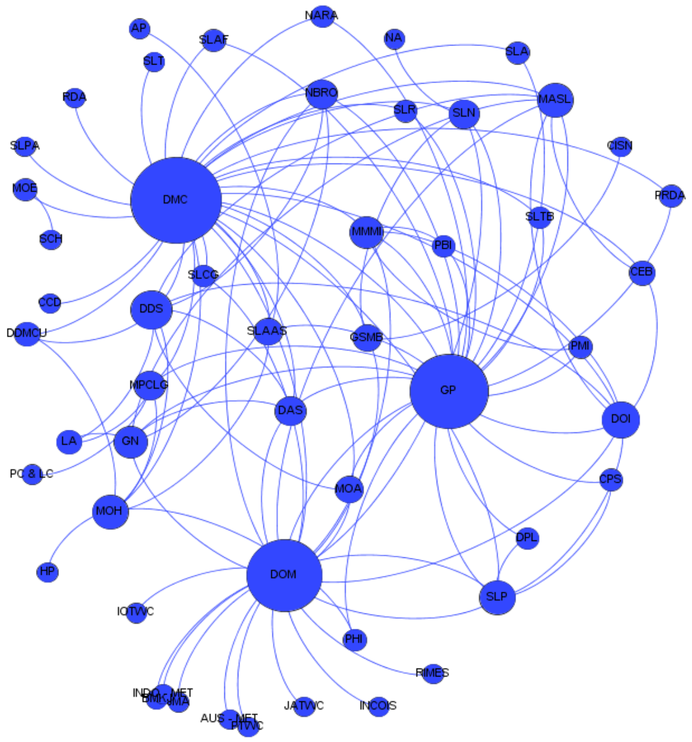

Figure 4.6: Communication network diagram of stakeholders pertaining to hazard scenario II

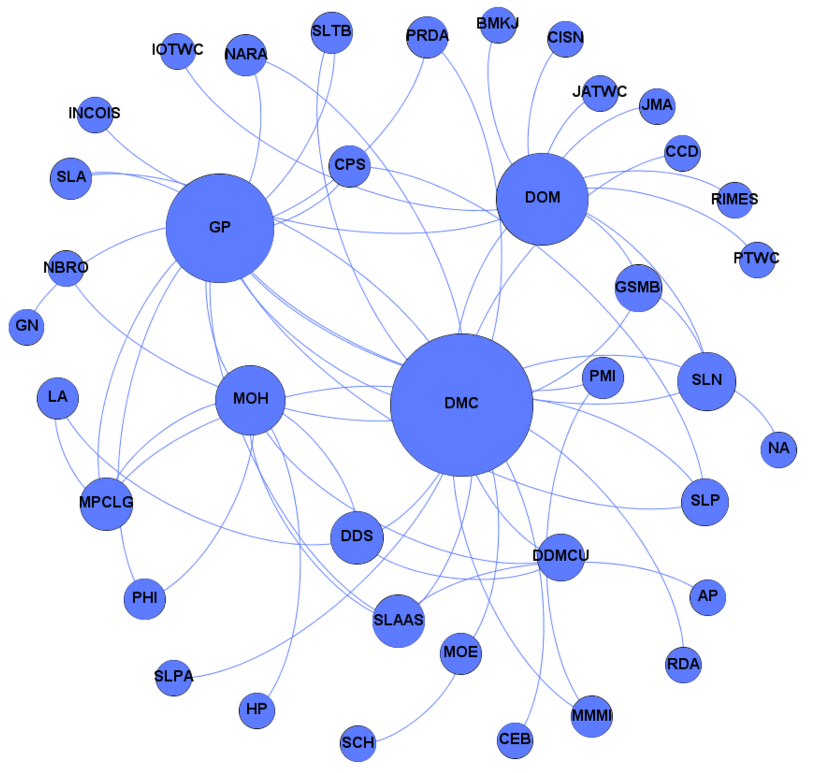

Figure 4.5: Communication network diagram of stakeholders pertaining to hazard scenario III

According to the SNA results, Table 4.13 presents the top-ranked stakeholders under four parameters selected for the analysis.

Table 4-13:Top-ranked stakeholders for centrality parameters

Hazard Scenario	**Degree Centrality**	**Closeness Centrality**	**Betweenness Centrality**	**Eigen Vector Centrality**
I	DMC	GP	DMC	GP
	GP	DMC	GP	DMC
	DOM	DOM	DOM	DOM
II	DMC	DMC	DMC	DMC
	GP	GP	DOM	GP
	DOM	DOM	GP	DOM
III	DMC	DMC	DMC	DMC
	GP	GP	DOM	GP
	DOM	DOM	GP	SLN
IV	DMC	GP	DMC	DMC
	GP	DMC	GP	GP
	MOH	MOH	MOH	DDMCU

The findings of the stakeholder analysis have highlighted four areas that have to be paid attention to in regard to enhancing health system resilience in the country against multi-hazard scenarios.

1) Complexity in governance aspects and stakeholder coordination in multiple hazard scenarios

These models have highlighted that the complexity of the communication network between stakeholders which is formed by the existing emergency operation procedures is considerably high. Past studies conducted on stakeholders of the disaster management mechanism in the country have also emphasized the high complexity of operation procedures, even if these studies have not particularly considered possible multiple hazard scenarios (Perera et al., 2020; Shehara et al., 2019). The high complexity operation procedures can create several consequences as follows.

1. Functions in DM activities can overlap which can cause losses in terms of resources
2. Power struggles can arise between authorities.

   Ex: Haphazard structures that were established in Sri Lanka during COVID-19 despite the presence of already organized institutions for coordinating and implementing DM activities in the country have created several commotions.

Furthermore, DMC has obtained the highest rank in degree centrality, showcasing that DMC has the highest ability to contact other stakeholders engaged in the network. In regard to responding to multiple hazard scenarios, taking rapid and strict decisions is paramount. Therefore, as the decision-making authority and coordinating agency, DMC needs to have a sound and strong legal basis to take necessary actions to execute and coordinate DM activities. However, a lack of consistency in decision-making in Sri Lanka was highlighted during the COVID-19 outbreak (Amaratunga et al., 2020a).

Currently, the Emergency Operation Centre (EOC) which is under the purview of the DMC, functions as the national-level focal point for coordinating activities pertaining to early warning dissemination (Disaster Management Centre, 2014b). Technical agencies are mandated to monitor, predict and forecast impending disasters and generate early warning messages. In addition to this process, EOC also maintains systems to receive warnings via websites, news channels, and local level officials from the ground level.

2) The accuracy of hazard forecasting and warnings and the lack of public trust in technical agencies

The communication network models depict that technical agencies such as the Department of Irrigation, Department of Meteorology, etc. have a high ability to control the flow of information. In responding to multiple hazard scenarios, it is required to be proactive to reduce the existing vulnerabilities. In this regard, the timeliness and accuracy of early warnings on impending disasters significantly affect the effectiveness of preparedness and response planning. Therefore, hazard monitoring, forecasting, and prediction have been vested with a pivotal role to play in preparedness and response planning. The findings of the analysis have also proved this since the obtained ranks by technical agencies under the selected centrality parameters are also high. Therefore, these agencies have the responsibility to focus more on increasing the accuracy, timeliness, and reliability of their functions. However, recent studies conducted in Sri Lanka have highlighted several issues related to the accuracy and timeliness of early warnings. For instance, public trust in warnings issued by authorities has been drastically reduced due to low accuracy, false predictions, delayed warnings, and lack of clarity in EWs (Jayasekara et al., 2021; Perera et al., 2020). Therefore, it is necessary to enhance the capacity of technical agencies to ensure the effectiveness of risk knowledge and hazard monitoring, prediction, and forecasting.

3) Lack of engagement of public health officials in preparedness planning for multiple hazard scenarios

According to the findings of Case Study 01, preparedness and response planning pertaining to biological hazards is mainly a health sector-led process, and the Ministry of Health, Sri Lanka has the highest capacity to control the flow of information within the stakeholder network. However, *Case Study II* highlights that the engagement of the Ministry of Health within the communication network for preparedness and response planning for multiple hazard scenarios, especially during a biological outbreak is comparatively low. COVID-19 became an eye-opener for authorities and its impacts during concurrent hazards stressed the need for strong coordination between disaster management authorities and the public health sector in the country. Due to this need, during the COVID-19 pandemic in Sri Lanka, the DPRD of the Ministry of Health, Sri Lanka in collaboration with the DMC prepared and disseminated guidelines for search and rescue missions and shelter management for the south-west monsoon period (DPRD and DMC, 2021). It was demonstrated, particularly during the southwest monsoon of 2021 in Sri Lanka, that the simultaneous presence of several hazards may devastate a country's public health system. Therefore, the adequate engagement of the health sector in preparedness and response mechanisms for multi-hazards is paramount in DRR.

4) Negligence of non-government organizations and private sector

The findings of the analysis under case study II have highlighted that the involvement of non-government and private sector organizations and relief services in preparedness and response planning is not satisfactory. Since most of these organizations directly focus on the humanitarian needs of victims, the lack of involvement during the preparedness planning phase can create severe consequences in the recovery phase. Within the existing mechanism, NGOs/INGOs do not have the power to join preparedness planning activities without an invitation from government authorities. Therefore, the government authorities have the responsibility of rearranging legal procedures to include NGO/INGOs and private sector organizations within the preparedness planning process to get the assistance of resources available to these organizations.

The findings of the recent studies conducted in Sri Lanka highlight that the special needs of vulnerable communities do not get adequate attention within existing DM activities in Sri Lanka (Jayasekara et al., 2021a; Perera et al., 2020). Since most NGOs/INGOs have the capability of addressing the special needs of vulnerable communities, DM officials can acquire the assistance of these organizations which have the objective of serving vulnerable communities. Another important method for developing multi-hazard response mechanisms is an efficient collaboration with local authorities and providing enough assistance to them. According to the findings, local governments play an important role in the communication network for certain threat situations. However, human resources, finance, and political backing are needed to further increase their commitment.

4.2.3 Summary

This section evaluates the stakeholder networks for compound hazard events that can occur during biological outbreaks, using SNA. Furthermore, it compares the stakeholder behavior in compound hazard events and biological outbreaks. The analysis demonstrates the significance of DMC as the most controlled actor in preparedness planning for multi-hazard contexts. Furthermore, the engagement of the health sector in stakeholder networks pertaining to multiple hazards amidst a biological outbreak has been observed low compared to other technical agencies. In addition to that, the findings depict that the preparedness of technical agencies for biological hazards is vested with a key role in the communication networks of stakeholders.

According to the results of the analysis, non-government organizations and donor agencies can pose a significant impact on preparedness and response planning procedures. Furthermore, according to the modeled networks, private sector organizations also play a key role in compound hazards, especially in relation to relief services. Last but not least, the results demonstrate a crucial involvement of local actors in these stakeholder networks. It is important to note that these findings are solely based on existing regulations which have been documented and approved by relevant authorities. However, still, the practical conditions at the ground level should be explored.

4.3 Dual Challenges of Compound Hazards Events During COVID-19

Sri Lanka reported the first imported COVID-19 case detected in the country on 27th January 2020. The detected patient was a Chinese tourist who had arrived in the country two weeks before this date. Later on the 11th of March 2020, the first local case was reported in Sri Lanka (Amaratunga et al., 2020a). Within the first wave of the COVID-19 outbreak in the country, Sri Lanka reported a total of 3396 cases with a death toll of 13 (Rodrigo, 2020). The second wave of COVID-19 in Sri Lanka started after a cluster was detected in early October. Subsequently, two major clusters were detected in an apparel factory and a wholesale fish market (PTI, 2020). The third wave of COVID-19 in Sri Lanka officially began in mid-April and daily new cases rose to 2,500. Amidst the surge in the number of infected cases, the nationwide lockdown imposed by the government of Sri Lanka lasted until the 1st of October 2021 (Kotelawala, 2021; PTI, 2021). By the end of 2021, Sri Lanka has reported 587,596 COVID-19 cases with a death toll closer to 15,000 (Worldometer, 2021a). It was only the COVID-19 pandemic that affect the country during the last two years but also several natural hazards severely tested the disaster management capacities of the country.

During the COVID-19 pandemic. Sri Lanka saw significant rains in May 2020, with over 200 mm of rain falling in less than 24 hours. Kegalle District was heavily impacted, with over two thousand victims and four hundred damaged houses (Flood List, 2020a). From December 2 to 5, 2020, the Northeast monsoon and the activation of a depression in the southeast Bay of Bengal brought significant rains to Sri Lanka. The Northern province of Sri Lanka has been hit the worst by these torrential rains (IFRC, 2020). DM authorities made precautions ahead of Cyclone Burevi, and hundreds of residents were guided to safety facilities in the Northern and Eastern regions (Flood List, 2020b). Due to the activation of the South-West monsoon winds in 2021, the Southwestern part of Sri Lanka got more than 300mm of rain in less than 24 hours. The DMC reports that 84 divisions in ten districts were affected, with 245,212 casualties. The readiness and reaction capacities of the country's DM system for numerous hazard scenarios have been thoroughly tested since the South-West monsoonal rains in 2021 were received throughout the third wave of COVID-19 in the country.

As stated in Section 3.3 field data collection has targeted the actual conditions at the ground level during concurrent hazards amidst COVID-19. Therefore, this section of data presentation is enriched by the second and third phases of key informant interviews. Accordingly, the impacts on three areas namely, EW Systems, evacuation and SAR, and shelter management were investigated under this phase. The following sub-sections present the challenges/impacts on the aforementioned areas. Furthermore, analysis has identified the strategies taken to face those challenges.

4.3.1 Impacts of COVID-19 on Early Warning systems & implemented strategies

The impacts on EW systems and respective strategies to overcome the impacts are categorized under three areas namely, hazard monitoring, forecasting, and prediction, EW dissemination and risk communication, and preparedness and response capacities. Accordingly, Table 4.14 presents the impacts of COVID-19 on EW systems and respective mitigation strategies

Table 4-14: Impacts of COVID-19 on EW mechanisms

Phase of the Early Warning System	Impact/ Challenge	Description
Hazard monitoring, forecasting, and prediction	Negligence of the possible impacts of biological outbreaks in contingency plans	The possible impacts of biological outbreaks have not been considered within the existing contingency plans of technical agencies. New strategies such as changes to work patterns, new communication methods, new health guidelines, etc. were introduced after experiencing the consequences of COVID-19.
	Reduced access to hazard monitoring systems	The Work From Strategy (WFH) was implemented to minimize the number of contacts inside office spaces. However, due to this strategy access to hazard monitoring stations was limited. Furthermore, travel restrictions and the unavailability of transportation methods also affected the access to hazard monitoring stations. Therefore, hazard monitoring and forecasting were challenging with monitoring systems that do not have remote access.
	Infected employees	Employees started to test positive for COVID-19, reducing the number of available human resources. Therefore, the number of measurements at hazard monitoring stations was reduced (ex; river level, rainfall, etc.). affecting hazard forecasting. Furthermore, the overloading of work has caused a delay in attending to warnings.

	Inadequate prioritization for employees	Officers who are engaged in the process of hazard forecasting and early warning generation have not been adequately prioritized for COVID-19 vaccination.
	Reducing the probability margin of hazards	Technical agencies have reduced the probability margin of hazard warnings to prevent unnecessary panicking during the pandemic.
	Reduction in ground-level information	In addition to warnings from technical agencies, DM authorities have used information from the ground level to monitor hazards. However, during the pandemic, there was a reduction in the information that come from the village level.
EW dissemination and risk communication	Meetings and gatherings were restricted during the COVID-19 pandemic.	Authorities were not permitted to conduct stakeholder meetings or awareness-raising sessions physically due to the ban on human gatherings. However, the use of technological platforms for stakeholder communication was improved due to this restriction. The frequency of meetings among national and district-level officials increased during the pandemic.
	Restrictions on door-to-door early warning dissemination	In several remote areas where communication methods such as TV, radio, etc. cannot be used, door-to-door early warnings are still practiced. However, this method was affected by the impacts of COVID-19, especially by travel restrictions and uncertainty, and fear of the virus.
	Impacts on the community awareness process	Ground-level community awareness-raising process was restricted by the rules imposed to control the pandemic. However, modes of communication such as

		SMS, online messenger groups, telephones, etc. were used by DM officials for the last-mile dissemination of risk information.
Preparedness and response capacities	Negligence of the possible impacts of biological outbreaks in contingency plans	Contingency plans and response mechanisms developed and practiced by most of the DM authorities do not consider the possible impacts of biological hazards. However, some agencies, mostly non-governmental organizations have included the impacts of biological hazards within their plans well before COVID-19 started. Ex. • Three levels of emergency modes practiced by the UNICEF • The contingency plans of the Red Cross were revised after the H1N1 influence in 2009
	Reluctance in adherence to social distancing and health guidelines	COVID-19 became a new experience for people and the rules and regulations imposed have been new to them. Therefore, employees were reluctant to follow the newly introduced procedures, especially in actions related to documentation and financial matters.

	Inability to develop risk maps for compound hazard events	During the first wave of COVID-19 in Sri Lanka, DMC has managed to develop risk maps considering the risks of both COVID-19 and the Southwest monsoon. However, during the third wave in the country, this measure was not practiced due to the unpredictability of the virus, which was a result of the lack of testing, rapid variation of the spread of the virus, and different variants of COVID-19, etc.

According to the analysis of collected data on responding to compound hazard events during COVID-19, travel restrictions and COVID-19 infections can be identified as the direct impacts of the pandemic on preparedness and response capabilities. These impacts have further cascaded into several impacts which hinder the preparedness and response activities for compound hazard events. Incorporating the concepts of systems thinking, cascading impacts were mapped using causal loop diagrams. In these diagrams, the positive (+) sign shows that one particular impact has increased the likelihood of the cascading impact. Furthermore, Figure 4.7 shows the strategies taken to mitigate the impacts on early warning and risk communication activities.

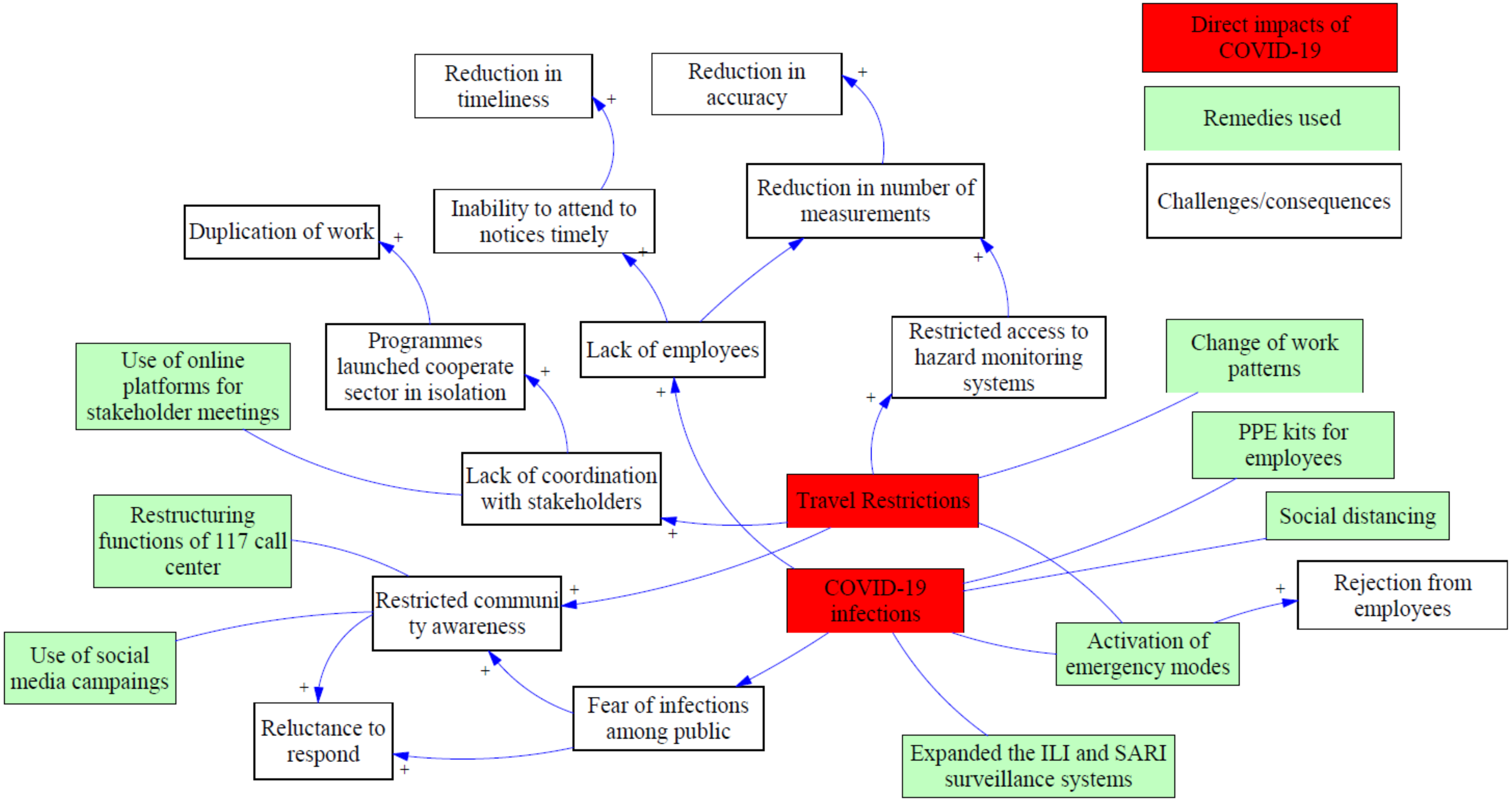

Figure 4.7: Map of cascading impacts of COVID-19 on EW mechanisms

4.3.2 Impacts of COVID-19 on evacuation and SAR and strategies to overcome

The impacts of COVID-19 are grouped under two areas namely, evacuation procedures and drills and SAR activities. Accordingly, Table 4.15 presents the impacts of COVID-19 on evacuation and response mechanisms with respective mitigation strategies.

Table 4-15: Impacts of COVID-19 on evacuation and SAR

Main aspect	Impact	Description
Evacuation procedures and drills	Inability to segregate between infected and non-infected people	Managing asymptomatic patients during evacuation procedures was difficult due to several reasons such as lack of testing facilities. However, evacuation plans were developed later while adhering to the required health guidelines and made provisions to conduct rapid antigen tests for victims but not for all districts.
	Adherence to health guidelines during the evacuation	It was challenging to adhere to health guidelines that were imposed to curtail the virus transmission during evacuation procedures. Therefore, new evacuation plans were devised incorporating the required health guidelines to be followed.
	Decreased community participation in evacuation planning and Absence of evacuation drills	Community participation in evacuation planning was limited due to COVID-19 restrictions. The developed guidelines have not captured insights from community perceptions and no drills and awareness-raising campaigns were conducted at the village level. However, only table-top exercises were allowed to conduct.

SAR activities	Not considering the impacts of pandemics in response plans	Rescue agencies did not have proper preparedness and response plans including the impacts of a pandemic such as COVID-19. However, these plans were newly introduced in response to hazard events that occurred during COVID-19.
	Evacuation of people in lockdown areas	To meet these difficulties, the Disaster Preparedness and Response Division, in partnership with the Disaster Management Centre, established, an operational guideline for SAR activities during COVID-19. This guideline included precautions to be followed in three stages, pre-evacuation, evacuation, and post-evacuation. Pre-identifying high-risk people and families within lockdown zones, keeping communication with crisis management and public health officials, and wearing suitable PPE during SAR operations were all underlined in the guideline.
	Pre identification of healthcare facilities in hazard-prone areas	
	Search, rescue, and evacuation of confirmed and suspected COVID-19 patients, transportation of infected victims	
	Restricted SAR drills	
	Impacts of infected team members	There was a great challenge since team members of SAR teams started to test positive for COVID-19. Therefore, a Bio-Bubble system was followed with the steps given below. • Restricted movements between districts for their team members. • Discouraging volunteers from participating in SAR, • Splitting SAR teams into small groups

Figure 4.8 shows the map of cascading impacts on evacuation and SAR activities, which is developed using the same concepts used in Section 4.31.

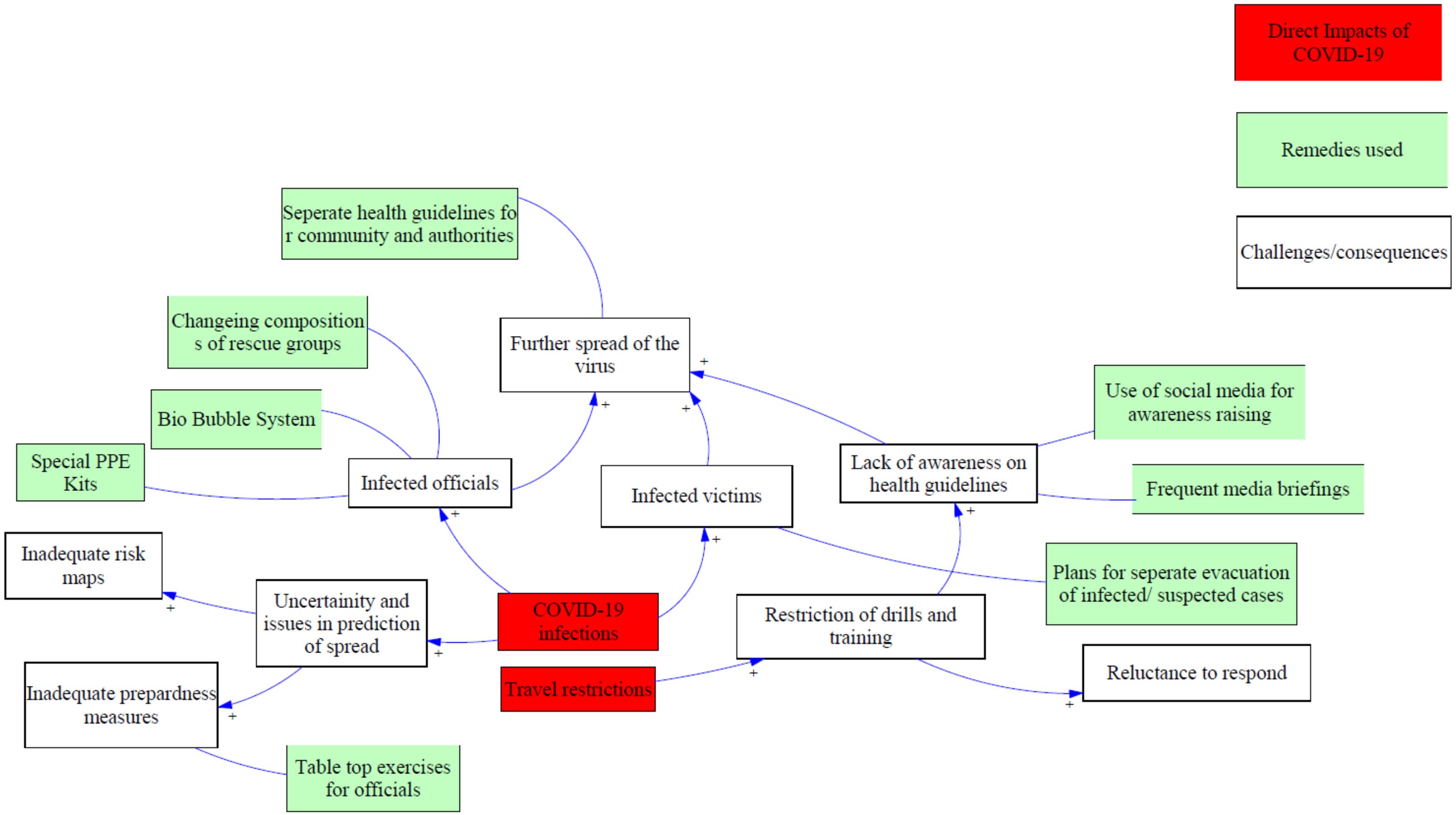

Figure 4.8: Map of cascading impacts of COVID-19 on evacuation and SAR

4.3.3 Impacts of COVID-19 on shelter management and actions taken

Safety shelter management and emergency relief services were also affected by the pandemic just as the other disaster management activities were disrupted. Table 4.16 describes what are the challenges posed by the pandemic and strategies implemented by authorities to overcome them during emergency shelter management and relief services.

Table 4-16: Impacts of COVID-19 on evacuation and SAR

Main aspect	Impact/challenge	Remarks
Shelter planning and relief services	Increased demand for space inside evacuation shelters	Since maintaining social distancing was a requirement inside evacuation shelters, there were several challenges related to limited space within existing safety centres. In places where both COVID-19 and monsoon risks were high, additional quarantine centres have been established. During the southwest monsoon of 2020, a concept called 'Friends and Relatives' was implemented. Rather than traveling to evacuation shelters, evacuees were encouraged to relocate to the homes of family and friends.
	Increased use of PPE	Within evacuation shelters, there was a high demand for PPE. However, victims were given surgical masks and other hygiene products such as sanitizers within evacuation shelters. As support to government authorities, NGOs and INGOs have provided PPEs, temporary shelters, and hygiene kits when the demand was high inside safety centres.

	Acquiring new places for evacuation centres	Officials from the District DM authorities have received approval from the provincial government to utilize schools as evacuation centres. This time, the utilization of religious sites as evacuation centres was limited.
	Uncertainty of the virus and fear among victims	People were hesitant to move to safety centres because they were afraid of contracting the virus. This was mainly because of the restricted community awareness on responding to other hazards while managing the COVID-19 situation.
	Lack of screening and testing facilities	Victims are supposed to be inspected for the temperature at the entry to evacuation shelters. Additionally, once victims arrive at the shelters, officials aimed to conduct headcounts followed by random Rapid Antigen Tests (RAT) and PCR tests. However, following this procedure was tough. Although temperature screening was done in evacuation shelters, according to some DM officials, no testing was done due to the lack of resources.
	Stressed victims	Advising mentally troubled victims to keep social distance, utilize PPE, and adhere to hygiene procedures was challenging. NGOs have aided DM authorities in dealing with these psychological effects on victims.
Special needs of vulnerable communities	Addressing gender-based issues	NGOs/INGOs in collaboration with government agencies have conducted several capacity development and awareness-raising programs to address the gender-based issues faced during concurrent hazards.

		• A three-day training program on handling telephone calls related to gender-based violence issues. • Increasing the number of communication modes that are available for victims of gender-based violence. • Training response teams on solving gender-based issues in shelters. • Developing the Gender Handbook which guides the disaster management mechanism on a gender-sensitive path. Furthermore, the • Keeping the treatment section in hospitals for victims of gender-based violence, 24/7 hours open under a special circular.
	Implementing child-friendly relief services	During the pandemic, situation officials have taken several steps to communicate the health guidelines to children. • A program called 'School Backpack Method' was launched as a support for education and to provide children with required learning materials. • U report platforms - Via U report platforms UNICEF has shared information on COVID-19 among children.
	Differently abled and older people	In addition to supporting required materials for differently abled and older people in evacuation shelters, several NGOs have taken actions to solve issues with their access to support services.

Figure 4.9 shows the map of cascading impacts on the emergency shelter management process, which is developed using the same concepts used in Section 4.31.

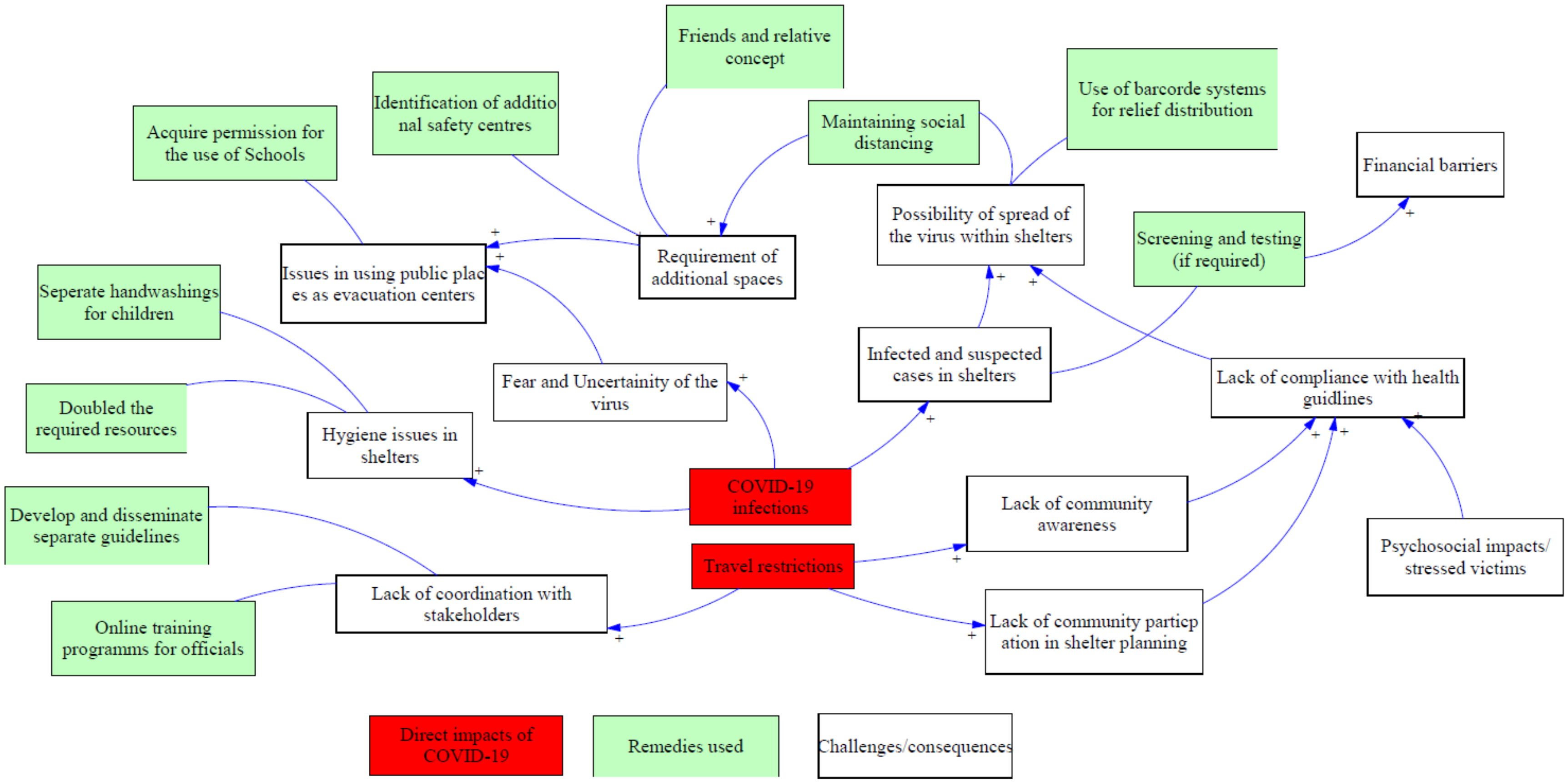

Figure 4.9: Map of cascading impacts of COVID-19 on shelter management

4.3.4 Epidemiological analysis of disaster preparedness and response activities

As explained in Section 3.3.5, a tailormade descriptive epidemiological analysis method was followed for exploring the strategies taken to mitigate dual impacts of concurrent hazards and COVID-19. During the process of analysis, the following four major areas in DM mechanisms were considered, risk knowledge; risk communication; preparedness and response planning; and disease surveillance. Accordingly, interventions taken under these areas were analysed for three different compound hazard events.

1. Southwest monsoon - 2020
2. Cyclone Burevi - 2020
3. Southwest monsoon - 2021

The following criteria were used for interventions taken under risk knowledge during each compound hazard event mentioned above.

1. Time – To what extent have interventions under risk knowledge been applied at the correct time considering the variation of outcomes of the applications over time?
2. Place – To what extent have interventions under risk knowledge captured geographical variability and applicability?
3. Person – To what extent have interventions under risk knowledge addressed the right audience considering their unique attributes

4.3.4.1 *Southwest Monsoon-2020*

A summary of epidemiological analysis on interventions taken for Southwest Monsoon – 2020 is shown below in Table 4.17.

Table 4-17: Epidemiological analysis of DM activities for Southwest Monsson - 2020

DM activity	**Time**	**Place**	**Person**
Risk Knowledge	During the first wave of COVID-19, risk maps were developed for compound risks of COVID-19 and southwest monsoon showers before the monsoon season. Possible impacts were identified in advance with monsoonal predictions.	High-risk areas for both COVID-19 and southwest monsoon showers were identified by superimposing the risk maps for both hazard events.	Vulnerable populations in high-risk districts with respect to COVID-19 and floods were targeted. This initiative was launched by the World Food Program in collaboration with Disaster Management Centre, USAID, and the Australian Government.
Risk communication	Special media efforts were undertaken via electronic and social media during the first wave of COVID-19 to raise public knowledge of preparedness measures and get compliance before the projected hazard events.	Due to the travel restrictions and limited public gatherings, online platforms and communication modes such as TV, Radio, and social media were used.	Different population groups including the young age cohort with high IT/social media literacy were targeted. Health Promotion Bureau took the lead while Disaster Management Centre took the initial steps in collaboration with technical agencies and nongovernmental organizations

Preparedness and response planning	Special instructions for reaction and relief management, preparation for early evacuation procedures to pre-identified safe centers, and camp management under health laws were released at the central and district levels prior to the Southwest Monsoon season 2020.	Each area that was vulnerable to the southwest monsoon was given its own quarantine center.	The vulnerability of first responders, including military personnel, was discovered. COVID-19 infections pose a threat to military personnel who will be on the front lines of the monsoon disaster response.

4.3.4.2 *Burevi Cyclone – 2020*

A summary of epidemiological analysis on interventions taken for Burevi Cyclone – 2020 is shown below in Table 4.18.

Table 4-18: Epidemiological analysis of DM activities for Burevi Cyclone - 2020

DM activity	**Time**	**Place**	**Person**
Risk Knowledge	During Cyclone Burevi, risk-prone areas were identified before the Cyclone hits the island.	Low-lying areas in Northern and Eastern provinces were highly affected by the Cyclone. Authorities have identified these areas as risk-prone areas for Cyclone Burevi.	Vulnerable population cohorts including fishing communities along the northeastern coastal belt were prioritized. The Sri Lankan Government has been proactive in identifying risk-prone areas.
Risk communication	Based on forecasting, warnings were issued on Cyclone Burevi before it hits the country. Those warnings were valid until the time when Burevi was expected to move out of Sri Lankan waters.	Media campaigns were carried out through television, radios. Etc.	Fishing communities were identified as a priority group. Department of Meteorology has issued prior warnings about the cyclone. Frequent media briefings were conducted through TV, radio, etc.

Preparedness and response planning	Before Cyclone Burevi prior evacuation process was carried out with the early warnings from DOM.	Due to the high probability of intense rainfall, gusty winds, and storm surges, authorities pre-emptively evacuated about 13,758 individuals residing in the eastern coastal zones of North and East. By the morning of December 3, 2020, the vast majority of these victims had returned home.	People living along the coastal belt were prioritized. Sri Lanka Government (Disaster Management Centre, District Officials, Ministry of Health, Military Forces took the initiative)

4.3.4.3 Southwest Monsoon – 2021

A summary of epidemiological analysis on interventions taken for Southwest Monsoon – 2021 is shown below in Table 4.19.

Table 4-19: Epidemiological analysis of DM activities for Southwest Monsson - 2021

Hazard event	**Time**	**Place**	**Person**
Risk Knowledge	During the third wave of the COVID-19 outbreak in Sri Lanka, risk-prone areas for compound hazard events were not identified properly before the heavy showers in May 2021. But later measures were taken to identify the high-risk areas.	Colombo, Kalutara, Gampaha, Galle, Matara, Ratnapura, and Kegalle districts are at very high risk of floods and landslides. And at the same time, Colombo, Gampaha, and Kalutara districts were reporting the highest number of COVID-19 cases in the country.	Population cohorts and residential areas within landslide and flood-prone areas were prioritized. As the mandated agency for the coordination of DM activities, DMC had the responsibility of developing risk maps for compound events with the assistance of technical agencies.
Risk Communication	Public awareness and stakeholder coordination were limited before the heavy showers during the 3rd wave of COVID-19 in the country.	Although media campaigns were initiated no specific target geographical areas were identified rather a generalized campaign was initiated.	The general population as an entire entity was targeted rather than identifying a specific target group. Although measures were not taken timely for risk communication, frequent awareness raisings campaigns were conducted during the period of heavy showers.

Preparedness and response planning	During the third wave of COVID-19 in Sri Lanka preparedness and response activities were delayed before the occurrence of heavy showers (floods and landslides)	Affected districts during Southwest monsoon 2021 include Colombo, Gampaha, Kaluthara, Rathnapura, Puttlam, Kegalle, and Nuwara Eliya.	The application of preparedness and mitigation strategies to vulnerable population cohorts was hampered due to multiple disaster situations and national-level preparedness measures were delayed. However, regional plans were developed for evacuation and shelter management. In addition to that, guidelines were developed by DMC in collaboration with the health sector.

4.3.4.4 Disease surveillance

Table 4.20 presents a summary of the outcomes of the epidemiological analysis under disease surveillance.

Table 4-20: Epidemiological analysis for interventions under disease surveillance

Time	**Place**	**Person**
During the COVID-19 outbreak, there were delays in reporting routine surveillance data on diseases other than COVID-19 to the respective authorities in the notification system. The timeliness issue was supplemented to some extent by e-surveillance mechanisms. Furthermore, incidents of cases also reduced probably due to restricted mobility of people as well. Attending to EWs and notices was delayed due to the increased workload for public health sector actors	At the hospital, reporting routine data for notifiable diseases except COVID-19 was delayed. At the regional level, attending to warnings on possible outbreaks (ex; dengue) was delayed.	Nurses who are responsible for infection prevention and control were engaged in reporting information related to COVID-19 cases. Furthermore, dedicated staff for routine disease surveillance was mobilized for COVID-19-related matters.

4.3.5 Summary

According to the epidemiological analysis, disaster management activities for the concurrent hazards that occurred during the first wave of the COVID-19 outbreak in the country have been successful. The results of the field data collection depict that, timely decisions have been taken by authorities after identifying the areas with the dual risks of COVID-19 and monsoonal showers. However, several deficiencies have been reported in relation to emergency finance management and staff contingency management at the initial stage and these have been addressed with immediate attention. Even during Burevi Cyclone in 2021, authorities have taken necessary response measures effectively. The low damage caused by the Cyclone in the North-eastern area evidenced the effectiveness of those response measures. Being proactive based on accurate hazard forecasting has been the reason behind this success story.

However, the concurrent hazards that occurred amidst the third wave of COVID-19 exposed severe gaps in the existing system for disaster management activities in the country. During this period response activities were delayed due to the lack of timeliness in forecasting and predicting hazards. Furthermore, several risk identification and preparedness activities were hindered due to delays in hazard monitoring and forecasting activities. This scenario proves the significant role played by technical agencies within stakeholder networks as identified by using the SNA method. Within the existing conditions, technical agencies lack the preparedness for biological hazards, thus reducing the accuracy and timeliness of hazard forecasting for possible concurrent hazards.

According to field data collection, the introduction of ad-hoc administrative structures has affected the mechanisms that are deployed by already existing structures. For instance, there is no adequate legal power for the DMC to coordinate with haphazard structures and monitor village-level officials. The results of the field data collection highlight that there is a separate communication network for biological hazards which is functioning under the purview of health authorities. However, according to existing national emergency operation procedures, as depicted in Section 4.2, the involvement of public health actors is comparatively low, as a technical agency, in communication networks of stakeholders for multi-hazard contexts.

Furthermore, the findings of Section 4.2 present that the involvement of non-government organizations has a critical role to play in preparedness planning for multi-hazards. However, in the practical scenarios, these agencies' involvement is hindered by the existing legal frames. The maximum benefits of capacities that NGOs/INGOs have can be gained by removing these legal barriers. It is important to note that according to legalized operation plans, local actors are vested with significant responsibility. However, field data collection has revealed that these local-level actors do not have adequate resources, skills, capacities, etc.

Last but not least, the role of hospitals and treatment facilities should be highlighted. During the third wave of COVID-19 in Sri Lanka, infected COVID-19 patients were treated at home as well. The hospital system has to cater to the demand for COVID-19 patients and injured people by floods and landslides as well. Furthermore, incidents were reported where treatment centers were affected by other hazards such as floods and electric failures. In this regard, the capacity of hospitals and treatment facilities was greatly tested during concurrent hazards that took place during COVID-19. Therefore, it is necessary to identify the areas that should be addressed to maintain the functionality of healthcare facilities for concurrent hazards during long-term emergencies that overwhelmed the capacities of the healthcare system.

4.4 Interdependencies Inside a Hospital System During a Hybrid Hazard Event

4.4.1 Factors Contributing to the Hospital Functionality

4.4.1.1 Patient flow

According to insights from previous steps, the number of patients who are arriving at the hospital increase considerably during a biological outbreak like COVID-19. For instance, most hospitals in Sri Lanka during dengue outbreaks in 2017 almost reached their maximum capacity (IFRC, 2018). Therefore, managing the flow of patients can be considered one of the main aspects of continuing the hospital functionality during an outbreak. Illustrating the patient flow of a hospital, Figure 4.10 presents the main elements of the flow of patients. It has three main steps namely, admitting patients, treating patients, and patients leaving the hospital.

Figure 4.10; Concept of patient flow inside a hospital

When considering the left side of the flow, several factors which are relevant to the inflow of patients can be identified as shown below in Table 4.21.

Table 4-21: Factors affecting the flow of patients in hospitals

Factors	**Description**
Admission rate	The admission rate of patients refers to the ability of a hospital to admit patients at a given time. In general, the admission rate is affected by the capacities of a hospital such as available bed capacity, staff members, technical facilities, etc. Illustrating the available bed capacity, the number of vacant beds is generally determined by the number of admitted patients and the number of maximum beds available. However, during an emergency, if there is an additional supply of beds, the number of maximum available beds will be increased.

Patients waiting in the queue	Patients who need to receive treatment will be waiting to get admitted and treated. The number of patients in the waiting queue is determined by the hospitalization rate and the admission rate. If the hospital capacity is fulfilled and the admission rate has started to decrease, the number of patients waiting in the queue will be increased.
Triage	The term ‘Triage’ refers to the sorting of injured or sick people according to the need for medical attention. It has a more impact on priority for patients who get care first rather than increasing the number of admitted patients.
Hospitalization rate	The rate at which patients are hospitalized is introduced as the hospitalization rate. All the patients who are injured or sick do not have the requirement for hospitalization. Based on the severity of the injuries or disease, the percentage of patients with the need for hospitalization can be determined.
Infection rate	Infection rate becomes the most important factor in the case of a transmissible disease. It presents the number of new infections detected per unit time. Several sub-factors contribute to the infection rate, infectivity, total population, and contact rate. In most cases, the location of the hospital determines the variation of the above-mentioned subfactors.

The outflow of patients is mainly determined by two variables namely, the number of discharged patients and the number of deaths. In relation to a disease, the number of discharged patients depends on the recovery rate which is affected by the average duration of illness. The number of deaths can be determined by the average death rate during a particular time period. The death rate generally depends on the fatality rate of the disease. According to key informants, the fatality rate can be impacted by the quality of care considerably. Accordingly, critical systems such as electricity and water directly affect the quality of care during treatments.

4.4.1.2 Quality of care

The quality of care delivered by a hospital does not solely depend on the capacity of the medical staff. There are several other factors such as the capacity of medical equipment, continuity of critical systems (electricity, water, fire protection, etc.), availability of medicine, and hygiene facilities. Table 4.22 details the factors that support the quality of medical services inside a hospital.

Table 4-22: Supporting factors of quality of care in hospital treatments

Supporting factors	**Description**
Capacity of medical staff	Human resources can be considered the most significant resources that affect the continuity of hospital functionality during an emergency. In relation to the services of medical staff, the availability of adequate medical staff for treating patients can significantly affect the quality of medical operations (A. et al., 2007). Furthermore, if a concurrent hazard affects the hospital staff in terms of injuries or death, only a fraction of the staff will be available for treating patients. Furthermore, working for extended hours can cause staff burnout among staff members if proper actions are taken to streamline the routine work of hospital staff. Not limited to the direct impact on quality of care, human resources in a hospital affect the effectiveness of command and control, emergency response, coordination, etc. during an emergency.
Medical supplies	The capacity of medical supplies depends on the availability of adequate medical equipment and medicines and the continuous supply of these materials (U.S. Department of Health and Human Services, 2021). In relation to a disease like COVID-19 which affects the respiratory system, the continuous supply of medical gases like Oxygen is vital for the survival of hospitalized patients. The adequate capacity of medical supplies can be achieved through streamlining the estimation of supplies and requirements including backups, maintaining inventories, proper and safe storing and stocking facilities, etc. In some cases, medical supplies such as gases depend on factors such as electricity and the safety of distribution lines as well.
Electricity system	Among technical systems that support the medical services inside a hospital, electricity plays a significant role since, the

	functionality of medical equipment depends on electricity most of the time (Khanmohammadi et al., 2018). For instance, the lives of patients who were connected to ventilators during COVID -19 were threatened by electricity failures. Therefore, a continuous supply of electricity for required units is essential for upholding the quality of care in treatments (Khanmohammadi et al., 2018). In case of damage to the main supply of electricity, the availability of additional electricity supply systems such as generators is essential to ensure the continuous supply of electricity. In this regard, generators should have the capability of meeting the demand of the hospital. At the same time, generators must be protected from other natural or man-made hazard events.
Water supply	Water supply systems have a crucial role in ensuring the quality of care within hospital premises (WHO and PAHO, 2015). In this regard safety of the water distribution system is considered paramount. If the existing mode of water supply is affected, water reserves should be available to continue the supply of water. Therefore, it is required to consider the protection of water tanks/storage as well.
Hygiene facilities	The availability of hygiene facilities is considered critical in providing quality health care in hospitals (UNICEF, 2019). Especially during an emergency, if hospitals get crowded and surpass the maximum capacity, existing hygiene facilities might not be able to meet the demand. Furthermore, disaster events can pose damage to existing hygiene facilities in a hospital, thus affecting the quality of medical services. Furthermore, inadequate hygiene facilities can be a reason for diseases like COVID-19 to spread further within hospital premises.

4.4.1.3 *Damage to the building*

A hazardous event that takes place within or outside the hospital premises has the possibility of damaging the hospital buildings. For instance, an earthquake can damage both structural and non-structural elements in hospital buildings. These damages can cause the dysfunctionality of operations inside a hospital. Furthermore, it is important to note that, damages to hospital buildings cannot be rectified instantly. The recovery process of buildings is time-consuming and depends on several factors which have dynamic relationships. The amount of damage can be determined based on the intensity of the hazard event. The repair and reconstruction of building elements are time-dependent. In addition to that, the speed of these activities depends on available monetary resources as well. Furthermore, the restoration of building elements, especially non-structural elements such as electricity, water supply system, internal circulation, etc. depends on the allocated financial resources for recovery.

4.4.2 Conceptualization of the Interdependencies

The first step under conceptualization is defining the purpose of the model. As described above, the purpose of this model is to conceptualize the interdependencies of hospital subsystems that contribute to the hospital's functionality. In this regard, the number of patients waiting in the queue was taken as the main determining factor. Therefore, the boundary of the model is defined as the hospital premises which consists of all the sub-systems within the hospital such as buildings, healthcare workers, critical lifeline systems, medical equipment, etc. Structures and human resources which are located outside the hospital premises but have an impact on the hospital are not considered in this model. Table 4.23 details the identified list of variables that affect the hospital functionality during/after a disaster event.

Table 4-23: Identified variables within a hospital system

	Variable Name	**Description**
Dependent Variables	Patients in Queue	Patients who are waiting to be admitted for being served
	Admitted infected patients	Number of patients who are admitted to the hospital and receiving treatments
	Recovered patients	Number of recovered patients
	Deaths	Number
	Vacant beds	Number of vacant beds
	Staff Capacity	Number of staff who can be allocated to treat a patient

	Average recovery time	The average time taken to treat and recover the patient from symptoms
	Available equipment (ventilators/ Oxygen)	Number of medical equipment available for patients
	Medicine Inventory	Number of PPE kits available for the hospital staff and patients
	Hospital Damage	Percentage of damage that occurred at the hospital (Damage Index)
	Quality of care	Quality of care in treatments for infected patients
	Staff capacity	The capacity of staff required for treatments (staff per patient value)
	Available medical consumables	Rate of available medical consumables per patient
	Available medical equipment	Rate of available medical equipment per patient
	Capacity of critical systems	The capacity of critical systems such as water, electricity,
	Building damage	Damage index of the hospital premises after a disaster
	Fuel storage	Amount of fuel available
	Building repair rate	The rate at which the hospital infrastructures are repaired
	Financial allocation rate	The rate at which financial resources are allocated for the recovery of the hospital
Independent Variables	Infection Rate	The rate at which people are being infected
	Financial allocations	Financial allocations available in the hospital
	Need for Hospitalization	The ratio between the number of patients who are being hospitalized and the number of patients who are infected
	Fatality rate	The rate at which patients die because of the infections
	Effect of Disaster Preparedness level	The effect of the disaster preparedness level of the hospital on its functionality during an emergency
	Population	The population within the hospital catchment area

4.4.3 Interdependencies of Hospital Subsystems

4.4.3.1 Flow of patients

The developed model captures the flow of patients using Susceptible, infections, patients in the queue, admitted patients, recovered patients, and deaths as stocks. Figure 4.11 shows the connectivity of selected stocks and flows that are related to them. *The infection rate* is considered the inflow of infections. *Infection rate* is affected by factors such as population, the infectivity of the disease, and contact rate. In this model, *Infections* as two outflows namely. *Asymptomatic recovery rate* is one of the outflows. In relation to diseases, there is a percentage of patients who are identified as asymptomatic patients and do not need hospitalization. The recovery rate of asymptomatic patients is decided by the average recovery time of the disease.

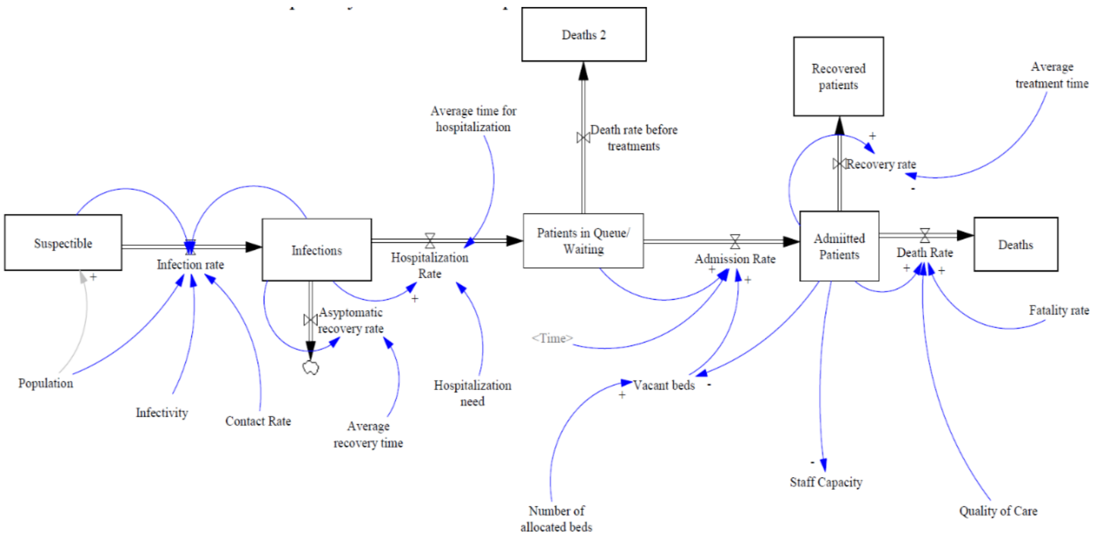

Figure 4.11: Dynamics of flow of patients inside a hospital during a compound hazard event

The second outflow is the hospitalization rate which is determined by the average time taken for hospitalization after getting infected and the fraction of infected patients who need treatments at the hospital. In addition to being an outflow to Infections, the *Hospitalization rate* works as an inflow to *Patients in Queue*. In this model, *Admission rate* refers to the ability of the hospital to admit patients and give required treatments. According to this model, the number of vacant beds and the time taken for administrative decisions affect the ability to admit patients. Recovery rate, which is an outflow for *Admitted patients*, is determined by dividing the number of admitted patients by the average treatment time at the hospital. In addition to that, the *Death rate* is determined by the *Fatality rate* and *Quality of care*. In this model, it is considered that the *Death rate* will be increased if the *Quality of care* is low value.

4.4.3.2 Quality of care

In the proposed model, *Quality of care* is taken as a variable that affects the Death rate. Accordingly, the Quality of care is determined by a set of factors such as staff capacity, availability of medicine, availability of medical equipment, drinking water supply, power supply, and hygiene facilities (see Figure 4.12). Out of these factors, the availability of medicine, availability of medical equipment, and power supply for treatments were taken as the most critical factors. If one of these factors is affected and the capacity of these factors reaches zero, it is assumed that the quality of care will be also zero. Thus, it increases the death rate considerably. Furthermore, water supply, staff capacity, and hygiene facilities are considered the second most important factors that affect the Quality of care. Accordingly, if one of these factors did not reach the required level, it is assumed that the quality of care is reduced by a pre-determined fraction and increases the death rate.

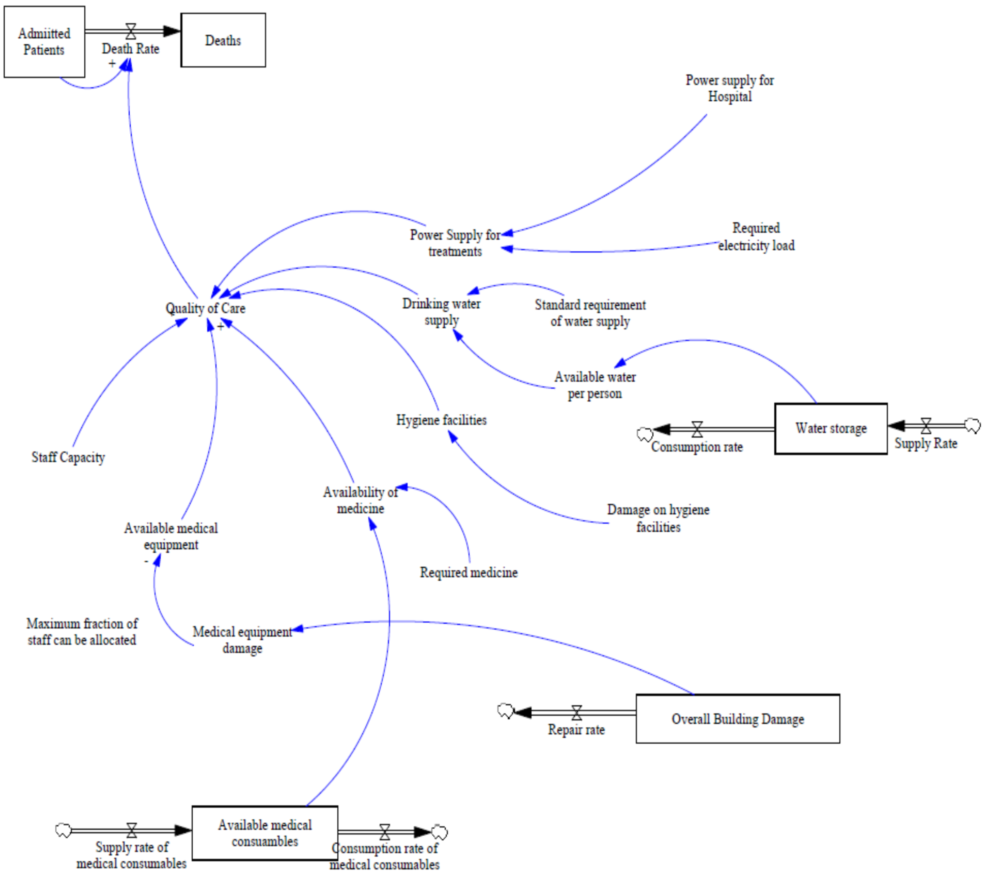

Figure 4.12: Dynamics of Quality of care inside a hospital

4.4.3.3 Staff capacity

The proposed model determines the service capacity of the staff using the existing patient-to-staff ratio. The patients to staff ratio depend on the available staff for treating the particular disease. According to the model, the staff allocation rate determines the number of staff allocated for the disease. This rate is impacted by several factors such as *Total number of staff available in the hospital*, *Number of in-house patients*, *Maximum percentage of staff that can be allocated for the disease*, *Time for staff allocation*, and *Required patients to staff ratio.* Illustrating the rationale behind deciding the *Staff allocation rate*, the number of staff allocated has to be able to satisfy the required patient to staff ratio of a particular disease. At the same time, even though there is a high demand for staff, the fraction of staff allocated cannot exceed the maximum limit of the said fraction which is decided by the hospital administration. Figure 4.13 illustrates the dynamics of staff service capacity of the considered disease in the model.

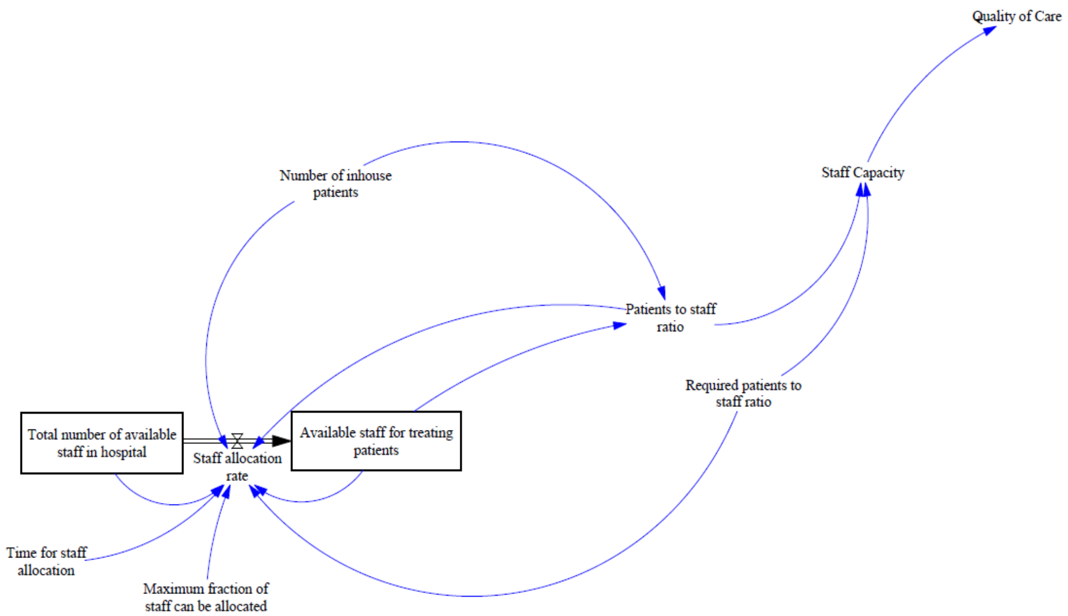

Figure 4.13: Dynamics of staff capacity in the hospital

4.4.3.4 Power supply

According to insights from the key informant interviews, the adequate power supply is a critical factor that decides the quality of care in medical services. In the hospital setting, electricity is mainly supplied by an outside organization. However, in case of damage to the supply from outsiders, the hospital has to depend on additional power supply systems within the hospital premises. Most of the time, generators are used in the Sri Lankan context as the emergency power supply. Power supply from generators mainly depends on fuel storage. The available amount of fuel decides the number of generators that can be operated in an emergency. Therefore, during an emergency that affected the main electricity supply of the hospital, the capacity of generator systems decides the amount of power supplied for activities in the hospital. If this value is not sufficient for the required power for medical equipment to function the quality of care in treatments will be reduced. Figure 4.14 presents the interdependencies that determine the dynamic behavior of the power supply system.

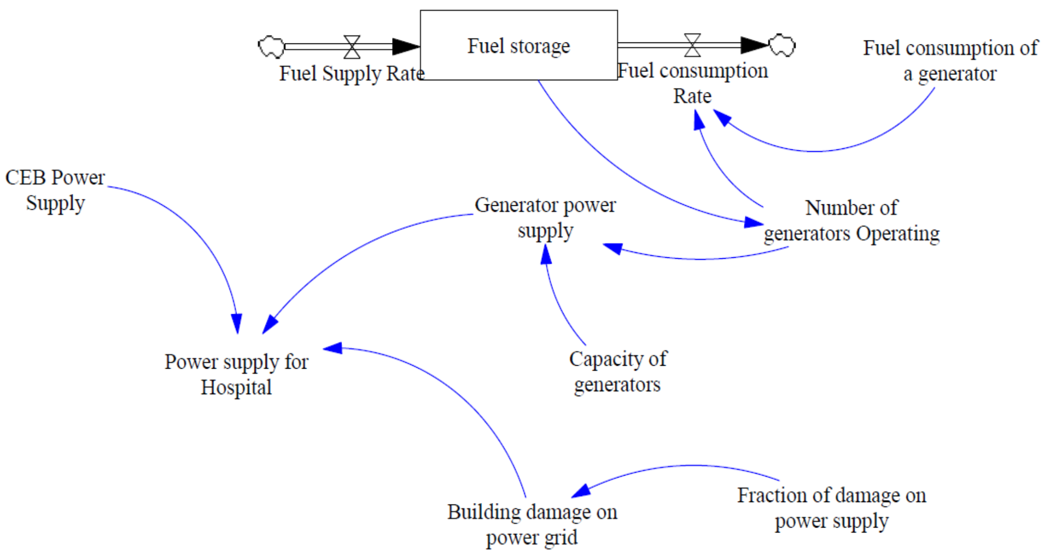

Figure 4.14: Dynamics of power supply for hospital functions

4.4.3.5 Water supply

Although water supply is not critically affecting the quality of care compared to the supply of electricity, it can reduce the quality of medical services, if a sufficient amount of water is not available for hospital functions. Figure 4.15 illustrates the dynamics of the water supply system. According to the proposed model, the *Available Water per Person* in the hospital depends on the number of patients and staff in the hospital and the total amount of water available. Furthermore, it is assumed that during a disaster, only the *Water Supply Rate* is affected.

Accordingly, the *Water Supply Rate* is affected by the *Water Storage*, *Maximum Water Storage*, and *Damage to Water Supply*. Illustrating the rationale behind *Water Supply Rate,* if the existing Water Storage reaches the maximum storage, Water Supply Rate should be zero. Furthermore, if the damage to the water supply is greater than zero, the Water Supply Rate will be reduced. However, if there is an Additional Supply of Water, the *Damage to Water Supply* will be neglected by the model. It will not affect the *Supply Rate of Water*.

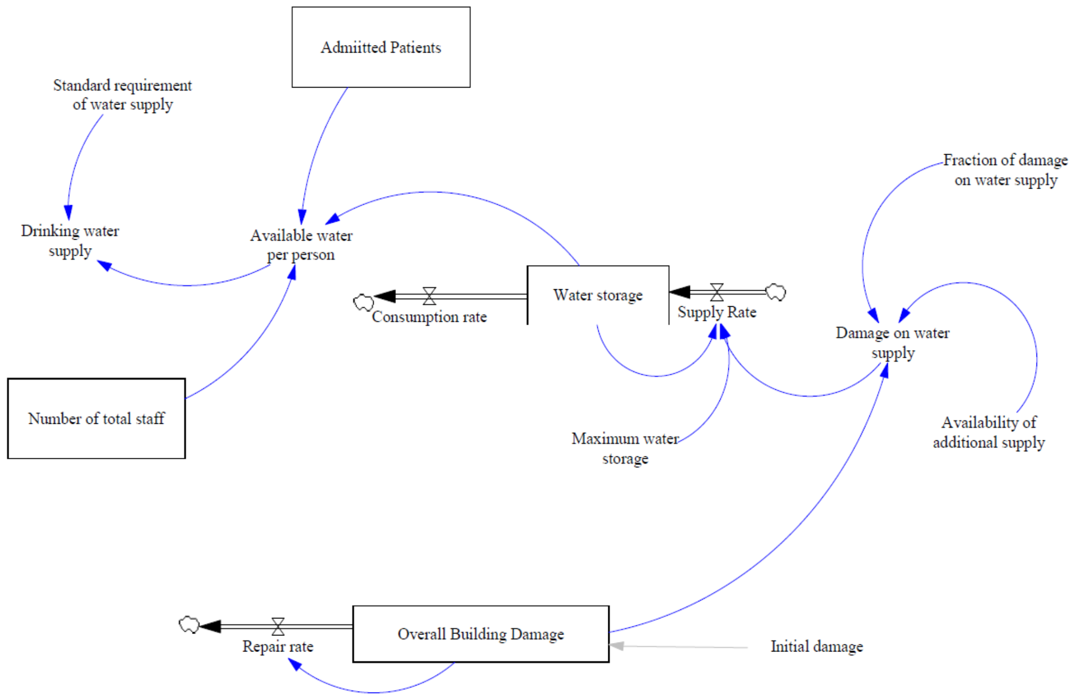

Figure 4.15: Dynamics of water supply facilities in the hospital

4.4.3.6 Building recovery

Building damage can significantly affect the functionality of the hospital during an existing emergency such as a biological outbreak where the hospital capacity is reached already. In this model, it is assumed that damage to buildings can affect the capacity of the power supply, water supply, hospital beds, and medical equipment. The *Overall building damage* at a particular time depends on the *Initial Damage* and *Repair rate*. Initial damage should be calculated as an index (Damage/Overall building damage). *Repair rate* is mainly affected by *Financial resources for Building recovery* and *Time for repairing*. Since the proposed model does not consider financial support from outside the hospital, financial resources for Building recovery depends on the *Available financial allocations* within the hospital. Figure 4.16 presents the dynamics of building recovery inside a hospital during a biological outbreak.

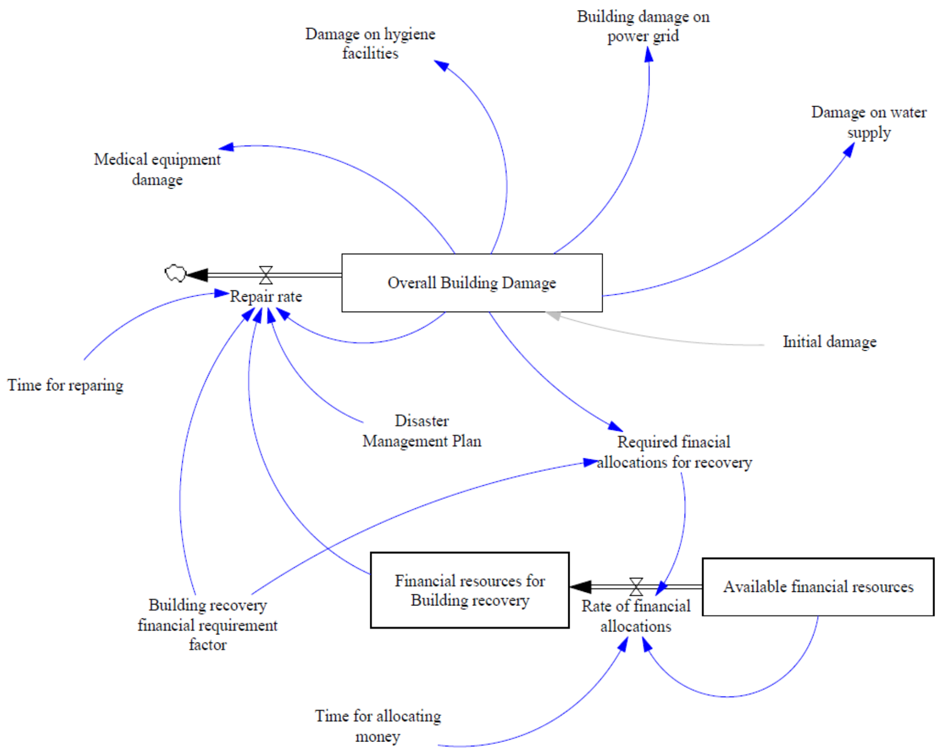

Figure 4.16: Dynamics of building recovery in the hospital

4.4.4 Summary

Accordingly, all mentioned subsystems were connected and presented as shown in Figure 4.17 below. This model can be incorporated into identifying the interdependencies that are present within a hospital. The model can assist the decision-makers in relation to hospital disaster management activities for a hybrid hazard scenario that can take place during a biological outbreak.

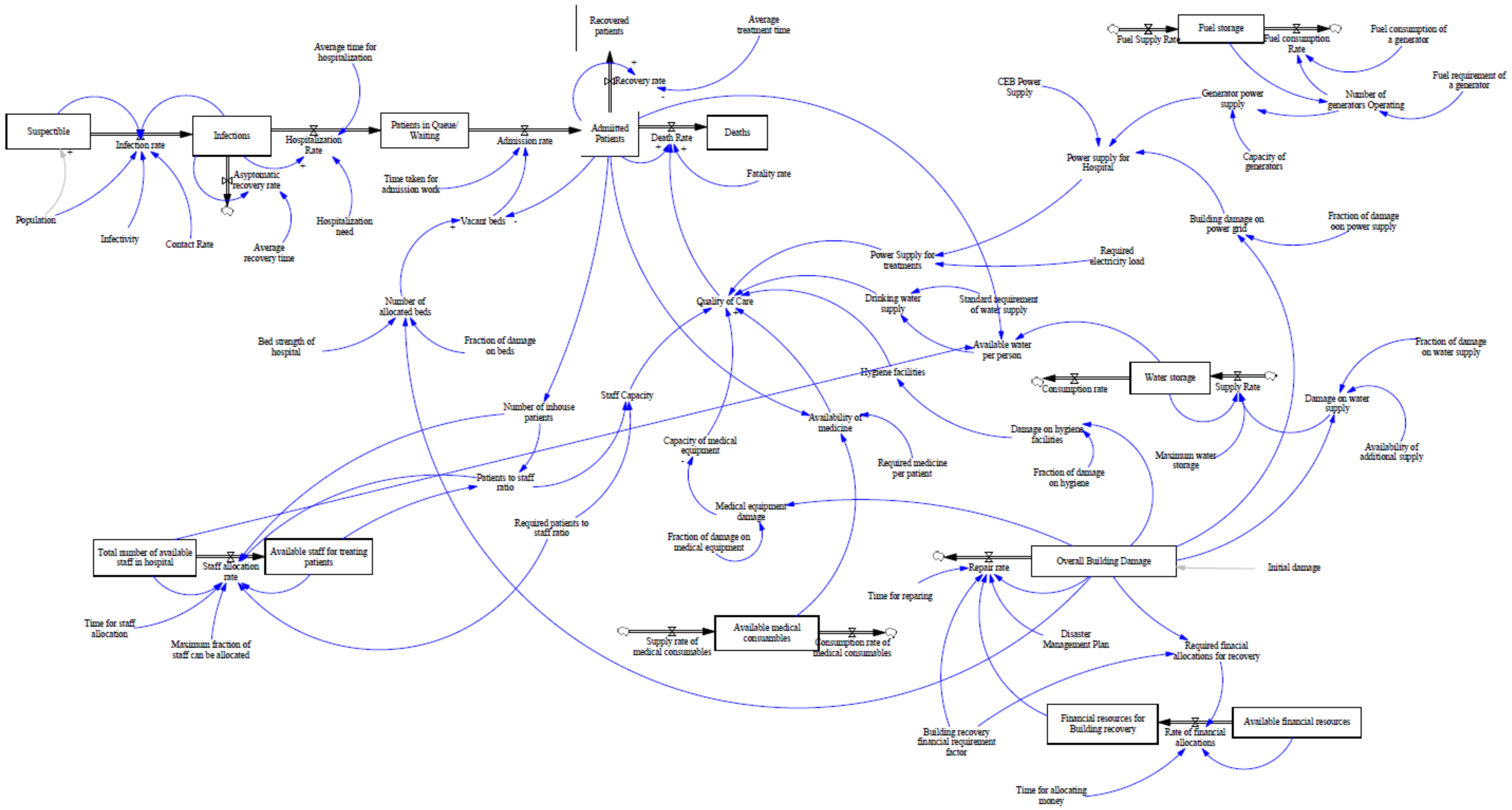

Figure 4.17: Conceptual model of dynamics of a hospital during a compound hazard event

5 DEVELOPMENT OF PUBLIC HEALTH RESILIENCE FRAMEWORK

During previous steps, it was identified that the public health system in Sri Lanka should be strengthened to be resilient against multi-hazard scenarios. Although the public health sector plays a major role in disaster management activities in multi-sector platforms, those initiatives are more reactive rather than proactive. Many interventions have been initiated in response to the COVID-19 pandemic. A few of those interventions are,

1) Active involvement of Public Health Inspectors at the village level in emergency shelter management
2) Deployment of emergency response funds for areas such as risk communication
3) Use of localized early warning systems for prepositioning of resources required for disaster response
4) Use of digital media platforms for effective stakeholder coordination among non-health sector-related stakeholders

Although these measures can be taken as positive signs, there are numerous areas that need improvements to enhance the resilience of the public health system against multi-hazard scenarios. Considering these aspects, this study has identified seven major areas which need to be looked into in exploring the disaster resilience of the public health system for multiple hazard scenarios. These areas are,

1) Governance and Leadership
2) Health Finances
3) Health Information Systems
4) Risk Communication
5) Health Service Delivery
6) Health Workforce
7) Medicines, Vaccines, and Equipment

Figure 5.1 presents the proposed framework for public health system disaster resilience. This framework consists of three layers. *Governance and leadership* and *Health information systems* provide the basis for the public health system resilience. *Health workforce* and *Health finances* can be considered the inputs to the system. It is important to note that Risk communication has a major role to play in a public health system since it works as a binding agent of all the elements in the system. Risk communication is vested with the responsibility for the coordination among these elements. Last but not least, *Health services,* and *Medicines and vaccines* work as the outcomes of the system. These can be identified as some sort of measuring criteria of health system resilience against a disaster.

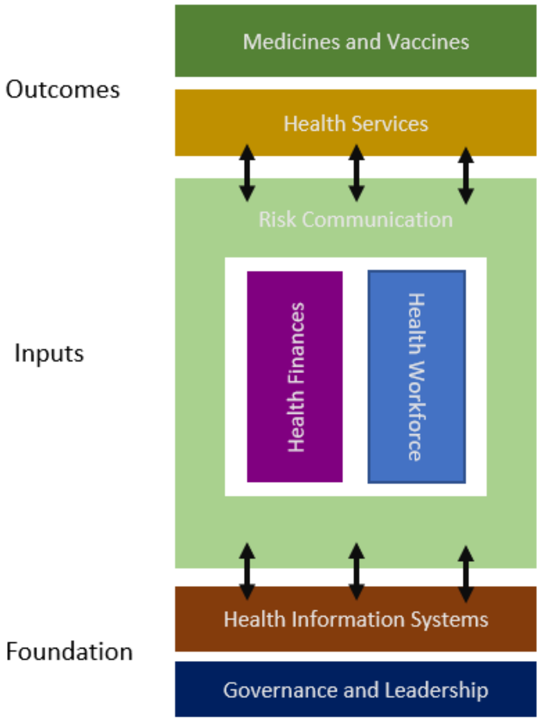

Figure 5.1: Public health systems resilience assessment framework for multiple hazards

The rationale used in selecting these main elements and indicators under each of them is described below in the below sub-sections. Furthermore, this study provides guiding questions to explore the performance of the health system under each sub-indicator that has been proposed below. Furthermore, this study provides guiding questions under each sub-indicator to explore the resilience of health systems under a particular element.

5.1 Governance and Leadership

In general, the term Governance refers to the process of transferring the responsibility and authority for decision-making from people to a governing body (Barbazza and Tello, 2014; Ciccone et al., 2014). These governing agencies can distribute across different levels from international to local. In relation to DRR, health sector governance and leadership plays a key role not only within the health sector but also beyond the sector as well (World Health Organization, 2014). Five main factors, which determine the level of effectiveness of governance and leadership were identified according to insights from the areas discussed in previous sections.

1. National policy and legislation

It was revealed that the presence of national health policies that integrate DRM into health aspects, can make a vast difference in the effectiveness of health systems resilience in a disaster situation (UNISDR, 2016). Currently, in Sri Lanka, the Disaster Management Act No. 13 of 2005 identifies Health as one of the major aspects of disaster management ("Sri Lanka Disaster Management Act, No.13 of 2005," 2005). However, the findings of the study reveal that the existing national health policy in Sri Lanka does not adequately address health sector preparedness and response planning in a multi-hazard context.

Furthermore, plans devised at the global and regional levels in relation to DRR emphasized the need for including health-related aspects in regional-level disaster planning in cities (UNDRR, 2020d). In Sri Lanka, plans have been developed in isolation to address issues in relation to disaster management by both public health and DM officials at the regional level. Considering these aspects under the National policy and legislation, three sub-indicators are introduced as shown below.

Sub indicator	**Guiding question**
National health policy and plan	To what extent public health disciplines are engaged in disaster management activities at decision-making levels
Integration of biological hazards into disaster risk reduction planning	To what extent emergencies like biological outbreaks are included in disaster management plans

Inclusion of health aspects in urban planning	To what extent health aspects are included in disaster preparedness and response planning within cities

2. Compliance with international regulations

In relation to global health security, International Health Regulation (IHR) 2005 functions as the main guiding framework (WHO, 2008). WHO does not provide guidelines only but also sets criteria for evaluating the compliance of country measures in relation to public health security with the IHR guidelines through the Joint External Evaluation (JEE). The results of this evaluation set the platform for the health security strategic plan of a country. Under the main indicator, Compliance with International Regulations, three sub-indicators have been identified as shown below.

Sub indicator	**Guiding question**
Implementation of International Health Regulations	What are the commitments toward implementing IHR [2005]?
Joint External Evaluation	What are the steps taken in relation to Joint External Evaluation?
Participation in International agreements	To what extent the country participates in international agreements related to health security?

3. Stakeholder coordination

Currently, due to the complexity and systemic nature of disasters have called for the need for emulating multi-sectoral practices in disaster risk reduction (AL-Fazari and Kasim, 2019; UNDRR, 2022). In the Sri Lankan context, the disaster management mechanism is decentralized from the national level to the village level. Furthermore, the public health sector in the country also has a decentralized mechanism from the central ministry to the regional level. During the field data collection, it was identified that although coordination between these two sectors functions effectively at the national level, effective coordination at regional and community levels needs to be looked into more.

Moreover, since technical agencies have a paramount role to play in stakeholder coordination as presented in Section 4.2, especially in relation to information sharing and enhancing risk knowledge, it is important to note that coordination with the public health sector across all administrative levels has to be more strengthened, especially at the grass-root level. In addition to that, there should be sound platforms to maintain effective coordination with stakeholders from institutions such as non-governmental organizations, donor institutions, etc. Considering these factors, the study proposes two sub-indicators that should be investigated under stakeholder coordination as shown below.

Sub indicator	**Guiding question**
Decentralization and Representation of the health sector in DRR mechanisms at different jurisdiction levels	What are the administrative levels that the health sector represents in disaster management mechanisms in collaboration with DM authorities?
Availability of platforms for multi-sectoral coordination	Are there platforms to coordinate with stakeholders from both government and non-government institutions which are from different sectors related to disaster management?

4. Political and security risk

According to the analysis conducted to investigate relationships between the preparedness parameters and effective response mechanisms during COVID-19, timeliness of government decision making plays a critical role in effective controlling of COVID-19 at the early stage (Jayasekara et al., 2021; Nuclear Threat Initiative and Johns Hopkins School of Public Health, 2019). Furthermore, during field data collection it was observed that hap-hazard structures and political impacts have hindered the effectiveness of already existing structures. The findings have highlighted that public confidence in government decisions and announcements during a health emergency situation can make a greater impact on the effectiveness of response and recovery measures. Considering these factors, a set of sub-indicators was identified as shown below.

Sub indicator	Guiding question
Government effectiveness	What is the government effectiveness score according to the World Bank Group?
Public confidence in government	What is the level of public confidence in decisions and rules made by respective government institutions
Risk of terrorism and conflicts	How likely to expect foreign or local territs attack during a disaster
International tension	What is the possibility of impacts on disaster management mechanisms by foreign tension?

5. Monitoring and evaluation

In Health Emergency and Disaster Management Framework developed by WHO, it is highlighted that there must be mechanisms to monitor progress in enhancing disaster resilience of the public health sector. In this regard, it is important to use standardized indicators to monitor existing risks, weaknesses, and capacities while making necessary recommendations for resilience enhancement (World Health Organization, 2019). Sub indicators identified under monitoring and evaluation are presented below.

Sub indicator	Guiding question
Availability of performance monitoring frameworks	Are there performance monitoring frameworks at the local level which are influenced by standardized global frameworks?
Policy Reviewing	Is there a mechanism to review the policy periodically and after a major health emergency?
Benchmarking with regional and international indicators	Is there a mechanism to benchmark national health sector capacities with international and regional standards and improve the preparedness and response mechanisms accordingly?
Capacity development	What are the mechanisms available for capacity development in health sector disaster resilience

5.2 Health Finances

In order to sustain and recover after external shocks, health systems need effective allocations of financial resources for health functions. Minimized risk of response mechanisms can be achieved through the availability of stable and diverse financial allocations (Ammar et al., 2016; European Commission, 2013; Hanefeld et al., 2018). There can be inequalities in access to healthcare services during an emergency, based on the socioeconomic status of victims. Therefore, it is necessary to take actions to minimize out-of-pocket payments for households in order to ensure the equal affordability of health services during an emergency. Furthermore, the financial resources needed for acquiring medical consumables during an emergency should be stable and affordable (European Commission, 2014; Kamal-Yanni, 2015). Considering these aspects, three indicators were proposed to investigate the readiness of health finances as described below.

1. Funds for health EDRM programs

During the field data collection, it was identified that it is the responsibility of relevant government stakeholders to ensure sufficient monetary resources for HEDRM programs. For instance, financial resources should be available according to requirements and without any geographical discrimination. Accordingly, the preparedness in financial allocations for health disaster management programs can be explored under three sub-indicators as shown below.

Sub indicator	**Guiding question**
Staff activities and supplies	To what extent funds are available for staff activities and equipment needed for capacity building in health disaster management?
Hospitals and infrastructure safety	To what extent funds are available to ensure the safety of hospitals and healthcare infrastructures?
Specific programs for HDRM	Are there funds available for special HDRM programs?

2. Emergency management

According to key insights from field data collection, it is required to focus on the management of emergency funds. Even though financial resources have been allocated for capacity building in health emergency disaster risk management, it is vital to allocate and manage contingency funds for emergency response mechanisms. Therefore, the study presents two sub-indicators to explore the level of preparedness in emergency fund management as shown below.

Sub indicator	Guiding question
Contingency funds for emergency response and recovery	Is there a contingency fund available for health emergency response?
Monetary resource mobilization	To what extent plans are available for financial resource mobilization?

3. Community needs

According to lessons learned from preparedness and response planning for compound disaster events that occurred during the COVID-19 outbreak in Sri Lanka, it was necessary to consider the financial needs of the community for acquiring health services as well. Therefore, the study provides a sub-indicator as shown below to explore the percentage of the population that needs out-of-pocket payments for healthcare services.

Sub indicator	Guiding question
Household out-of-pocket payments	What is the percentage of the population whose direct out-of-pocket payments to providers for health during more than 10% of their total income

5.3 Health Information Systems

During the key informant interviews, it was identified that lack of disaster risk knowledge of compound hazards is the major reason for hindered preparedness and response mechanisms in Sri Lanka during recent hazard events that occurred amidst COVID-19. In responding to compound hazard events it is crucial to be proactive and minimize existing vulnerabilities (Quigley et al., 2020). Considering the insights gathered from previous sections, five main elements were identified under 'Health and Information Systems'.

1. Surveillance and early warnings

The effectiveness of early warning systems plays a crucial role in preparedness planning. This relationship was greatly highlighted during floods and landslides that occurred in 2021 in Sri Lanka. The findings highlight that the accuracy and timeliness of early warnings enable proactive measures well before a disaster occurs. At the global level, it is recommended to use the extensive use of hazard monitoring and forecasting within early warning systems. However, Sri Lanka lacks such technical advancement according to insights gathered from experts in the disaster management field. Considering these aspects, this main element presents five sub-indicators as shown below.

Sub indicator	**Guiding question**
Indicator and event-based surveillance systems	What is the level of using the indicator and event-based surveillance systems in the country?
Inclusion of public health concerns into national multi-hazard early warning system	To what extent do existing national early warning systems monitor and forecast health risks?
Transparency and ethical consideration of surveillance data	Does the existing information system consider ethics and maintain transparency in relation to collected surveillance data?
Analysis of surveillance data	What are the outcomes of collected surveillance data and hazard monitoring?
Reporting	What are the mechanisms in place to report trends identified through surveillance systems or early warning systems?

2. Risk assessment

Risk assessment is considered one of the major sub-elements under disaster risk knowledge of a Multi-Hazard Early Warning System (WMO, 2018). The existing risk assessment plans in Sri Lanka have a hazard-by-hazard approach which is defied by the increased likelihood and intensity of hazards. During a biological outbreak, that can last for a long time, the inclusion of possible impacts of compound hazards within risk assessment plans can be considered paramount since the likelihood of concurrent hazards is high. As shown below a set of sub-indicators was identified based on insights from steps described in previous chapters.

Sub indicator	**Guiding questions**
Comprehensive disaster risk assessment at the national and local level	How does the national disaster risk assessment plan function? Does it cover the regional level as well including all the possible hazards?
National health surveys and resource tracking	Does the national health survey cover the capacities related to national health risks?
Inclusion of biological hazards in national risk assessment planning	Does the existing risk assessment plan include biological hazards as well?
Availability of risk assessments for compound events [including biological hazards]	To what extent compound hazards are included in national risk assessment plans?
Community need assessments	To what extent do existing risk assessment plans identify community needs including marginalized communities (Ex; Rapid need assessments)?
Use of technology in risk assessments	To what extent technological applications such as GIS are used in risk assessment approaches?

3. Information management system

Information management systems are essential to uplift the proper use of collected raw data, information, warnings, etc through approaches such as surveillance systems (Aung and Whittaker, 2013). During the COVID-19 pandemic in Sri Lanka, issues related to the lack of proper information systems, mainly the absence of databases, were greatly highlighted at the community level. In the recent past, no major incidents have been reported in relation to the impacts of disasters on information management systems. However, it is a crucial need to pay attention to hazards such as cyber-attacks against information systems. Considering these insights, the following sub-indicators were defined to investigate the information management systems.

Sub indicator	**Guiding questions**
Fundamental databases	Are there fundamental databases covering all health records?
Protection of information from a disaster	What are the measures available to protect information from disasters?

4. Information products

The set of sub-indicators identified under information products is shown below.

Sub indicator	**Guiding questions**
Development of guidelines/ protocols/ good practices	Are there plans to devise guidelines, protocols, etc. based on the information collected?
Availability of information sharing procedures	To what extent are information-sharing procedures available? Are there procedures available to share all health records?
Data from other critical systems shared with the public health sector	Are there procedures available for public health officials to access data from other critical systems such as weather forecasts, expected power failures, etc.?

5. Research and development (R&D)

Although R&D activities carry numerous benefits, there are a number of challenges such as lack of financial resources, issues in promoting research findings, implementing research outcomes, etc. (Aung and Whittaker, 2013). However, currently, the Sri Lankan health sector does not adequately address research activities in the area of disaster resilience focusing on a multi-hazard context. Therefore, to investigate the effectiveness of health disaster resilience R&D, this section presents two sub-indicators as shown below.

Sub indicator	Guiding questions
Availability of research and development agenda in the health sector	To what extent national health research and development agenda covers the health sector resilience?
Institutionalization of research recommendations	To what extent research outcomes are used to enhance the health system resilience?

5.4 Risk Communication

Risk communication occupies a major component in an MHEW system. It engages in disseminating early warnings and risk information to people at risk and receives feedback and information from the ground level (WMO, 2018). In regards to global health security as well, risk communication is considered the main element that affects the resilience of health systems (World Health Organization, 2018b). In Sri Lanka, according to the national early warning system, DMC functions as the coordinating agency for the dissemination of early warnings to the public. This process continues in collaboration with stakeholders at different administrative levels as mandated by the national disaster management plan (Disaster Management Centre, 2015). During previous investigations conducted in previous steps, five main indicators were identified to investigate the health systems resilience under risk communication.

1. Public communication

According to the Joint External Evaluation, public communication mechanisms should be equipped with dedicated teams, new strategies to reach the public, fast and reliable media platforms, etc (World Health Organization, 2018b). Furthermore, the effectiveness of public communication measures depends on public access to media platforms as well (Nuclear Threat Initiative and Johns Hopkins School of Public Health, 2019). There were several issues during compound hazards that occurred in Sri Lanka in 2021 since people were not adequately aware of health-related information. Therefore, this framework provides five sub-indicators, as shown below to investigate the effectiveness of public communication systems.

Sub indicator	Guiding questions
Availability of a guiding document to outline public communication	Are there procedures, guidelines, or other agreements between public health and security authorities to respond, in relation to public communication, to a potential compound hazard event or public evidence on exercises carried out for a potential compound hazard event?
Use of media platforms to risk communication	To what extent do authorities use technological platforms for risk communication and how effective they are?
Access to mobile phones	What is the level of access to mobile phones?
Access to internet	What is the level of internet access?
Inclusion of people with special needs in communication methods	To what extent marginalized communities are included in the risk communication plan?

2. Stakeholder communication

As mentioned earlier, under governance and leadership, stakeholder communication plays a major role in decision-making in relation to preparedness and response planning for disaster resilience. Therefore, the presented sub-indicators below set out a basis to look into the stakeholder communication networks. Currently, in Sri Lanka, several modes are available to communicate between stakeholders within the health sector and other DRR sectors as well (Amaratunga et al., 2020b).

Sub indicator	Guiding questions
Platforms for internal stakeholder communication	What are the methods available for health sector internal stakeholder communication? What is the level of effectiveness of these modes?
Regular testing of coordination platforms	Are there procedures available for regular testing of stakeholder coordination platforms?
Coordination with officials from DRR planning	Are there modes of communication, procedures, etc. available for communication between the public health sector and DRR officials?

3. Risk communication system management

Management systems related to communication mechanisms are vested with major responsibility in regard to ensuring the smooth functioning and effectiveness of risk communication (Radovic and Mercantini, 2015). In relation to managing the risk communication system in Sri Lanka, outcomes of the Joint External Evaluation that was conducted in 2017, have stressed the need for publishing a national risk communication plan (World Health Organization, 2017). According to DM officials in the country, there are no established mechanisms to evaluate the effectiveness of existing early warning systems in terms of public feedback, acceptance ratio, timeliness, accuracy, etc. Considering these insights, two sub-indicators were identified as shown below for investigating the level of preparedness.

Sub indicator	**Guiding questions**
Risk Communication plan	Is there a national risk communication plan available for management of human resources, financial arrangements, testing exercises, and measures for updating?
Effectiveness of EWs and risk communication system	To what extent the existing EW and Risk communication systems are tested and checked for effectiveness?

4. Rumour monitoring and management

Rumour management is necessary to identify rumours, misinformation, false information, etc. early and take proactive actions to mitigate the consequences (Frost et al., 2019). In an era where platforms like social media can spread information rapidly, any effort in risk communication and early warnings should be supported with dynamic rumour management systems (Berríos-Torres et al., 2017). In Sri Lanka, during COVID-19, HPB has used real-time communication channels for rumour verification and taking necessary actions (Ranasinghe et al., 2020).

Sub indicator	Guiding questions
Dynamic listening and Rumour monitoring system	To what extent rumour monitoring and management mechanisms are used within MHEW systems and what is the level of success?

5. Community engagement

Community, as a sub-system of the public health system, can be considered a factor that decides the effectiveness of all the measures taken at the decision-making levels. Therefore, community engagement cannot be neglected within risk communication mechanisms. Community compliance to risk information varies among different communities due to reasons such as socioeconomic differences (Chandra et al., 2013; Prior and Paton, 2008). In relation to risk communication, it is a necessity to identify target audiences, the most effective dissemination modes, feedback mechanisms, etc. before any kind of information is disseminated to the grass-root level (World Health Organization, 2018b). A major issue that affects the effectiveness of public engagement in risk communication is the lack of public trust in information issued by authorities in Sri Lanka (Perera et al., 2020). As a recommendation to address most of these issues, establishing two-way communication systems can be identified a more frequent suggestion made by expertise. Considering these key insights, four sub-indicators were identified as shown below to investigate the community engagement level in risk communication.

Sub indicators	Guiding questions
Community compliance to risk information	To what extent community is ready to accept warnings and risk information and act as necessary?
Public awareness programs	What are the public awareness programs in place to cover different groups in the community (Ex; children, women, differently abled people, marginalized groups, etc.)?
Public trust monitoring system	Is there a publicly available system to monitor public trust and feedback and improve risk communication strategies?
Two-way communication systems	Do two-way communication systems exist? Is the information gathered through these systems used effectively?

5.5 Health Services

As the main objective of health systems is to ensure the health and well-being of the community, during an emergency/disaster situation, public health systems need to take care of the health needs of the entire population at risk (Abimbola and Topp, 2018; Barasa et al., 2018; Blanchet et al., 2017). Both curative and preventive sectors are supposed to deliver their services without disruptions. For instance, hospitals should be able to function at the maximum capacity while withstanding the impacts of hazards themselves (WHO, 2015). Furthermore, preventive health services are supposed to carry out activities such as controlling infectious diseases, safety center management, etc. Therefore, this section provides a set of indicators to explore the level of readiness in the delivery of health services.

1. Healthcare facility capacities

Healthcare facilities are supposed to be better prepared to deal with emergencies that might but have not yet occurred. Inadequate preparedness and experience in handling emergencies can lead to severe sequences (Krishnan and Patnaik, 2020; A. Raeisi et al., 2018). It is evident that healthcare facilities must be resilient to disaster situations. In this regard, healthcare facilities should be safe from hazards and be able to ensure the safety of patients, healthcare workers, and visitors (WHO, 2015). Furthermore, healthcare facilities should be able to meet the surge capacity while managing routine functions inside a hospital (Sheikhbardsiri et al., 2017). During the COVID-19 situation, it was evident that healthcare facilities were reshaped to meet the demand and strengthen the network of hospitals (Jayasekara et al., 2022). Therefore, this element presents four sub-indicators as shown below to investigate the resilience of healthcare facilities.

Sub indicator	**Guiding questions**
Safety of public healthcare facilities	What is the level of safety of healthcare facilities in the country? Are there healthcare facilities that are at risk of hazards?
Surge capacities of hospitals and emergency care centres	What are the plans available to meet the surge capacities of hospitals and emergency treatment centres during a disaster?

Availability and continuity of healthcare services for non-affected patients	What are the plans available to ensure the continuation of treatments for patients who are not affected by the disaster?
Operability of the network of healthcare facilities during disasters	To what extent is it possible to connect existing healthcare facilities and deliver health services during a disaster?

2. Laboratory system

As a support to the surveillance system which functions within the public health systems, laboratories are supposed to function well to detect diseases emerging within a community. Therefore, this indicator assesses the capacity of laboratory systems under three sub-indicators as shown below.

Sub indicator	**Guiding questions**
Laboratory capacity for detecting priority diseases	What is the capacity of the laboratory system to conduct core tests named by the WHO?
Specimen referral and transport system	To what extent does the specimen transportation system cover the country?
Laboratory quality systems	What are the plans available to ensure the quality of laboratory systems?

3. Emergency health response

The emergency health response system constitutes a network of resources that have been brought together to provide emergency care for disaster-affected populations and transport victims of sudden illness or injury to a medical facility for definitive care (Ministry of Health and Indigenous Medical Services, 2020). In Sri Lanka Hospital Emergency Incident Command System plays a significant role in responding to disaster situations by performing functions like controlling and coordinating hospital activities, providing additional resources, and liaising with the National Emergency Operations Centre [EOC] of the DMC. However, according to the findings, the emergency medical system in Sri Lanka still needs to be developed in terms of human resources, coordination, and equipment. Therefore, four sub-indicators have been presented under emergency health response as shown below, to explore the readiness of emergency capacities of the health system in the country.

Sub indicator	Guiding questions
The public health sector and professionals integrated with the emergency management team	To what extent do public health officials collaborate with emergency response teams?
Health emergency operations program	What is the level of success in implementing a national health emergency operation plan?
Availability of procedures for immediate case management	What are the procedures available for immediate case management in public health emergency/ disaster?
Testing and practicing emergency response plans	What are the procedures available to test the capacities of emergency response plans?

4. Preventive health services

Preventive health services in the country mainly focus on the prevention of communicable diseases, environmental and occupational health, food and nutrition-related issues, etc. in the community. In Sri Lanka, the responsible health units for both of these health services have been decentralized from the central government to the provincial government. Furthermore, there are several designated agencies that have the responsibility of specific preventive health services. Therefore, based on global and national guidelines available for preventive health, seven sub-indicators were identified as shown below for exploring the resilience of preventive health services.

Sub indicator	Guiding questions
Medical countermeasures during an emergency	What are the plans available to receive or send medical countermeasures during a public health emergency?

Immunization	What is the rate of vaccination for measles among children below 12 years old?
Public health and security authorities	What are the legal agreements available between public health and security authorities for collaboration during a health emergency?
Point of entries	What is the status of implementing contingency plans at the point of entries in the country?
Infection control practices and availability of equipment	What are the plans available for infection control? Do these plans adequately cover all the areas of infection control?
Environmental Health	To what extent plans are covering the concerns of environmental health?
Food and nutrition	What are the measures taken to ensure the food security and nutrition requirements of affected communities?

5. Post-disaster planning

Ministry of Health has emphasized post-disaster planning as one of the main responsibilities of public health inspectors at the village level in relation to disaster management (Ministry of Health, 2010). Under these activities, public health officials are supposed to take necessary actions to mitigate the long-term health impacts of disasters. For instance, ensuring food security and hygiene facilities can be considered a few interventions. Furthermore, public health officials have the responsibility of contributing to the recovery planning process as well. Last but not least, it is the responsibility of health authorities to enrich the post-disaster management process through learning from mistakes as well. Considering these aspects, three sub-indicators were identified as shown below to assess the post-disaster planning.

Sub indicator	**Guiding questions**
Mitigating long term impacts on public health and well-being	What are the mechanisms available to address long-term health impacts on victims after a disaster?
Recovery planning	To what extent recovery plans have been developed for public health services?

Learning and improving	What are the plans available to learn from public health emergency responses and improve the preparedness level?

6. Community engagement

In a public health system, community engagement plays a vast role in responding to and recovering from disasters. It mainly depends on identifying the needs of the community during and immediately after a disaster. Since healthcare facilities can reach their maximum capacities within a shorter period during a disaster, it is a requirement to prepare beforehand for supplying healthcare services to people at risk. Furthermore, community healthcare facilities play a major role in addressing the immediate health needs of victims (UNDRR, 2020d). In this regard, primary medical care units provide health services at the village level. Furthermore, addressing the issues related to the mental health of victims is also considered a major task of health services. For instance, during the COVID-19 pandemic, people who were affected by floods and landslides were mentally stressed. They were not even adhering to health guidelines. Therefore, it is needed to focus on three sub-indicators as shown below.

Sub indicator	**Guiding questions**
Consideration of higher-risk populations in healthcare	To what extent populations at risk who need healthcare have been identified and ready to be supported during a disaster?
Availability of community health services	To what extent do primary health care services cover the community?
Mental health	What are the plans available for addressing issues related to the mental health of victims?

5.6 Health Workforce

The HEDRM identifies the workforce as the main component that facilitates that disaster resilience in the health sector (World Health Organization, 2019). Skills, strength, knowledge, and experience in the health workforce in both curative and preventive sectors are considered crucial factors especially in responding to multiple disaster events. According to field data collection done and stakeholder analysis in previous sections three main areas that need attention in relation to the health workforce.

1. Multidisciplinary workforce capacity

In Sri Lanka, public officials can be categorized under curative and preventive health sectors. Accordingly, there are designated public health institutions that are working towards different sub-objectives in health sector emergency and disaster management. For instance, DPRD, the Ministry of Health functions as the coordinating agency for health sector disaster management activities. Furthermore, the National Dengue Control Unit (NDCU) functions as the responsible agency for the mitigation of dengue outbreaks in the country. Likewise, public health officials look into a vast range of activities in health emergency and disaster management. Considering these aspects, the present study introduces a set of sub-indicators that enable the investigation of capacities related to the multidisciplinary workforce as shown below.

Sub indicator	**Guiding questions**
Available human resources for the broader healthcare system	What is the strength of the health workforce (Doctors, nurses) in the country?
Competencies and skills of healthcare workers for disaster resilience	Do public health officials have adequate skills and experience in disaster resilience?
System for receiving foreign health personnel	Are procedures available to receive support from foreign healthcare workers during a disaster situation?
Healthcare workers' access to healthcare	Is there a mechanism to prioritize treatment for health officials who are affected because of a disaster situation?
Communication with healthcare workers and other responders	What are the mechanisms available to communicate between healthcare workers and other first responders during a disaster situation?

2. Workforce development

Workforce development is a key research area in health emergency and disaster risk management (Hung et al., 2021). At the initial stage, it is necessary to identify existing gaps in workforce development in terms of the expected requirements to fulfil and required skills for them (Aung et al., 2019; Kayano et al., 2019). Furthermore, it is a requirement to identify what are the required strategies and programs to address the identified gaps initially (Djalali et al., 2014). Currently, there are various educational programs, training campaigns, etc. developed around the world by different countries (Djalali et al., 2014; Hsu et al., 2006). Due to these vast variations, the focus of these strategies can divert more towards preparedness and response rather than comprehensive disaster risk reduction (Ripoll Gallardo et al., 2015). Therefore, it is necessary to align the educational programs, curricula, and training agendas according to globally recommended frameworks and country needs. Considering these aspects, three sub-indicators can be identified under workforce development as shown below.

Sub indicator	**Guiding questions**
Analysis of training needs	Are there systems available to assess the training needs of the health workforce in disaster risk management, covering the entire health sector?
Workforce development strategies	To what extent strategies are implemented for workforce development according to identified needs in disaster risk management?
Curriculum development	Are there procedures available to update the existing curriculum in training and education in relation to health sector disaster risk management?

3. Staff contingency planning

During a disaster or any health emergency number of people who need assistance in terms of immediate care, hospital treatments, mental healthcare, etc increases rapidly. It is the prime duty of the healthcare workforce to address the surge capacity (Dewar et al., 2014). During a disaster, healthcare workers also can get affected by direct or indirect impacts of the disaster. In such cases, health sector officials are expected to deliver their services while withstanding the impact on themselves as well. Therefore, staff contingency planning has a major role to play in enhancing the resilience of the health workforce in relation to disasters (Daniels et al., 2014). During the COVID-19 situation in Sri Lanka, there were several incidents where the safety of healthcare workers was threatened due to reasons such as unauthorized entries into hospitals, discrimination inside public places, etc. Illustrating on strategies taken, security at healthcare facilities was strengthened and measures were taken to ensure welfare facilities for healthcare workers. Most importantly, health authorities have taken steps to address mental health impacts among healthcare workers who were directly engaged in COVID-19 response activities. Therefore, two sub-indicators are introduced to analyze the resilience in staff contingency planning aspects as shown below.

Sub indicator	**Guiding questions**
Contingency planning for staff deployment	To what extent are there plans available for health sector staff deployment during emergencies and disasters?
Safety and security of HCW	Are there plans to ensure the safety, security, and welfare of health workers during an emergency or disaster?

5.7 Medicines, Vaccines, and Equipment

The number of victims who turn to health services is considerably high during a disaster. Therefore, an adequate supply of medical products such as medicines and vaccines is crucial for the functionality of health services (World Health Organization, 2015b). In Sri Lanka Medical Supply Division (MSD) functions as the responsible authority to ensure the adequate supply of medicines, vaccines, and medical equipment. However, the access and availability of medical products depend on several factors. According to field data collection and analysis of existing frameworks, three aspects were identified, which contribute to the adequate access to medicines, vaccines, and equipment.

1) Procurement

Availability of medicine and related costs are determined by systems available for medicine procurements (Management Sciences for Health, 2012). Therefore, in all levels of healthcare services procurement systems, procurement systems play an important role. It is important to note that, procurement systems are responsible to ensure the availability of the right medicine that satisfies required standards, in the right quantities at right time for the right people at risk. Considering these aspects which were identified during the data analysis, the following sub-indicators were selected for this framework as shown below.

Sub indicator	**Guiding questions**
Methods of quantification	Are there approved methods available to quantify the requirement of medicines for healthcare services?
Availability of procurement plans	Is there a procurement plan covering all healthcare facilities in the country?
Budgeting for health emergency medical supplies	Is there a budget available for purchasing medical supplies in an emergency?

2) Storages

Adequate and safe storage is needed to ensure that requirements of medicines, vaccines, and other medical equipment are fulfilled timely. Especially, the storage of medicines should be safe from both natural and manmade hazards. According to insights from the field data collection, the following sub-indicators were identified for securing storage for medical supplies as shown below.

Sub indicator	**Guiding questions**
Prepositioning of medical supplies	What are the mechanisms to preposition medical supplies to use in an emergency?
Temporary healthcare facilities	Are there enough resources to establish temporary healthcare facilities?
Security of medical storage	Is there a mechanism to ensure the security of medicine/ vaccine storage?

3) Supply chain management

Supply chain management in the health sector involves obtaining medical consumables, handling supplies, and delivering necessary medicines, vaccines, equipment, and services to people in need. In this regard, medical consumables are handled by a set of various stakeholders during the management process. Therefore, to successfully deliver medical products to victims during an emergency, supply chain management should be strong enough. Therefore, three sub-indicators are presented in this sub-section to investigate the readiness of supply chain management in the public health system in the country as shown below.

Sub indicator	**Guiding questions**
Ability to deliver public health supplies to people in need	What are the mechanisms available to deliver medical supplies to people at risk during emergencies?
Logistic supplies (medicines, emergency kits, etc.)	What are the plans available to distribute emergency medical logistics around the country?
Cold chain system for vaccines	To what extent cold chain systems for vaccines is implemented in the country?

5.8 Summary

As mentioned in the introduction, this section presents the framework which consists of a set of indicators under each major drivers of public health system resilience. Furthermore, each of these indicators is provided with benchmarking criteria based on experts' opinions and insights from literature. Following guidelines were mainly referred during this process.

1. Disaster Resilience Scorecard for Cities: Public Health System Resilience - Addendum. Version 2 by (UNDRR, 2020d)
2. Health Emergency and Disaster Risk Management Framework (WHO, 2019)
3. Global Health Security Index by (Nuclear Threat Initiative and Johns Hopkins School of Public Health, 2019)
4. Joint external evaluation tool: International Health Regulations (2005), second edition by (World Health Organization, 2018)
5. Multi-hazard Early Warning Systems: A Checklist by (WMO, 2018)
6. Sendai Framework for Disaster Risk Reduction 2015-2030 by (United Nations, 2015)

6 VERIFICATION OF PUBLIC HEALTH SYSTEM RESILIENCE FRAMEWORK

6.1 Validation of the Framework

After the initial validation of the framework by a panel of three reviewers, during the next step framework was needed to be validated by a larger audience. In this regard, a validation workshop was planned with the participation of experts across several fields. Workshops as a research methodology focus on producing reliable and valid data about the domain in a research question (Baran et al., 2014; Jaipal and Figg, 2010; Wakkary, 2007). There are common basic features in workshops. For instance, workshops are arranged for a limited duration with participants who share a common domain; Ex: work in the same field or share the same agendas (Chambers, 1983; Jaipal and Figg, 2010). In a workshop, the participants are expected to actively participate and influence the workshop's direction. As an outcome of a workshop, organizers expect a new generation of valid and insightful new recommendations or suggestions (Ørngreen and Levinsen, 2017). Accordingly, the framework shown in Figure 6.1 was used for conducting the validation workshop in the present study.

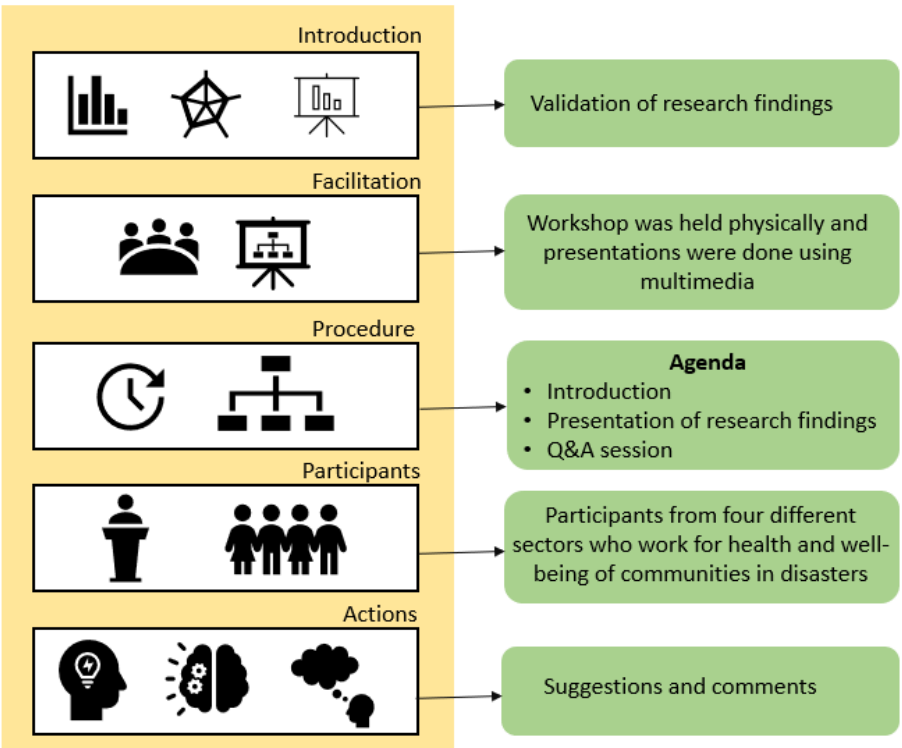

Figure 6.1: Overview of the validation workshop

6.1.1 Details of participants

According to the features of workshops as a research methodology, participants who are working for the same agenda, ensuring the health and well-being of the community during a disaster, were invited to the validation workshop. It is important to note that these participants were not taken as key informants during the earlier steps of the research. Accordingly, altogether 12 experts from four different fields participated in this workshop. Table 6.1 presents a summary of the details of the participants.

Table 6-1: Details of participants

Sector	No.	Specialization	Years of Experience
Public health Services	01	Medical services, and Public Health Administration	35+
	02	Public Health, Epidemiology, and Public Health Administration	35+
	03	Public Health with special reference to Dengue prevention and control	30+
	04	Medical services, and Public Health Administration	25+
	05	Community Health, Disaster Management	10+
	06	Community Health, Disaster Management	10+
Sociology	07	Sociology	40+
Disaster management	08	Preparedness and Response, Disaster Risk Reduction	25+
	09	Climate forecasting, Early Warnings, Weather	30+
	10	Geology, Preparedness and Response, Early Warning	15+
Managers/ Engineers	11	Supply Chain Management, Logistic Management	20+
	12	Construction Management, Disaster Risk Reduction, Early Warnings	20+

6.1.2 Presentation of the research findings

The validation workshop was conducted as a part of a major research project which aims at improving pandemic preparedness through multi-hazard early warning systems. Under this research project, the developed research project covered two major research questions; 1) What is the impact of COVID-19 on the response capabilities for other hazards either multiple, simultaneous events or cascading impacts? What components of the early warning system are greatly affected due to dual challenges associated with COVID-19? and 2) How can public health actors be better included within a multi-hazard early warning environment?

As the initial step, an introduction was presented on the research objectives and methodology used in gathering both primary and secondary data. Furthermore, the analysing methods were presented during the introduction session. During the next session, findings were presented under the above-mentioned two research questions. Accordingly, the impacts of health emergencies, that directly affect the public health system, on the response capacities for other potential hazards, which can occur concurrently, were covered within the first question. Subsequently, the role of a resilient public health system within an MHEW environment was covered by the second question. Accordingly, the findings from the above sections were presented in these two sessions. The outlines of the two presentations were done as shown in Figures 6.2 and 6.3.

As depicted by Figure 6.2, the impact of public health emergencies on response capacities for other hazards were presented under three major areas namely, hazard forecasting and early warning dissemination, evacuation and search and rescue, and shelter management and relief services. Under each of these key themes, findings were categorized under impacts, gaps and challenges, and best practices. The role of public health systems in an MHEW environment was presented under the four elements of an MHEW system (see Figure 6.3). Accordingly, their roles were discussed for both biological hazard and multi hazard contexts. Finally, the selected areas of the framework were presented as recommended areas to be strengthened in order to secure the public health systems resilience for multi hazard contexts.

Accordingly, as a final step, the role of a resilient public health system was presented under the key seven thematic areas of the developed framework and its indicators. This step was done as recommendations for public health system resilience in a multi-hazard context. After each of these presentations, participants were given time to deliver their opinions, and comments, and discuss research findings with the research team.

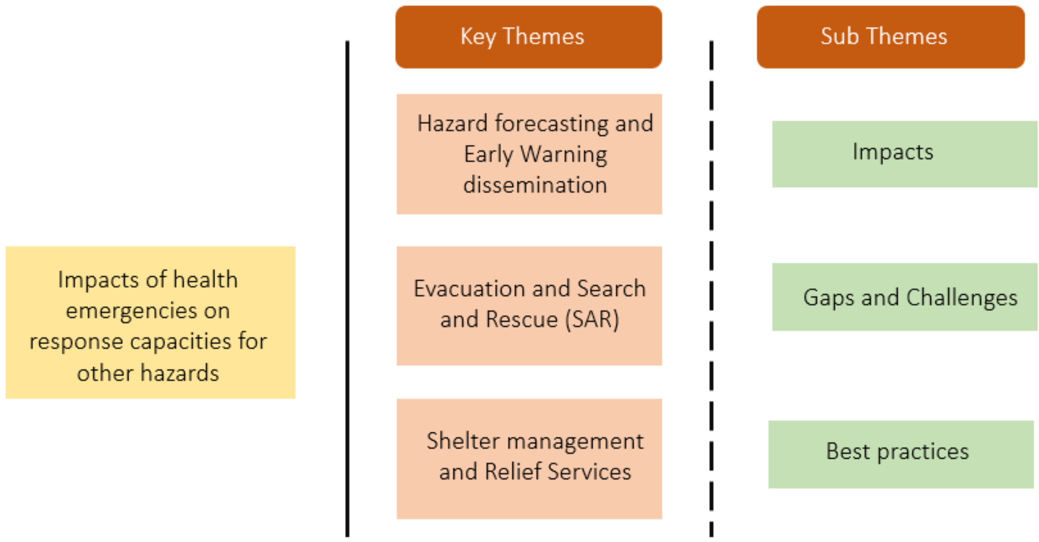

Figure 6.2: Outline of research findings under impacts of COVID-19 on response capacities for other hazards

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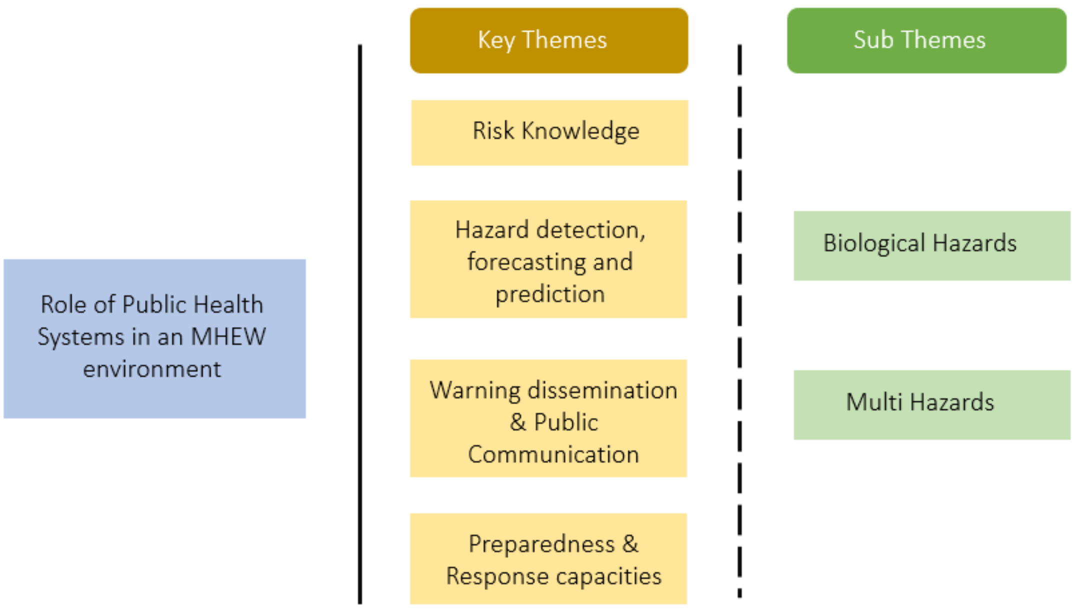

Figure 6.3: Outline of research findings under the role of resilient public health systems in an MHEW environment

6.1.3 Changes to the initial framework

According to the suggestions made by the experts, a set of changes were made to sub-indicators in the framework under seven key elements. Table 6.2 presents a summary of changes that have been done in the sub-indicators according to experts' comments. The amended framework according to experts' opinions is shown in Annex C.

Table 6-2: Changes done according to experts' comments on research findings

Indicator	Changed sub-indicators	Reason
Surveillance and early warnings	The sub-indicator "Analysis of surveillance data" was removed	Analysing surveillance data can be identified under "Information products"
Risk assessment systems	The following sub-indicators were removed, • Inclusion of biological hazards in national risk assessment planning	These three sub-indicators were removed since reviewers' comments suggested that these should be included inside one element.
	• Availability of risk assessments for compound events [including biological hazards]	
	• Community need assessments	
Health information management systems	"Protection of information from a disaster" was combined with another sub-indicator.	It was decided to include the safety databases within the availability of databases.
Public communication	The following sub-indicators were removed. • Access to mobile phones	These two sub-indicators were considered as one sub-indicator namely, the "Use of technological platforms for risk communication"
	• Access to internet	

Stakeholder communication	A sub-indicator was added for "Communication with non-government agencies and donor institutes"	Since the communication with non-government agencies is considered significant this sub-indicator was newly added.
Community engagement and empowerment	The sub-indicator "Public trust monitoring system" was removed	Since the public trust relates to their compliance to risk information, both sub-indicators were combined.
Laboratory system	Specimen referral and transport system	In the current context, this aspect is covered by the availability of laboratory facilities
Emergency health response	The sub-indicator "Availability of procedures for immediate case management".	According to comments, it was decided to include procedures for immediate case management under health emergency response teams.
Preventive health services	"Point of entries" was removed from the preventive health services.	Based on comments, this sub-indicator was combined under countermeasures for disease prevention.
	The guiding question for "Immunization" was removed.	The guiding question provided under this sub-indicator was amended to the availability of vaccination procedures to be used in an outbreak
Post-disaster planning	"Learning and improving" was removed from Post Disaster Planning	This indicator was removed since it is already considered recovery planning.
Community needs	An indicator was added in relation to the Availability of measures for need assessments of vulnerable communities.	In the current context, several issues have arisen due to the lack of understanding of community needs, especially in relation to vulnerable communities.

		Therefore, this was included under health services for community needs.
Multidisciplinary workforce capacity	The following sub-indicators were removed. • Healthcare workers' access to healthcare	Both of these aspects are covered under contingency planning for staff.
	• Communication with healthcare workers and other responders	
Workforce development	The sub-indicator "Curriculum development" was removed.	This is a development strategy
Procurement strategies	The sub-indicator "Methods of quantification" was removed.	According to experts' opinion quantification methods can be covered under procurement plans.
Supply chain management	The sub-indicator "Temporary healthcare facilities" was removed.	In the current context, temporary healthcare facilities are related to the capacity of healthcare facilities.

6.2 Applicability of the Framework

6.2.1 Introduction to Scenario Workshops

The Scenario Workshop method has its origin in technical assessments, and it was designed to carry out discussions and debates between the scientists and community on anticipated scenarios in the future (Mayer, 1997, Andersen and Jaeger, 1999). Van der Helm (2003) claims that it is a promising tool for long-term planning, stakeholder, and public involvement. In general, scenario workshops predict both procedural goals, such as communication between scientists and citizens, as well as substantive outputs, such as agreements and action plans (Andersen and Jaeger, 1999; Street, 1997). It includes three main tasks: visioning, idea generation, and action planning. Accordingly, the methodology shown in Figure 6.4 was used for scenario workshops in the present study.

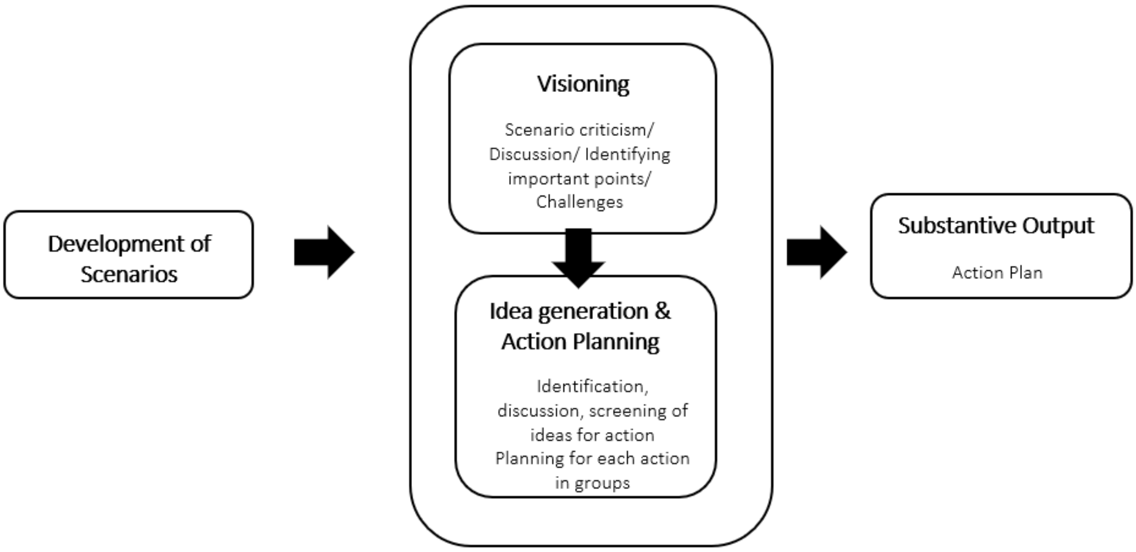

Figure 6.4: Methodology for conducting scenario workshops

During this present study, three scenario workshops were held in three different areas. Table 6.3 presents a summary of these three workshops. These scenario workshops were held as a part of a major study titled “Improving Pandemic Preparedness through Downstream of MHEW systems”.

Table 6-3: A summary of Scenario Workshops

No.	District	Hazards with the highest risk	Participants	Language used
01	Matara	Tsunami, Floods, Landslides, Dengue	Public health inspectors An expert panel including community physicians, public health administrators, sociologists, engineers	Sinhala
02	Ratnapura	Floods, Landslides, Dengue	Members of Community based organizations, Public Health Inspectors, Public Health Midwives, An expert panel including community physicians, public health administrators, sociologists, engineers	Sinhala
03	Jaffna	Tsunami, Floods, Dengue, Malaria	Members of Community based organizations, Public Health Inspectors An expert panel including community physicians, public health administrators, sociologists, engineers	Tamil

6.2.2 Development of Scenarios

After identifying possible locations and participants for scenario workshops, the next step was to develop the scenarios. In this regard, as an initial step potential hazards with the highest risk were considered. Accordingly, six scenarios were developed (two for each workshop) considering multi-hazard contexts. In developing these scenarios, three main elements in the proposed framework for public health systems resilience for multi-hazard contexts amidst biological outbreaks, namely

1) Health Information Systems,
2) Risk Communication,
3) Health Services were considered.

This decision was made based on comments from the panel of experts who participated the scenario workshops. Since these workshops have targeted the downstream of the health system which includes services of regional health officials and the status of the community, it was decided to include only these three elements. Accordingly, it was planned to evaluate the inclusivity of sub-indicators, under each of these major elements, inside the outputs of three scenario workshops.

6.2.3 Scenario Workshop 01

The first scenario workshop was held in Matara. The main objective of the workshop was to identify the key drivers of risk communication and health information systems at regional and village levels pertaining to multi-hazard scenarios. Public health inspectors participated in the workshop covering divisions from three districts namely, Galle, Matara, and Hambanthota. It is important to note that these participants have actively engaged in disaster management activities during past disaster events in the area.

During the workshop, participants were educated on community empowerment, multi-hazard disaster risk reduction, and risk communication. After diving participants into groups of nine people, they were given two multi-hazard scenarios. Accordingly, they were asked to present their activities based on instructions provided under each scenario after a certain period of time. Since Sinhala is the local language, scenarios were given, and presentations were done in Sinhala. The presentations were assessed by a panel of experts. Table 6.4 presents a summary of the details of experts who evaluated the presentations.

Table 6-4: Details of experts who participated in Scenario workshop 01

No. of Expert	Area of specialization	Experience
01	Public Health, Epidemiology, and Public Health Administration	35 yrs
02	Public Health with special reference to Dengue prevention and control	30 yrs
03	Sociology, Community engagement, Disaster risk Reduction	10 yrs
04	Community medicine, Disaster management	10 yrs
05	Public Health, Epidemiology, and Public Health Administration	10 yrs

6.2.3.1 Scenario I

6.2.3.1.1 Description of the Scenario I

Around sixty families who were affected by the flash flood and landslide events in the Kotahapola North Public Health Division are staying at a safety centre established in Kotahapola National School. The Grama Niladhari officer of the area has informed the MOH office that there have been a few patients reported with fever inside the safety centre. The MOH asks for a plan to identify the disease immediately, inform public officials about the situation, and maintain the well-being of the camp through community empowerment.

6.2.3.1.2 Results of the Scenario I

As described earlier two major steps were carried out under a particular scenario namely, visioning and idea generation & planning. Accordingly, under the step, visioning, key points to be considered and main challenges to be addressed were identified initially. Accordingly, during the next step, action planning was done with ideas from all the participants and panels of experts. This process was carried out for all the scenarios during three workshops. Table 6.5 presents the outputs of Scenario I.

Table 6-5: Outputs of Scenario I

Visioning	
Key points to be considered	
• Presence of crowded victims inside the safety center • Rapidly spreading fever among victims • Fear and uncertainty among victims	
Identification of main challenges	
1) Identifying the disease immediately 2) Stopping the further spread of fever among victims and the possibility of having a severe infectious disease outbreak 3) Directing infected victims to treatments without a further delay 4) Coordinating with required health officials and other stakeholders in the division 5) Addressing the needs of victims who are inside the safety center 6) Improving the community engagement	
Action plan	
Actions	**Stakeholders**
Testing and detection	

• Carry out laboratory tests for people who already have symptoms, to identify the disease	Hospitals, Private sector laboratories, NGOs
• Establish a communication mechanism for communicating test results and containment measures to the safety centre immediately	Hospitals, Private sector laboratories, PHI, GN, Camp administration
• Ensuring the privacy of infected patients	Camp administration, CBOs
• Discuss and preposition resources to test remaining victims	Hospitals, Private sector laboratories
Rapid response	
• Request the support of emergency medical teams to treat victims who need immediate treatments	Hospitals, 1990 Suwaseriya, EMS teams, NGOs, DDMCU
• Take necessary actions to guide infected victims to the hospital immediately	Hospitals, 1990 Suwaseriya, EMS teams, NGOs, DDMCU
• Maintain a record of victims and infected patients within the camp	Camp administration
• Establish a network among healthcare centres in the area to treat an excessive number of patients if an outbreak occurs	Hospitals, Camp administration
• Prioritize high-risk groups such as elderly people, pregnant women, etc. for treatments	Hospitals, Camp administration
• Establish a system to ensure the safety of victims' belongings when they are sent to hospitals (Ex; Safety points, designated personnel for security, etc.)	Camp administration, CBO, PHM
• Conduct a rapid risk assessment including community insights as well	Camp administration, PHI, GN, NGOs
Risk communication	

• Develop a communication strategy to inform the victims about the dual risk and get their feedback	Camp administration, PHI, GN, CBO, NGO
• Form a risk communication committee within the center for public awareness including people with special needs	CBOs, Camp administration, GN, PHI
• Establish a communication mechanism with local authorities, health officials, and donor agencies	LA, RDHS, MOH, PHI, GN
• Keeping on the alert for misinformation shared among victims	CBO, PHI, GN
Health services	
• Use of infection control measures within the safety center	Camp administration, PHI, MOH
• Get the support of public health officials for the management of the camp	Camp administration
• Conduct a need assessment of victims	Camp administration, PHI, PHM, DDMCU
• Ensure that patients with long term diseases are getting treatments	Camp administration, Hospitals, PHI, PHM
• Ensure fulfilling food and nutrient needs and hygiene facilities of victims, especially for vulnerable groups such as elders, women, children, etc.	Camp administration, GN
• Implement waste management and vector control mechanisms	LA, Camp administration, DDMCU
• Request the support of health officials for addressing the mental health issues of victims	RDHS, MOH, PHI, PHM
• Promoting vaccination procedures if needed	RDHS, MOH, PHI, PHM
Community engagement	
• Form a group of volunteers within the safety centre for camp management activities	CBO, Camp administration, GN
• Identify community leaders in the area and get the support	CBO, GN, PHI, PHM

• Take insights from the victims for future planning of the center	Camp administration, CBO, GN, PHI, PHM
• Implement different initiatives such as dramas, and musical sessions to address the mental well-being of victims	CBO, Camp administration

6.2.3.2 Scenario II

6.2.3.2.1 Description of the Scenario II

There are nearly 3000 students in the Walsmulla National School, which is the leading educational institution in the area. During the past week, more than 15 students have been reported with symptoms such as fever, cold, and headache. Furthermore, according to a vector controlling activity conducted last month, several mosquito breeding places have been found within school premises. The principal of the school has informed the MOH office that parents are reluctant to take their children to hospital treatments due to fear of getting labelled as COVID-19 patients. The MOH has requested a plan to communicate with parents regarding this situation.

6.2.3.2.2 Results of the Scenario II

The same process described under Scenario I was performed under this as well. Accordingly, Table 6.6 presents the outputs of Scenario II.

Table 6-6: Outputs of Scenario II

Visioning	
Key points to be considered	
• Presence of students with symptoms like fever, cold, and headache • Fear among parents • Fear and uncertainty among victims	
Identification of main challenges	
1) Identifying the disease immediately 2) Stopping the further spread of fever among students 3) Implementing infection control activities within the school 4) Communicating the risk to parents 5) Maintaining the health guidelines within the school for a long period	
Action plan	
Actions	**Stakeholders**

Testing and detection	
• Coordinate with laboratory facilities for students to get correct results	Hospitals, Private sector laboratories, NGOs
• Communicate results of tests to stakeholders such as parents, school administration, public health officials, and healthcare facilities using technological platforms	Hospitals, Private sector laboratories, NGOs, PHI, GN, School administration, Parents
• Ensure the privacy of students and their human rights are protected	School administration
• Maintain a record of suspected and infected students	School administration, PHI
Rapid response	
• Guide parents to take their children, who show symptoms, for treatments	School administration, PHI
• Inform the hospitals close by about reported cases and maintain the communication with hospitals for future outbreaks	PHI, MOH
• Identify close contacts of students with symptoms and advise to isolate if necessary	School administration, PHI
• Bring a medical emergency team to guide both parents and school administration in taking rapid actions	PHI, MOH, NGOs
• Inform local authorities, public health officials, and non-government organizations in the area	School administration, PHI, MOH, NGOs, LAs
Risk communication	
• Form a communication committee and a plan with the participation of parents and school administration and guide them	School administration, PHI, Parents/ School Development Society
• Use of interactive methods to communicate with students about the risk of biological outbreaks	School administration, PHI, Parents/ School Development Society
• Conduct awareness-raising campaigns for all the stakeholders in the school on, the impacts of communicable diseases, types of diseases, and prevention of diseases	School administration, PHI, Parents/ School Development Society
• Counterattack on misinformation shared among students and parents	School administration, PHI, Parents
Health services	

• Promote infection control methods among students, teachers, and parents	School administration, PHI, MOH, Parents/ School Development Society
• Conduct vector controlling activities within school premises	School administration, PHI, MOH, Parents/ School Development Society
• Promote good waste management practices	School administration, Parents, Students LAs
• Enhance hygiene facilities of students	School administration, PHI, MOH, Parents
• Take necessary measures to address mental issues among students which arose with the fear of infections	School administration, PHI, MOH
Community engagement	
• Form school emergency management team for vector controlling	School administration, PHI, MOH, Parents, Students
• Develop a plan to make school a healthy and safe environment including ideas of students, parents, and teachers	School administration, PHI, MOH, LAs, Parents, Students

6.2.4 Scenario Workshop 02

The second workshop was held in Ratnapura. The main objective of the workshop was to identify the key drivers of risk communication, health information systems, and delivery of health services at regional and community levels pertaining to multi-hazard scenarios. Public health inspectors, public health midwives, members of community-based organizations such as Suvodaya (which functions under the Sarvodaya movement), and village-level government officials participated in this workshop. These participants were selected from divisional areas which are frequently affected by floods and landslides. Furthermore, it is important to note that these participants have actively engaged in disaster management activities during past disaster events in the area.

During the workshop, participants were educated on community empowerment, multi-hazard disaster risk reduction, and risk communication. After diving participants into groups of nine people, they were given two multi-hazard scenarios. These teams consisted of a combination of all the participant categories. Accordingly, teams were asked to present their activities based on instructions provided under each scenario after a certain period of time. Since Sinhala is the local language, scenarios were given, and presentations were done in Sinhala. The presentations were assessed by a panel of experts. Table 6.7 presents a summary of the details of experts who evaluated the presentations.

Table 6-7: Details of experts who participated in Scenario workshop 02

No. of Expert	Area of specialization	Experience
01	Public Health, Epidemiology, and Public Health Administration	35 yrs
02	Public Health with special reference to Dengue prevention and control	30 yrs
03	Public Health	15 yrs
04	Sociology, Community engagement, Disaster risk Reduction	10 yrs
05	Community medicine, Disaster management	10 yrs

6.2.4.1 Scenario III

6.2.4.1.1 Description of the Scenario III

Thirty families who were affected by recent floods are staying at the safety center established at Sinhalagoda Central School. Grama Niladhari Officer of the area has informed us that there is a fever condition spread fast among these victims. According to him, victims with fever conditions do not ask for treatments from the health center at the school due to the fear of getting hospitalized. Furthermore, the GN officer has noted that there are water stagnating places within the shelter site due to unplanned waste disposal. The public health inspector of the area has requested the Youth Society of the area to assist him in starting a process of communicating the risk and taking necessary preventive actions. As active members of the youth society what will be your actions?

6.2.4.1.2 Results of Scenario III

The same process described under Scenario I was performed under this as well. Accordingly, Table 6.8 presents the outputs of Scenario III.

Table 6-8: Outputs of Scenario III

Visioning	
Key points to be considered	
• Presence of crowded victims inside the safety centre • Rapidly spreading fever among victims • Fear and uncertainty among victims	
Identification of main challenges	
1) Informing the victims about the risk of spreading fever within the centre and the possibility of having a severe infectious disease outbreak 2) Directing infected victims to treatments without a further delay 3) Stopping the further spread of fever among victims 4) Addressing the needs of victims who are inside the safety centre	
Action plan	
Actions	**Stakeholders**
Rapid response	
• Request the support of emergency medical teams to treat victims who need immediate treatments	PHI, Hospitals, EMS, NGOs, Camp administration
• Take necessary actions to guide infected victims to the hospital	PHI, Hospitals, EMS, NGOs, Camp administration
• Establish a network among healthcare centres in the area to manage infected victims if there is a major outbreak in the future	Hospitals, PHI, MOH, DDMCU
• Prioritize high-risk groups such as elderly people, pregnant women, etc. for treatments	Hospitals, EMS, NGOs, PHI, PHM
• Establish a system to ensure the safety of victims' belongings when they are sent to hospitals (Ex; Safety points, designated personnel for security, etc.)	Camp administration, CBOs, PHI, PHM
Testing and detection	
• Establish a mechanism to test remaining victims for infectious diseases with the help of public health officials and laboratories in the area	Hospitals, MOH, PHI, Private sector laboratories, NGOs
• Establish a communication mechanism for communicating test results and containment measures	Hospitals, MOH, PHI, Private sector

	laboratories, NGOs
• Keep records of infected victims and ensure the privacy of information	PHI, GN, Camp administration
• Establish a separate quarantine area within the centre for suspected cases	Camp administration, PHI
Risk communication	
• Develop a communication strategy to inform the victims about the dual risk and get their feedback	Camp administration, CBOs, PHI, PHM, NGOs
• Use of megaphones for effective and timely communication	Camp administration, CBOs, PHI, PHM, NGOs
• Build up risk knowledge on dual impacts of having fever inside the centre	Camp administration, CBOs, PHI, PHM, NGOs
• Establish a communication mechanism with local authorities, health officials, and donor agencies	Camp administration, CBOs, PHI, PHM, LAs, GN, NGOs
• Use of communication strategies to communicate with people with special needs	Camp administration, CBOs, PHI, PHM, NGOs
• Keeping on the alert for misinformation shared among victims	Camp administration, CBOs, PHI, PHM, NGOs
• Establish a mechanism to monitor how well victims are complying with health guidelines	Camp administration, CBOs, PHI, PHM, NGOs
Health services	
• Implement infection control methods within the safety centre	Camp administration, PHI, NGOs
• Request the support of military forces from other areas as well if necessary	Camp administration,

	GN, LAs, DDMCU
• Conduct a need assessment of victims	Camp administration, GN, PHI, PHM, DDMCU, NGOs
• Ensure fulfilling food and nutrient needs of victims	Camp administration, GN, DDMCU, PHI, PHM, NGOs
• Enhance hygiene facilities inside the centre, especially for vulnerable groups such as elders, women, children, etc.	Camp administration, GN, DDMCU, PHI, PHM, NGOs
• Implement a waste management mechanism	Camp administration, GN, LAs, NGOs
• Take necessary measures for vector controlling	Camp administration, GN, DDMCU, NGOs
• Request the support of health officials for addressing the mental health issues of victims	Camp administration, PHI, PHM, MOH, NGOs
• Promoting vaccination procedures if necessary	Camp administration, PHI, PHM, MOH
• Ensure that patients with long term diseases are getting treatments	Camp administration, PHI, PHM, MOH, Hospitals, NGOs
Community engagement	
• Form a group of volunteers within the safety centre for risk communication and camp management activities	Camp administration, CBOs, PHI, PHM, GN
• Take insights from the victims for future planning of the center	Camp administration, CBOs, PHI, PHM, GN
• Promote community awareness within the site on emergency management through conducting programs	Camp administration,

	CBOs, PHI, PHM, GN, NGOs
• Implement different initiatives such as dramas, and musical sessions to address the mental well-being of victims	Camp administration, CBOs, NGOs

6.2.4.2 Scenario IV

6.2.4.2.1 Description of the Scenario IV

The risk of landslide is considerably high in Erathna 66B Grama Niladhari Division and landslide events are frequently reported in this area. Although villagers have been informed to move away from the area, they do not leave the area due to the fear of losing their properties. During the District Disaster Management Coordination Committee, it was proposed to develop a system to disseminate warnings within this area with the participation of the community. As a community-based organization develops a process to disseminate early warnings (including possible early warning messages) in such a situation.

6.2.4.2.2 Results of Scenario IV

The same process described under Scenario I was performed under this as well. Accordingly, Table 6.9 presents the outputs of Scenario IV.

Table 6-9: Outputs of Scenario IV

Visioning
Key points to be considered
• The reluctance of people to leave the high landslide risk area • Dissemination of early warnings to the public in rural areas • Community participation in awareness-raising
Identification of main challenges
Short term 1) Disseminating early warnings to the village within a short period 2) Managing safety centers for evacuees for a potential landslide 3) Increasing the community awareness among villagers Long term 1) Relocating the village to a safer area 2) Addressing community needs of the relocated village
Action plan

Actions	Stakeholders
Pre-disaster planning	
• Use of risk assessment strategies to identify vulnerabilities and capacities in the village	GN, DDMCU, PHI, PHM, CBOs
• Keeping a database with Grama Niladhari officer on people in high-risk areas	GN, DDMCU
• Prepositioning of resources based on risk assessments	GN, DDMCU, NGOs, CBOs
• Preposition health emergency response teams and implement emergency management programs within the village with proper testing	PHI, PHM, MOH, EMS, NGOs, GN, DDMCU
Early warnings	
• Promote self-evacuation	GN, DDMCU, LAs, CBOs
• Establishment of localized early warning systems and promote information sharing	DDMCU, LAs, GN
• Customized early warning generation with the use of technological platforms	DDMCUs, LAs
• Establishment of a link with public health authorities in relation to landslide risk	PHI, GN, CBOs
Public communication	
• Development of a risk communication plan including public communication methods	GN, DDMCU, CBOs, PHI, PHM, MOH
• Use of announcements through modes such as loudspeakers, megaphones, etc.	GN, PHI, CBOs
• Implement unorganized clusters within the community for public awareness of the value of their lives	GN, PHI, PHM, CBOs
• Use of new technologies such as messenger groups	GN, DDMCU PHI, PHM, MOH, CBOs
• Inclusion of people with special needs in warning dissemination	GN, DDMCU PHI, PHM, MOH, CBOs
Stakeholder coordination	
• Coordination with local actors for early warning and risk communication	LAs, GN, DDMCU, CBOs
• Communication between village-level organizations, donor agencies, and public health officials	PHI, PHM, MOH, CBOs

Rapid response	
• Coordination with healthcare facilities in relation to treatments for injured victims and regular patients	Hospitals, DDMCU, GN, PHI, MOH
• Prioritization of people with special needs for hospital care	GN, PHI, CBOs
Disaster relief services	
• Establishment of a safety centre or identifying a possible existing building	NDRSC, GN, CBOs, DDMCU, PHI
• Ensure the safety of healthcare facilities in the area	RDHS, PDHS, Hospital administration
• Implementing community need assessment strategies	NDRSC, CBOs, PHI, GN, NGOs
• Addressing preventive health needs such as infection control, waste management, vector control, food needs, etc.	NDRSC, CBOs, PHI, GN, NGOs, DDMCU
• Pre identification of sources for addressing risks for vulnerable communities and mental health issues for victims	NDRSC, CBOs, PHI, GN, NGOs, DDMCU
Post Disaster planning	
• Identification of a safe location for relocation (geographical, economic, social, cultural aspects, long-term health issues, etc.)	NDRSC, CBOs, PHI, GN, NGOs, DDMCU
• Involvement of community in identifying alternative lands	NDRSC, CBOs, PHI, GN, NGOs, DDMCU
• Community awareness-raising through village-based community groups on the importance of relocation	CBOs, PHI, GN, NGOs, DDMCU
• Coordinating with local stakeholders for bringing back lives of relocated people to the normal status	NDRSC, CBOs, PHI, GN, DDMCU, LAs, MOH
• Documentation of lessons learned	GN, PHI, DDMCU, NDRSC, MOH

6.2.5 Scenario Workshop 03

The second workshop was held in Jaffna. The main objective of the workshop was to identify the key drivers of risk communication and health information systems, and the delivery of health services at regional and community levels pertaining to multi-hazard scenarios. Public health inspectors, members of community-based organizations such as Suvodaya (which functions under the Sarvodaya movement), and village-level government officials. These participants were selected from divisional areas which are frequently affected by floods. Furthermore, it is important to note that these participants have actively engaged in disaster management activities during past disaster events in the area.

During the workshop, participants were educated on community empowerment, multi-hazard disaster risk reduction, and risk communication. Two multi-hazard scenarios were given to participants. Although this workshop was similar to workshop 02, the hazard scenarios given for the participants were different. Accordingly, they were asked to present their activities based on instructions provided under each scenario after a certain period of time. Since Tamil is the local language, scenarios were given, and presentations were done in Tamil. The presentations were assessed by a panel of experts. Table 6.10 presents a summary of the details of experts who evaluated the presentations.

Table 6-10: Details of experts who participated in Scenario workshop 03

No. of Expert	Area of specialization	Experience
01	Public Health, Disaster Management, Public Health Administration	35 yrs
02	Public Health, Epidemiology, and Public Health Administration	35 yrs
03	Sociology of disasters, Relocation	30 yrs
04	Public Health with special reference to Dengue prevention and control	30 yrs
05	Geology, Disaster Management	10 yrs
06	Sociology, Disaster Management, Public engagement	10 yrs

6.2.5.1 Scenario V

6.2.5.1.1 Description of the Scenario V

People who were displaced by recent floods in Chundukuly, Jaffna have been placed in a temporary shelter near Nallur. Several inhabitants of this temporary shelter have been hospitalized with a rapidly spreading illness which includes symptoms of high fever and body aches. Public Health Inspector who is responsible for the area states that people are reluctant to go to a hospital fearing they might contract COVID-19 during their stay. PHI has requested your community-based organization to come up with a plan to address this issue and increase the health-seeking behaviour of the inhabitants.

6.2.5.1.2 Results of Scenario V

The same process described under Scenario I was performed under this as well. Accordingly, Table 6.11 presents the outputs of Scenario V.

Table 6-11: Outputs of Scenario V

Visioning	
Key points to be considered	
• Presence of crowded victims inside the safety centre • Rapidly spreading fever among victims • Fear and uncertainty among victims	
Identification of main challenges	
1) Informing the victims about the risk of spreading fever within the centre and the possibility of having a severe infectious disease outbreak 2) Directing infected victims to treatments without a further delay 3) Stopping the further spread of fever among victims 4) Addressing the needs of victims who are inside the safety centre	
Action plan	
Actions	**Stakeholders**
Rapid response	
• Request the support of health emergency teams to treat victims at the centre immediately	EMS, PHI, GN, CBOs, Camp administration
• Take necessary actions to guide infected victims to the hospital	PHI, GN, EMS, NGOs, Camp administration
• Establish a mechanism to provide transport facilities for victims to reach hospitals	NGOs, PHI, GN, CBOs

• Establish a network among healthcare centres in the area to manage infected victims if there is a major outbreak in the future	Hospitals, MOH, RDHS
• Prioritize high-risk groups such as elderly people, pregnant women, etc. for treatments	PHI, PHM, EMS
• Ensure the safety of victims' properties while they are in hospitals	GN, CBOs, Camp administration
• Conduct emergency management programs within the site	PHI, Camp administration, EMS, NGOs, DDMCU, MOH
Testing and detection	
• Establish a mechanism to test remaining victims for infectious diseases accurately	Hospitals, Private laboratories, PHI, Camp administration
• Communicate test results and containment measures fast with health officials and disseminate required guidelines among victims	PHI, MOH, Camp administration
• Keep a record of victims and maintain their privacy	Camp administration, GN, PHI
• Establish a separate quarantine area in the safety centre for suspected cases	Camp administration, CBOs, PHI, PHM, NGOs,
Risk communication	
• Develop a communication strategy to inform the victims about the dual risk and get their feedback	Camp administration, PHI, PHM, GN, NGOs, CBOs
• Use of megaphones for effective and timely communication	Camp administration, PHI, PHM, GN, NGOs, CBOs
• Build up risk knowledge on dual impacts of having fever inside the center	Camp administration, NGOs, CBOs
• Establish a communication mechanism with local authorities, health officials, and non-government organizations	Camp administration, PHI, PHM, MOH, GN, DDMCU, LAs, NGOs, CBOs

• Use of communication strategies to communicate with people with special needs	Camp administration, PHI, PHM, GN, NGOs, CBOs
• Keeping on the alert for misinformation shared among victims	Camp administration, CBOs
Health services	
• Implement infection control methods within the safety centre	Camp administration, PHI, NGOs, CBOs
• Request the support of public health officials from other areas as well if necessary	Camp administration, PHI, MOH, RDHS
• Conduct a need assessment of victims	Camp administration, PHI, GN, PHM, NGOs, CBOs, NDRSC
• Ensure healthy living within the camp through addressing needs of food, hygiene facilities, waste management, vector control, etc.	Camp administration, PHI, GN, PHM, NGOs, CBOs, DDMCU, LAs, NDRSC
• Collaborate with tri forces for camp management	GN, DDMCU, LAs
• Request the support of health officials for addressing the mental health issues of victims	PHI, PHM, MOH, NGOs
• Promoting vaccination procedures within the camp	Camp administration, PHI, PHM, MOH,
Community engagement	
• Use of community-based organizations and religious societies for risk communication and awareness-raising	Camp administration, CBOs, GN, NGOs
• Take insights into the victims for future planning of the centre through identifying possible long-term impacts	CBOs, GN, NGOs, DDMCU, NDRSC

• Implement different initiatives such as dramas, and musical sessions to address the mental well-being of victims	Camp administration, CBOs

6.2.5.2 Scenario VI

6.2.5.2.1 Description of the Scenario VI

The Navy detachment camp in Point Pedro has been converted into a COVID-19 Intermediate Care Centre (ICC). There is a warning that a huge earthquake has occurred near the island of Sumatra and a tsunami warning has been issued. Waves are expected to reach the coast around Point Pedro in three hours. As members of the civil defence circle of the village, you have been requested by the district disaster management coordination unit to develop a plan to evacuate inmates of ICC to a safety centre.

6.2.5.2.2 Results of Scenario VI

The same process described under Scenario I was performed under this as well. Accordingly, Table 6.12 presents the outputs of Scenario VI.

Table 6-12: Outputs of Scenario VI

Visioning	
Key points to be considered	
• Evacuation of COVID-19 infected patients • Continuity of treatments after evacuation • Re-establishing the care centre	
Identification of main challenges	
1) Identifying a safe location to evacuate the treatment centre 2) Evacuating the patients within a short period and managing transport facilities 3) Continuing the care for infected patients 4) Addressing the basic needs of patients at the safe location 5) If the existing ICC gets destroyed by waves planning to re-establish the ICC.	
Action plan	
Actions	**Stakeholders**
Rapid response	
• Prioritizing the evacuation process	ICC Admin., PHI, GN

• Advising the patients to follow health guidelines such as wearing masks	ICC Admin., SAR teams, PHI
• Identifying safe locations to evacuate infected patients	GN, PHI, MOH, DDMCU, CBOs
• Coordinating with rapid response teams for an evacuation plan with their resources	SAR teams, Tri Forces, ICC Admin.
• Coordinating with local actors to preposition resources for evacuees	ICC Admin., DDMCU, LAs, GN
• Coordinating with public health officials for required guidelines and countermeasures	PHI, MOH, ICC Admin
• Prioritizing patients who are already vulnerable in evacuation	ICC Admin., SAR teams, Tri-Forces
• Use of national health database for identifying resources	DDMCU, MOH, RDHS, Hospitals
Early warning dissemination	
• Use of megaphones to disseminate the warning to the island	ICC Admin., SAR teams, Tri-Forces
• Use of short alert messages to communicate the risk quickly but without making unnecessary panicking	DMC, DDMCU, ICC Admin
• Disseminating the warning alert to people with special needs as well	ICC Admin., SAR teams, Tri-Forces
Health information management	
• Protecting records of patients in ICC	ICC Admin.
• Sharing the records of patients with required stakeholders for evacuation purposes and resource identification (Military forces, local government, religious people, etc)	ICC Admin., DDMCU, LAs, Tri-Forces, SAR teams, CBOs
• Implement a real-time information sharing platform including information about patients and ensure its safety	ICC Admin., DDMCU, MOH, RDHS, Hospitals
Risk communication	
• Develop a risk communication plan and a guiding document to inform the risk during different phases of evacuation	SAR teams, Tri-forces, ICC Admin, PHI, MOH
• Ensure communication between patients and their families or close contacts through technological platforms	PHI, MOH, DDMCU, GN

• Ensure the compliance of the adjacent communities to establish the evacuation shelter for COVID-19 infected patients	Camp administration, PHI, NGOs, CBOs, GN
• Keep on alert for misinformation shared among communities	Camp administration, PHI, NGOs, CBOs, GN
Health services	
• Take infection control measures within the safety location	Camp administration, PHI, NGOs, GN
• Make sure medical care is given to patients by coordinating with healthcare facilities in the area	Camp administration, PHI, Hospitals
• Maintain the link between hospitals in the area to ensure the routine functions of adjacent hospitals	MOH, Hospitals, RDHS
• Make necessary arrangements to transfer patients whose symptoms have become severe during the evacuation	MOH, Hospitals, RDHS, EMS, Suwaseriya
• Ensure the safety of vulnerable communities at the new center	PHI, PHM, GN, NGOs, Camp administration, NDRSC
• Carrying out a need assessment of patients since location is changed	PHI, PHM, GN, NGOs, Camp administration
• Take care of food and nutrient needs and waste management aspects along with vector controlling	PHI, PHM, GN, NGOs, Camp administration, LAs, NDRSC
• Take care of the mental well-being of patients	PHI, PHM, MOH, NGOs, Camp administration,
Post-disaster planning	
• Conduct an extensive risk assessment for a new location using multi-sectoral and technological platforms	NDRSC, DDMCU, RDHS, MOH, PHI, GN, CBOs, NGOs, Tri-forces
• Coordinate with multi-stakeholders to plan a new establishment	NDRSC, DDMCU

• Assessment of long-term health issues with community participation	MOH, PHI, GN, CBOs, NGOs
• Conducting emergency management programs in a multi-hazard context for all the stakeholders	DDMCU, RDHS, MOH, PHI, GN, CBOs, NGOs, Tri-Forces, SAR teams

6.3 Outcomes of Scenario Workshops

6.3.1 Inclusivity of indicators of the proposed framework

The inclusivity of indicators under the main elements, within the action plans developed as an outcome of scenarios, was analysed during this step. In this regard, opinions of the panel of reviewers, who have given comments on the initial framework, were received in determining whether the indicators of the framework are included within the substantive action plans of scenarios. In some cases, there was no need of considering several indicators within action plans due to the nature of the given multi-hazard context. These incidents were determined by reviewers during the development of scenarios.

After determining the inclusivity of indicators within the action plans of each scenario, it was calculated as a percentage out of all possible scenarios in which indicators were expected to be included. Table 6.13 presents the details of calculating the percentage of inclusivity. Except for one indicator, other indicators which were expected to be included in action plans developed based on six scenarios have a rate of inclusivity equal to or more than 50%. Accordingly, the indicator “Mechanisms for testing the effectiveness of risk communication system” under “Risk Communication” has an inclusivity rate of 20% since only one action plan considered this indicator although it was expected to be included in five scenarios. However, it was decided not to alter or remove the indicator since the necessity of testing the effectiveness of risk communication systems is confirmed a necessity in a resilient health system.

Table 6-13: Inclusivity of indicators within action plans developed during scenario workshops

I – Included, N – Not included, X- Not applicable								
Indicator	**Sub indicator**	**Inclusivity**						
		SN I	**SN II**	**SN III**	**SN IV**	**SN V**	**SN VI**	**%**
Risk communication								
Public communication	Availability of a guiding document to outline public communication mechanisms	I	I	I	I	I	I	100%
	Use of media platforms such as television, radio, and modes such as megaphones, and early warning towers for risk communication	I	I	I	I	I	I	100%
	Use of technological platforms for public communication [social media, SMS, WhatsApp, etc.,}	N	N	N	I	I	I	50%
	Mechanisms to communicate with people with special needs	I	I	I	I	I	I	100%
Stakeholder communication	Availability of platforms for internal stakeholder communication (Health sector)	I	I	I	I	I	I	100%
	Coordination with officials from Disaster Management authorities and technical agencies	I	I	I	I	I	I	100%
	Communication with non-government agencies and donor institutes	I	I	I	I	I	I	100%
	Regular testing of coordination platforms	X	X	X	X	X	X	X
Risk communication system management	Availability of a risk communication plan	I	I	I	I	I	I	100%
	Mechanisms for testing the effectiveness of risk communication system	N	N	I	N	N	X	20%
Rumour monitoring	Dynamic listening and rumour monitoring system	I	I	I	N	I	I	83%
	Availability of public awareness programs	I	I	I	I	I	I	100%

Community engagement	Use of two-way communication systems during emergency [Messenger groups, telephones, etc.]	I	N	X	I	I	I	80%
	Monitoring systems for community compliance to risk information and public trust	I	I	I	N	I	I	83%
Health information systems								
Surveillance and early warnings	Indicator and event-based surveillance systems	I	I	I	X	I	X	100%
	Inclusion of public health concerns into national multi-hazard early warning system	N	X	I	I	X	I	75%
	Transparency and ethical consideration of surveillance data	I	I	I	X	I	I	100%
	Real-time reporting among stakeholders	I	I	I	I	I	I	100%
Risk assessments	Comprehensive health emergency and disaster risk assessment at the national and local level for multiple hazard events	I	N	I	I	N	I	67%
	National health surveys and resource tracking	X	X	X	X	X	I	100%
	Use of technological platforms for comprehensive risk assessment	N	N	I	I	X	I	60%
Information management	Availability and safety of fundamental databases	I	I	I	I	I	I	100%
Information products	Development of guidelines/ protocols/ good practices based on surveillance data	N	I	I	X	I	I	80%
	Availability of information sharing procedures	I	I	I	I	I	I	100%
	Data from other critical systems shared with the public health sector	X	N	I	I	X	I	75%
Health services								
Healthcare facilities	Safety of public healthcare facilities	X	X	X	I	X	I	100%
	Treating all the victims who need medical care at the hospitals within the area during a multi-hazard disaster context.	I	I	I	I	I	I	100%

	Availability and continuity of healthcare services for people who are not affected by the disaster but receive treatments regularly	I	X	I	N	I	I	80%
	Ability to connect with other hospitals outside the area if the capacity of hospitals closer to the disaster site exceeds during the disaster	I	I	I	I	I	I	100%
Emergency health response	The public health sector and professionals integrated with the emergency management team	I	I	I	I	I	I	100%
	Conducting health emergency operations programs at disasters sites and safety centres	N	I	I	I	I	I	83%
	Testing and practicing health emergency and disaster response plans before a multi-hazard event	X	X	X	I	X	N	50%
Laboratory services	Availability of laboratory facilities to test for diseases spreading within the area	I	I	I	X	I	X	100%
	Accuracy of test results given by the laboratories in the area	I	I	I	X	I	X	100%
Preventive health services	Participation of public health officials when taking countermeasures for diseases spreading rapidly in the area	I	I	I	X	I	I	100%
	Availability of vaccination procedures when there is a biological outbreak within the area	I	X	I	X	I	I	100%
	Collaboration between public health officials and security forces (Ex; Police, Tri-forces) when taking measures during a multi-hazard event or biological outbreak	N	X	I	I	I	I	80%
	Availability of diseases prevention measures and required equipment during a multi-hazard event	I	I	I	I	I	I	100%
	Addressing the food and nutrient requirements of victims	I	N	I	I	I	I	80%
	Availability of measures to ensure the environmental health during a multi-hazard event	I	I	I	I	I	I	100%

Post-disaster recovery	Identification and taking necessary measures for possible long term health impacts after a disaster	N	I	I	I	I	I	80%
	Community engagement for recovery planning after a disaster	I	I	I	I	I	I	100%
Community needs	Paying more attention to high-risk communities when delivering healthcare during a multi-hazard event	I	I	I	I	I	I	100%
	Availability of public health services within the area even before a biological outbreak starts	X	I	X	X	N	X	50%
	Availability of measures for need assessments of vulnerable communities after a multi-hazard event	I	X	I	I	I	I	100%
	Availability of mental health services for victims	I	I	I	I	I	I	100%

6.3.2 Determining the level of agreement of indicators

In addition to scenario analysis, a questionnaire was distributed to determine the level of participants' agreement on how sub-indicators under above mentioned three main elements, contribute to a smoothly functioning public health system during a multi-hazard context. In this questionnaire, all the sub-indicators under each main element were presented to the participants. Accordingly, they were asked to vote for each sub-indicator based on the level of contribution to a resilient public health system during a multi-hazard context that can occur amidst a pandemic. In this regard, a 5-points Likert scale was used to express the level of agreement; 1- Very low, 2- Low, 3- Moderate, 4 – High, and 5 – Very high.

During three scenario workshops, these questionnaires were distributed after translating into the local languages (Sinhala and Tamil). Accordingly, 102 questionnaires were distributed during workshops among participants and 78 completed questionnaires were returned with a response rate of 76%. The reliability of data was determined and verified using the reliability coefficients named Cronbach alpha. When the Cronbach alpha is less than 0.3, the data is considered not suitable for further analysis as the reliability level of data is considered low. When the Cronbach alpha is more than 0.7, data is considered suitable for further analysis as the reliability level is considered high (Taber, 2018). The Cronbach alpha for ordinal data in the results was determined through IBM SPSS 22 software and the obtained value for Cronbach alpha was 0.89. The results obtained from the software analysis are presented in Table 6.14.

Table 6-14: Processing summary from IBM SPSS Software for Cronbach Alpha

Case processing summary		N	(%)
Cases	Valid	75	96.15
	Excluded	3	3.85
	Total	78	100.00
Cronbach alpha	0.89		

After the reliability check, an average score was calculated for each sub-indicator. Accordingly, Table 6.15 presents the average scores obtained by each sub-indicator.

Table 6-15: Average scores obtained by each sub-indicator

Risk Communication		
Indicator	**Sub indicator**	**%**
Public communication	Availability of a guiding document to outline public communication mechanisms	3.85
	Use of media platforms such as television, radio, and modes such as megaphones, and early warning towers for risk communication	4.40
	Use of technological platforms for public communication (social media, SMS, WhatsApp, etc.)	4.37
	Mechanisms to communicate with people with special needs	3.91
Stakeholder communication	Availability of platforms for internal stakeholder communication (Health sector)	3.86
	Coordination with officials from Disaster Management authorities and technical agencies	3.65
	Communication with non-government agencies and donor institutes	4.10
	Regular testing of coordination platforms	3.64
Risk communication system management	Availability of a risk communication plan	4.31
	Mechanisms for testing the effectiveness of risk communication system	4.00
Rumour monitoring	Dynamic listening and rumour monitoring system	4.01
Community engagement	Availability of public awareness programs	3.85
	Use of two-way communication systems during an emergency (Messenger groups, telephones, etc.)	4.41
	Monitoring systems for community compliance to risk information and public trust	3.79

Health Information Systems		
Indicator	**Sub indicator**	**%**
Surveillance and early warnings	Indicator and event-based surveillance systems	4.56
	Inclusion of public health concerns into national multi-hazard early warning system	3.96
	Transparency and ethical consideration of surveillance data	4.12
	Real-time reporting among stakeholders	4.53
Risk assessments	Comprehensive health emergency and disaster risk assessment at national and local levels for multiple hazard events	4.62
	National health surveys and resource tracking	4.05
	Use of technological platforms for comprehensive risk assessment	4.01
Information management	Availability and safety of fundamental databases	4.03

Information products	Development of guidelines/ protocols/ good practices based on surveillance data	3.91
	Availability of information sharing procedures	4.56
	Data from other critical systems shared with the public health sector	4.06

Health Services		
Indicator	**Sub indicator**	**%**
Healthcare facilities	Safety of public healthcare facilities	4.12
	Ability to treat all the victims who need medical care at the hospitals within the area during a multi-hazard disaster context.	4.50
	Availability and continuity of healthcare services for people who are not affected by the disaster but receive treatments regularly	3.99
	Ability to connect with other hospitals outside the area if the capacity of hospitals closer to the disaster site exceeds during the disaster	3.91
Emergency health response	The public health sector and professionals integrated with the emergency management team	4.13
	Conducting health emergency operations programs at disasters sites and safety centres	3.87
	Testing and practicing health emergency and disaster response plans before a multi-hazard event	3.86
Laboratory services	Availability of laboratory facilities to test for diseases spreading within the area	4.64
	Accuracy of test results given by the laboratories in the area	4.03
Preventive health services	Participation of public health officials when taking countermeasures for diseases spreading rapidly in the area	3.99
	Availability of vaccination procedures when there is a biological outbreak within the area	4.55
	Collaboration between public health officials and security forces (Ex; Police, Tri-forces) when taking measures during a multi-hazard event or biological outbreak	3.95
	Availability of diseases prevention measures and required equipment during a multi-hazard event	3.88
	Addressing the food and nutrient requirements of victims	3.99
	Availability of measures to ensure the environmental health during a multi-hazard event	4.03
Post-disaster recovery	Identification and taking necessary measures for possible long term health impacts after a disaster	3.97
	Community engagement for recovery planning after a disaster	4.56
Community needs	Paying more attention to high-risk communities when delivering healthcare during a multi-hazard event	4.12
	Availability of public health services within the area even before a biological outbreak starts	4.09
	Availability of measures for need assessments of vulnerable communities after a multi-hazard event	4.05

	Availability of mental health services for victims	3.85

Accordingly, all the indicators indicate an average score of more than 3.7. This is closer to a high level of contribution according to the scale used in the questionnaire. It depicts the validity of selected indicators within the framework under three main elements, Health Information Systems, Risk Communication, and Health Services. Furthermore, results depict participants of the workshops agree to a very high level of contribution in relation to the following sub-indicators (Please note that these indicators have obtained a value of 5 [very high] after rounding up to the closest integer).

Risk Communication

1) Use of media platforms such as television, radio, and modes such as megaphones, and early warning towers for risk communication *(Public Communication)*
2) Use of technological platforms for public communication (social media, SMS, WhatsApp, etc.) *(Public Communication)*
3) Availability of a risk communication plan *(Risk Communication System Management)*
4) Use of two-way communication systems during emergency [Messenger groups, telephones, etc.] *(Community engagement)*

Health Information Systems

1) Indicator and event-based surveillance systems *(Surveillance and Early Warnings)*
2) Real-time reporting among stakeholders *(Surveillance and Early Warnings)*
3) Comprehensive health emergency and disaster risk assessment at national and local levels for multiple hazard events *(Risk Assessments)*
4) Availability of information sharing procedures *(Information products)*

Health Services

1) Ability to treat all the victims who need medical care at the hospitals within the area during a multi-hazard disaster context *(Healthcare facilities)*

2) Availability of laboratory facilities to test for diseases spreading within the area *(Laboratory services)*
3) Availability of vaccination procedures when there is a biological outbreak within the area *(Preventive health services)*
4) Community engagement for recovery planning after a disaster *(Post disaster recovery planning)*

Accordingly, it suggests that at the regional and village levels these areas need to be prioritized to streamline the resilience of a public health system.

6.4 Summary

Accordingly, this chapter presents the validation of developed framework and its applicability at the ground level in a multi hazard context. The initially developed framework in Section 4.5 was amended based on comments given by experts on presentation of research findings. These comments have mainly focused on the applicability of proposed recommendations in the Sri Lankan context. Accordingly, changes have made to the proposed indicators in the framework.

The applicability of the developed framework for strengthening public health systems resilience at the community level was tested through three scenario workshops. In this workshops, public health action plans were developed for given six multi hazard scenarios. Through outputs of these scenario workshops, the applicability of three main elements of the framework, namely, Health Information Systems, Risk Communication, and Health Services was established. However, the other four elements were not tested since those are involved mostly in higher levels than the community level. This can be identified as a limitation in this study and future studies have the potency of improving the framework through testing the applicability of other main elements as well.

Accordingly, the outputs of the given scenarios have proved the significance of presented indicators in the framework, for public health systems resilience during multi-hazard scenarios amidst a biological outbreak. Furthermore, the votes of participants in three scenario workshops have made it evident that selected indicators under three main elements highly contribute to the smooth functioning of a public health system.

7 CONCLUSION

There is no doubt that the severity and frequency of weather-induced hazards are now increasing due to climatic change. Furthermore, it is proven that biological hazards such as COVID-19 have increased, thus maximizing the likelihood of natural hazards to concur biological hazards. Hazards no longer affect discreet parts of a system but render the failure of the whole system. The present world has become a complex system in which different sectors are interconnected and depend on each other. These conditions have provoked the stakeholders to rethink and reshape existing approaches in disaster management. Being one of the prominent critical infrastructure sectors, public health systems have a major role in disaster risk reduction mechanisms. In relation to this, COVID-19 perfectly tested the effectiveness of existing DM approaches connected to the health sector and shed light on new avenues. The impacts of the COVID-19 and associated concurrent hazards have shed the light on the need for inclusive approaches to DRR. with the integration of public health into disaster management.

Being a tropical country, which is affected by monsoonal showers annually, Sri Lanka experiences climatic-related hazards more frequently. And also, Sri Lanka is frequently affected by epidemics such as dengue as well. Although Sri Lanka has universal healthcare coverage and a disaster management mechanism, it is evident that the emulation of integrated risk management approaches in the country still needs to be improved vastly. This study has attempted to develop a framework that can be taken as guidance in strengthening the health system resilience of the country for multiple hazard events.

This study has been started with a desk study on the pandemic history and the relationship between preparedness plans and response mechanisms during pandemics. The statistical analysis on preparedness levels and response mechanisms of 145 countries, has depicted that higher preparedness levels can sometimes cause delays in taking stringent measures. It emphasizes that preparedness in health systems cannot control a biological outbreak alone and strengths in areas such as infrastructure adequacy, stakeholder networks, and political decision making are also key drivers of resilience to biological hazards. Adding to the need for multi sectoral approaches in DRR related to multi hazard contexts, the results of stakeholder analysis revealed that although public health actors play a major role in biological hazard preparedness in the country, their involvement in multi-hazard scenarios is considerably low compared to other technical agencies. Timely and accurate early warning generation, presence of a sound legal basis for the Disaster Management Coordination Unit (DMC in Sri Lanka) and affiliated agencies, strength of local actors, and engagement of non-government organizations play critical roles in multi hazard resilience.

A field data collection was carried out qualitatively to investigate compound impacts of multi-hazard scenarios on public health systems taking COVID-19 as a case in point. Furthermore, the analysis has identified what health sector infrastructures lack in preparedness and response planning for compound hazard events. It has mainly focused on the challenges experienced by DM mechanisms and strategies that were implemented. Insights from field data have shed light on several areas that need immediate actions in the existing health infrastructures. Since the functional continuity of healthcare facilities was highlighted as crucial in Sri Lanka for a resilient public health system, this study presents a conceptual model of the interdependencies of hospital subsystems. This model presents on what are the factors that affect the hospital functionality and the variation of their impacts. In this regard, the model has drawn causal loop diagrams and stocks and flows to represent dynamic relationships between hospital sub-systems.

As the main outcome of this study, a framework has been presented that can assist in enhancing the resilience of the public health system in the country for multiple hazard events. This framework constitutes of three stages that compromise seven major elements namely, Governance and leadership; Health finances; Health information systems; Risk Communication; Health services delivery; Health workforce; and Medicines, vaccines, and equipment. The study provides a set of guiding questions to explore the level of resilience in each major area of the health system. These sub-indicators and guiding questions were verified using experts' opinions. During the present study, the applicability of the framework was tested for three elements; Health information systems, risk communication, and health services at the ground level. Furthermore, the applicability check at the ground level has revealed a set of areas that should be prioritized for enhancing public health resilience for emergencies.

The findings emphasized that starting from the policy planning stage existing public health systems should be integrated with the DM mechanism in the country until the grass-root level. Although advanced methods are used by both public health and DM sectors, these mechanisms work in isolation and effective collaboration can enhance the resilience of public health infrastructures in responding to multiple hazard contexts. Furthermore, existing mechanisms do not incorporate cascading effects of disasters. For instance, public health emergencies are seen as only health-related disasters rather than seeing the cascading impacts induced by those emergencies. Gaps that need to be addressed in enhancing the multi-hazard resilience of the public health system in the country can be concluded as follows.

1. Absence of adequate integration of disaster management practices into national health policies and planning. Integrated risk management strategies are not adequately addressed in policies related to the public health system.
2. Lack of involvement of health sector authorities in preparedness and response planning for multi-hazard contexts.
3. It is crucial to strengthen the governance of the public health system to eliminate haphazard structures that are being established in responding to disasters.
4. Existing strategies implemented by both public health and DM authorities lack adequate knowledge of multi-hazard contexts.
5. Although detection, monitoring, and forecasting of hazards such as tsunamis, floods, landslides, etc. are not directly connected to the public health system, timely and accurate hazard forecasting can enhance proactive disaster management approaches for multiple hazards.
6. In relation to risk communication, the country has the need for having an emergency fund for risk communication during emergencies.
7. The of technological platforms for risk communication, it should be extended towards multi-hazard contexts while covering remote areas and marginalized communities as well.
8. In Sri Lanka functionality of healthcare facilities should be strengthened to accommodate large surge capacities. Although existing healthcare facilities accommodate victims/patients, the quality of care can be affected due to the insufficient capacities of critical systems.

9. In relation to preparedness and response planning, community engagement with the public health sector should be improved. Some issues have been reported due to not incorporating factors such as social norms, beliefs, etc. in preparedness and response measures.
10. Last not but not least, the need for active particip1ation of public health officials at the grass-root level for preparedness planning and implementation of response mechanisms should be improved through capacity building.

8 RECOMMENDATIONS FOR FUTURE RESEARCH

The limitations of the study need to be discussed for identifying possible future research areas. In the first step of analysing key drivers of public health security, data were collected only during the initial stages of COVID-19. Therefore, findings presented under that analysis can be limited to an initial stage of a public health emergency. However, there is an opportunity to analyse how conditions have varied with time and compare with initial findings. It will pave the way for identifying specifically what are enablers behind resilient systems over a time period of more than two years.

Furthermore, the stakeholder analysis which was based on the existing national disaster management plan and emergency operation procedures considers some stakeholders which have different branches under them, as one particular stakeholder. For instance, several units are functioning under the Ministry of Health while collaborating with other outside stakeholders individually representing the Ministry of Health. This analysis does not consider the coordination network among those inter-agencies. Strengths and drawbacks in those stakeholder networks also should be assessed to enhance the performance of the public health system.

Moreover, the conceptual model of hospital functionality, which is based on interdependencies within hospital subsystems does not present dynamic impacts within a hospital system quantitatively. It is important to note that quantitative measurements of functionality dynamics assist the parametric analysis of resilience enhancement measures more accurately. Therefore, it is recommended to develop the proposed model to quantify the hospital functionality. Furthermore, the proposed model considers the building damage in a generic form. Therefore, based on the type of hazards, the overall damage should be converted into a general status. However, this process can cause less accuracy in quantifying the building damage. Therefore, it is recommended to modify the model to encounter the different damage types based on the type of the hazard.

The proposed framework in this study provides a benchmark to enhance the existing level of resilience in the health system qualitatively. It aims at providing conditions of an ideal status of a resilient public health system for multi-hazard contexts, thus reveals gaps in the existing conditions. However, these conditions can be modified based on the variation in dimensions such as vulnerability, capacity, and likelihood. Last but not least, it is important to note that this framework needs more validation based on experts who represent different sectors attached to the national disaster management mechanisms.

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ANNEX A

Annex A.1

Integrating Epidemic and Pandemic Preparedness into DRR Planning

Qualitative Surveys

Epidemic and Pandemic Preparedness

1. To what extent is epidemic/pandemic preparedness currently embedded within existing **disaster risk reduction plannin**g?
2. What **role does your organization play in** epidemic and pandemic preparedness planning in Sri Lanka?
3. What are the **legal provisions** which define your role in epidemic and pandemic preparedness planning?
4. Have you worked closely with the Disaster Management Centre [DMC] in carrying out epidemic/pandemic preparedness activities? Please explain your relationship with the DMC.
5. In what **level of administration (National, provincial, local)**, is your organization involved in epidemic and pandemic preparedness planning?
6. Who are the stakeholders in epidemic/pandemic preparedness that are connected with your organization (National governing bodies, Ministries engaged in the process, Disaster Management Center, Public Health Authorities, Tri-forces, NGO/INGOs)?
7. How does your organization connect with the **other stakeholders** of epidemic and pandemic preparedness planning?
8. How are **potential cascading impact**s addressed in your process of epidemic and pandemic preparedness planning?
9. Are there already developed **SOPs/ guidelines/ circulars etc.** to be followed by your organization in relation to epidemic/pandemic preparedness?
   If yes, what are they?

   If no, what are the underlying reasons?
10. Are the above-mentioned SOPs/ guidelines/ circulars etc. in effect same **across all the administration levels**?
11. What is the level of involvement of the **Public Health Authorities** in the process of epidemic/pandemic preparedness?
12. What are the public health authorities involved in epidemic/pandemic preparedness planning?
13. How effective is the coordination between the Public Health Authorities?
14. Are the needs of vulnerable groups identified in your preparedness planning? How do you identify vulnerable groups? Have vulnerable populations undergone preparedness training?
15. How is your preparedness towards the sudden outbreaks of diseases with unknown sources?

Epidemic and Pandemic Response

16. Have you/your organization been involved in planning and/or developing strategies to respond to COVID19? What was that involvement? Was that involvement adequate?
17. Is the role of your organization in epidemic and pandemic **response**, pre-defined? If yes where it is defined and what is the role?
18. Who are the stakeholders coordinating with your organization in the phase of epidemic/pandemic response?
19. How do you **coordinate with the other stakeholders** in the phase of the epidemic/pandemic response?

Early Warning System for Epidemics and Pandemics

20. Does your organization have the authority to generate early warning messages pertaining to epidemics/pandemics? If no, who is the responsible authority?
21. Does your organization have the authority to disseminate early warning messages? If no, who is the responsible authority?
22. How does your organization connect with the existing national early warning system?
23. What sorts of gaps (if any) do you see within the epidemics and pandemics early warning systems?
24. How can the existing early warning systems for epidemic and pandemic be strengthened?
25. Is there any other information that you would like to provide other than what you have mentioned?

Annex A.2

Identifying the impacts of biological hazards on disaster risk management activities for other hazards

Pilot Survey

Guiding question	**Data collection/key questions**
1. Do existing Early Warning Systems adequately address systemic risks under pandemic conditions?	1. Is your organisation currently engaged in early warning systems? If so, which systems? What legal provisions are made for this engagement? 2. Have you made changes to your early warning processes to take account of the conditions experienced during the COVID-19 pandemic? If so, what are they? (e.g., to take account of social distancing, changes to work patterns) 3. Were these changes part of pre-existing policies and contingency planning, or introduced in response to the pandemic? 4. Who are the stakeholders collaborating with you to address COVID-19 pandemic conditions? - At the National level - At the Local level 5. Have these collaborations been effective? If not, why? 6. What changes would you suggest to better integrate your early warning system with those for other hazards, such as pandemics, or cascading impacts?
2. How are the impacts of pandemics addressed in current practices of evacuation during disasters?	1. Is your organisation engaged in evacuation planning during multi-hazard events, such as a pandemic or cascading threat? Who are the other stakeholders engaged in the process? What is the level of institutional collaboration between them? - At the National level - At the Local level 2. Are there evacuation plans developed especially for pandemic conditions? What are they? - At the National level - At the Local level 3. Does your organisation adequately collaborate with public health authorities in the process of planning, disseminating, and executing evacuation planning? 4. What is the level of community participation in evacuation planning for multi-hazard events?

	5. Have you modified the warning information being given to communities regarding what to do in the event of a hazard threat during the pandemic? 6. Is land use planning incorporated in evacuation plans for multi-hazard events? If not, why? 7. Does your organisation conduct pre-evacuation drills and/or awareness raising? What are they? 8. Did you notice any problems in the evacuation process during a recent hazard event that took place during the pandemic (e.g., a recent monsoon, flooding) What were they?
3. What are the preparedness measures to stop shelters from being a super spreader of the pandemic?	1. Is your organisation engaged in planning for the provision of safe assembly areas / sheltering sites? - National level - Local level 2. Are there any specific guidelines / SOPs that have been developed for safe assembly areas / sheltering sites during the pandemic? 3. Is the capacity of safe assembly areas / sheltering sites adequate to take account of social distancing and other measures? 4. For the provision of relief activities at safe assembly areas / sheltering sites, what measures have been taken to ensure physical distancing, personal hygiene, contact tracing, etc.? 5. Has the community been engaged in the planning of safe assembly areas / sheltering sites that may be used during the pandemic? 6. Did you notice any problems in the evacuation process during a recent hazard event that took place during the pandemic (e.g., a recent monsoon, flooding) What were they?

Annex A.3

Identifying the impacts of biological hazards on disaster risk management activities for other hazards

Interview Guide – Disaster Management Authorities

Guiding question	**Data collection/key questions**
1. Do existing Early Warning Systems adequately address systemic risks under pandemic conditions?	7. Is your organisation currently engaged in early warning systems? If so, which systems? What legal provisions are made for this engagement? 8. Have you made changes to your early warning processes to take account of the conditions experienced during the COVID-19 pandemic? If so, what are they? (e.g., to take account of social distancing, changes to work patterns) 9. Were these changes part of pre-existing policies and contingency planning, or introduced in response to the pandemic? 10. Who are the stakeholders collaborating with you to address COVID-19 pandemic conditions? - At the National level - At the Local level 11. Have these collaborations been effective? If not, why? 12. What changes would you suggest to better integrate your early warning system with those for other hazards, such as pandemics, or cascading impacts?
2. How are the impacts of pandemics addressed in current practices of evacuation during disasters?	7. Is your organisation engaged in evacuation planning during multi-hazard events, such as a pandemic or cascading threat? Who are the other stakeholders engaged in the process? What is the level of institutional collaboration between them? - At the National level - At the Local level 8. Are there evacuation plans developed especially for pandemic conditions? What are they? - At the National level - At the Local level 9. Does your organisation adequately collaborate with public health authorities in the process of planning, disseminating, and executing evacuation planning? 10. What is the level of community participation in evacuation planning for multi-hazard events?

	11. Have you modified the warning information being given to communities regarding what to do in the event of a hazard threat during the pandemic? 12. Is land use planning incorporated in evacuation plans for multi-hazard events? If not, why? 9. Does your organisation conduct pre-evacuation drills and/or awareness raising? What are they? 10. Did you notice any problems in the evacuation process during a recent hazard event that took place during the pandemic (e.g., a recent monsoon, flooding) What were they?
3. What are the preparedness measures to stop shelters from being a super spreader of the pandemic?	7. Is your organisation engaged in planning for the provision of safe assembly areas / sheltering sites? - National level - Local level 8. Are there any specific guidelines / SOPs that have been developed for safe assembly areas / sheltering sites during the pandemic? 9. Is the capacity of safe assembly areas / sheltering sites adequate to take account of social distancing and other measures? 10. For the provision of relief activities at safe assembly areas / sheltering sites, what measures have been taken to ensure physical distancing, personal hygiene, contact tracing, etc.? 11. Has the community been engaged in the planning of safe assembly areas / sheltering sites that may be used during the pandemic? 12. Did you notice any problems in the evacuation process during a recent hazard event that took place during the pandemic (e.g., a recent monsoon, flooding) What were they?

Interview Guide – Technical Agencies

Guiding question	Data collection/key questions
1. Do existing Early Warning Systems adequately address systemic risks under pandemic conditions?	1. Is your organisation currently engaged in early warning systems? If so, which systems and what is your role? 2. What legal provisions are made for this engagement? Are there any guidelines/SOPs developed for your functions? 3. Does your organization conduct a risk assessment process at the disaster prevention stage? What are they? What are the outcomes? (Ex; Risk maps, vulnerability maps) 4. Has your organization identified vulnerable groups in your risk assessment process? If yes what is the next step regarding those groups? 5. What are the techniques that your organization use for forecasting/ disseminating early warning messages? 6. What is the institutional mechanism to connect with relevant authorities during this process? 7. Does your organization use technological platforms such as social media for early warning dissemination? If yes what are they? If not do find any possible reason behind it? 8. Has your organization implemented any mechanism to measure public trust and take actions accordingly? 9. Is there a rumor monitoring mechanism in place? 10. Does your organization take actions to conduct educational and preparedness programmes in your expertise area? 11. Have you made changes to your early warning processes to take account of the conditions experienced during the COVID-19 pandemic? If so, what are they? (e.g., to take account of social distancing, changes to work patterns) 12. Were these changes part of pre-existing policies and contingency planning, or introduced in response to the pandemic? 13. Who are the stakeholders collaborating with you to address COVID-19 pandemic conditions? - At the National level

	- At the Local level 14. What changes would you suggest to better integrate your early warning system with those for other hazards, such as pandemics, or cascading impacts?
2. How are the impacts of pandemics addressed in current practices of evacuation during disasters?	15. Is your organisation engaged in evacuation planning during multi-hazard events, such as a pandemic or cascading threat? (Ex; insights from risk assessment outcomes) 16. Are there evacuation plans developed especially for pandemic conditions? What are they? - At the National level - At the Local level 17. Does your organisation conduct pre-evacuation drills and/or awareness raising? What are they? 18. Did you notice any problems in the evacuation process during a recent hazard event that took place during the pandemic (e.g., a recent monsoon, flooding) What were they?
3. What are the preparedness measures to stop shelters from being a super spreader of the pandemic?	19. Is your organisation engaged in planning for the provision of safe assembly areas / sheltering sites? - National level - Local level 20. Did you notice any problems in the shelters during a recent hazard event that took place during the pandemic (e.g., a recent monsoon, flooding) What were they?

Interview Guide – Search and Rescue (SAR) teams

Guiding question	**Data collection/key questions**
1. Do existing Early Warning Systems adequately address systemic risks under pandemic conditions?	1. Is your organization currently engaged in early warning systems? If so, which systems and what is your role? 2. What legal provisions are made for this engagement? Are there any guidelines/SOPs developed for your functions? 3. Does your organization conduct a risk assessment process at the disaster prevention stage? What are they? What are the outcomes? (Ex; Risk maps, vulnerability maps) 4. Has your organization identified vulnerable groups in your risk assessment process? If yes what is the next step regarding those groups? 5. What are the techniques that your organization use for receiving early warning messages? 6. What is the institutional mechanism to connect with relevant authorities during this process? 7. Does your organization use technological platforms such as social media for early warning dissemination? If yes what are they? If not do find any possible reason behind it? 8. Has your organization implemented any mechanism to measure public trust and take actions accordingly? 9. Is there a rumor monitoring mechanism in place? 10. Does your organization take actions to conduct educational and preparedness programmes in your expertise area? 11. Have you made changes to your early warning processes to take account of the conditions experienced during the COVID-19 pandemic? If so, what are they? (e.g., to take account of social distancing, changes to work patterns) 12. Were these changes part of pre-existing policies and contingency planning, or introduced in response to the pandemic? 13. Who are the stakeholders collaborating with you to address COVID-19 pandemic conditions? - At the National level - At the Local level

	14. What changes would you suggest to better integrate your early warning system with those for other hazards, such as pandemics, or cascading impacts?
2. How are the impacts of pandemics addressed in current practices of evacuation during disasters?	15. Is your organization engaged in evacuation planning during multi-hazard events, such as a pandemic or cascading threat? (Ex; insights from risk assessment outcomes) 16. Are there evacuation plans developed especially for pandemic conditions? What are they? - At the National level - At the Local level 17. Does your organization conduct pre-evacuation drills and/or awareness raising? What are they? 18. Did you notice any problems in the evacuation process during a recent hazard event that took place during the pandemic (e.g., a recent monsoon, flooding) What were they?
3. What are the preparedness measures to stop shelters from being a super spreader of the pandemic?	19. Is your organization engaged in planning for the provision of safe assembly areas / sheltering sites? - National level - Local level 20. Are there any specific guidelines / SOPs that have been developed for safe assembly areas / sheltering sites during the pandemic? 21. Did you notice any problems in the shelters during a recent hazard event that took place during the pandemic (e.g., a recent monsoon, flooding) What were they?

Interview Guide – Non-Government Organizations

Guiding question	**Data collection/key questions**
1. Do existing Early Warning Systems adequately address systemic risks under pandemic conditions?	1. How does your organization receive early warning messages and risk information? 2. How does your organization use the early warnings and risk information you received? (Ex; further disseminating, awareness-raising) 3. Have you made changes to your process of using risk information to take account of the conditions experienced during the COVID-19 pandemic? If so, what are they? (e.g., to take account of social distancing, changes to work patterns) Were these changes part of pre-existing contingency planning, or introduced in response to the pandemic? 4. Who are the stakeholders collaborating with you to address COVID-19 pandemic conditions (in early warning disseminating and risk communication)? - At the National level - At the Local level 5. Does your organization identify vulnerable communities for possible multi-hazards (Ex; differently abled, older people, etc.) If yes, how do you continue the process? 6. What changes would you suggest to better integrate your risk communication system with those for other hazards, such as pandemics, or cascading impacts?
2. How are the impacts of pandemics addressed in current practices of evacuation during disasters?	7. What role does your organization play in evacuation planning during multi-hazard events, such as a pandemic or cascading threat? What is the level of institutional collaboration between them? - At the National level - At the Local level 8. Does your organization adequately collaborate with public health authorities in the process of evacuation? 9. Does your organization implement special plans for vulnerable communities? Explain. 10. Does your organization support pre-evacuation drills and/or awareness-raising? What are they? 11. Did you notice any problems in the evacuation process during a recent hazard event that took place

	during the pandemic (e.g., a recent monsoon, flooding) What were they?
3. What are the preparedness measures to stop shelters from being a super spreader of the pandemic?	12. Is your organization engaged in planning for the provision of safe assembly areas / sheltering sites? - National level - Local level 13. Are there any specific guidelines / SOPs that have been developed for safe assembly areas / sheltering sites during the pandemic? 14. Does your organization play a role in managing sheltering camps? What is it? 15. For the provision of relief activities at safe assembly areas / sheltering sites, what measures have been taken to ensure physical distancing, personal hygiene, contact tracing, etc.? 16. Has your organization taken actions at the community level to address the special needs of victims? 17. Are there any plans to address the people with special needs inside sheltering camps (Differently abled, older adults, etc.)? 18. Did you notice any problems in the sheltering sites during a recent hazard event that took place during the pandemic (e.g., a recent monsoon, flooding) What were they?

Annex A.4

Interview Schedule: Preventive Sector Public Health Officers

Risk Knowledge

a) Systematic collection of data
   i. What is the existing mechanism for data collection in your organization?
   ii. Is there any institutional mechanism to check on the timeliness, quality, and consistency of data you received?
   iii. Have you noticed any delays, deviations in quality or consistency in routine data due to COVID-19 pandemic?
   iv. If yes by any means these limitations in data collection have affected your early warning systems.
   v. What are the mechanisms in place to prevent interruptions of data flow due to events like COVID-19 pandemic and its consequences?
   vi. What are the institutional mechanisms you propose in the event of a future shock, to sustain your data flow?

b) Risk assessments
   i. Is there any risk assessment plan currently in use for your institutional setup and your client base?
   ii. If yes, what are the key elements covered under the existing risk assessment (Hazard profiles, vulnerability assessments, exposure status and capacity profiles)
   iii. Are biological hazards such as COVID-19 included in your existing risk assessment plan
   iv. If yes, what more improvements you suggest enhancing the existing plans in view of a cascading event/ simultaneous disasters?
   v. If No, what new interventions you suggest incorporating cascading/ simultaneous disaster events to the existing plan?

Risk communication and dissemination

a) Risk communication
   i. What are the existing risk communication strategies (to public/ partner institutions) in your organizations?
   ii. Have you mapped out your target audience for delivery of risk communication messages?
   iii. Have you included special provisions to incorporate biological hazards such as COVID-19 in your risk communication plans?
   iv. Is there any M & E plan to assess the reach of your message and whether the message have reached the intended audience?

b) Early warning
   i. What are the existing mechanisms at place for early warning at your institution?

ii. Is there any institutional plan to identify the audience, best method of delivery, timeliness, and escalation plan?
iii. Is there any collaboration with stakeholders within your organization and outside to share this early warning?
iv. Is there any provisions to include a cascading or simultaneous disaster events in your early warning system?
v. What improvements you suggest augmenting the operability of your EW in a pandemic situation?

Response Capacity

i. Is there any regular capacity assessment (human, logistics and financial) at your institution (National/grass root level)?
ii. Do you think COVID-19 pandemic has negatively affected on your existing response capacity? If yes explain how. If no, why?
iii. Do you think your institution is better prepared to address multiple hazard scenarios at any given moment?
iv. How would you suggest improving the response capacity of your organization in view of this pandemic?

Monitoring and Warning Services

i. Is there any institutional provision to monitor hazards relevant to your subject area in your institutional plan?
ii. Is there any institutional provision to monitor hazards not directly related but might influence your organization in your institutional plan?
iii. Is there any written policy on modality, timing, frequency, and feedback on warnings issued by your organization?
iv. How often you have monitored a hazard other than what directly relevant to you in recent past?
v. Is there any institutional monitoring mechanism in place to identify a biological hazard that pose a threat to operations of your institution (in relation to COVID-19)?

Annex A.5

Interview Guide: Curative Sector Health Officers

General Information

1. What is your profession?

2. What is the type of the hospital?

   a) National hospital
   b) Teaching hospital
   c) Provincial General Hospital
   d) District General Hospital
   e) Base Hospital
   f) Divisional Hospital
   g) Other

3. What is the bed strength of the hospital?

4. What is the bed occupancy rate (per day)?

5. Does the hospital have a disaster management plan?

- ☐ Yes
- ☐ No

6. In which year the disaster preparedness plan was tested and updated last?

Impacts of biological outbreaks on hospitals

7. Did your hospital cater for COVID-19 patients, if so under which category?

- ☐ The entire hospital is a dedicated COVID-19 hospital
- ☐ The hospital has both dedicated COVID-19 and non-COVID-19 wards
- ☐ Not the entire ward but only a section of award is a COVID-19 treating area
- ☐ Only isolation facilities are available, no dedicated COVID-19 wards
- ☐ Not used for COVID-19 treatment or isolation

8. Did the bed capacity of your hospital [or bed capacity of dedicated wards] exceed during the COVID-19 pandemic?

- ☐ Yes
- ☐ No

9. Did the bed capacity of medical wards exceed during the 2017 Dengue outbreak?

- ☐ Yes
- ☐ No

10. Please mention challenges that hospital faced during the COVID-19 pandemic.

- Management of patients
- Issues related to staff management
- Infection control
- Critical lifeline management
- Administration
- Impacts from outside parties

11. Please mention whether you have done the following changes inside hospitals to overcome the above-mentioned challenges or not.

- Wards
- Management of patients
- Staff
- Infection control
- Critical lifeline services
- Administration aspects

12. Was there a plan for cadre and other resource escalation during an emergency before the COVID-19?

- ☐ Yes
- ☐ No

13. Were the above-mentioned changes that were made during the COVID-19 parts of pre-existing contingency plans?

- ☐ Yes
- ☐ No

14. Do you think further improvements are needed in the existing contingency future?

- ☐ Yes
- ☐ No
- ☐ No contingency plan is present

15. What are the procedures that you followed related to reporting number of cases?

16. Please factors that have a contribution to continuing hospital functions during a biological outbreak such as COVID-19.

- Resources in terms of beds, ICUs, medical equipment
- Management of patients
- Staff related aspects
- Critical lifeline services
- Communication

- Administration aspects
- Emergency management plans

17. If there are any other factors that affect hospital functions during biological outbreaks or other emergencies according to your opinion and not mentioned above, please mention them.

Interdependencies between hospital subsystems

18. Please mentions factors that affect the following areas related to the functions of the hospital.

Quality of Care

Staff availability for treating infected patients

Rate of transferring patients

Impacts of other hazards during a biological outbreak

19. Did you experience any other hazards that affect the hospital while managing biological outbreaks?

- ☐ Yes
- ☐ No

20. If yes please mention the hazards you experience (Ex; floods, fire, high winds)?

21. What are the challenges that occurred/ or you expected when there is a hybrid hazard scenario?

22. Have you developed any disaster management plans to address multiple hazards affecting the hospital especially during a biological outbreak (Dengue, COVID-19)?

- ☐ Yes
- ☐ No

23. What are the factors that you have considered when recovering to the previous state after a concurrent hazard?

ANNEX B

Identified Interlinks Between Stakeholders for Four Multi-Hazard Scenarios						
No	**Institution**	**Label**	**Scenario I**	**Scenario II**	**Scenario 3**	**Scenario 4**
1	Disaster Management Centre	DMC	2, 7, 6, 12, 50, 20, 15, 21, 13, 10, 4, 16, 50, 6, 19, 5, 10, 13, 15, 21, 20, 29, 4, 24, 9, 25, 6, 13, 19, 32, 55, 21, 2, 6, 7, 29, 48, 25, 4, 20	15, 19, 5,10,13, 24, 29, 25, 6, 14, 9, 21, 22,23, 20, 50, 4, 52, 2, 12, 7, 50, 16, 28, 30, 32, 26, 5, 45, 48, 55	2, 7, 6, 12, 50, 13, 25, 30, 29, 15, 10, 32, 50, 4, 7, 21	2, 7, 6, 12, 50, 4, 50, 9, 25, 24, 6, 52
2	Ministry of Health	MOH	12, 50, 46, 1, 3	46	12, 50, 46, 1, 3	12, 50, 46
3	Hospitals	HP		2		
4	Department of Meteorology	DOM	7, 22, 18, 50, 57, 56, 21, 7, 45, 48, 5	50, 7, 22, 18, 52, 16	31, 54, 34, 26, 35, 21, 27, 37, 33, 36	52, 24
5	Sri Lanka Airforce	SLAF	50, 1	50		
6	Sri Lanka Army	SLA	50	50	1, 50	50
7	Sri Lanka Police	SLP	50	50, 51, 4	50	50, 51
8	Public Media Institutions	PMI	50	9, 50	50	50
9	Ministry of Mass Media and Information	MMMI	8, 1, 1, 4, 8, 50,	50, 24, 8, 4	1, 8	1, 8
10	Ministry of Education	MOE	11,	11	11	
11	Schools	SCH				
12	Divisional/ District Secretary	DDS	22, 17	17, 14, 22, 24, 52, 2	17	24
13	Road Development Authority	RDA				

14	District Disaster Management Coordination Unit	DDMCU	1, 12, 2	2	1, 12, 2	1, 12, 2, 50
15	Sri Lankan Transportation Board	SLTB	50, 1	50	50	
16	National Building Research Organization	NBRO	18, 50, 12	50, 18, 12		
17	Local Authorities	LA	18,	18,	18,	18,
18	Gram Niladari	GN	50, 17	50, 22, 52	50, 17	50, 52
19	Ministry of Provincial Council and Local Government	MPCLG	50, 1, 2, 17, 1, 49	49, 2, 17, 50	50, 1, 2, 17	1, 2, 17, 50,
20	Provincial RDA	PRDA		50	1, 50	
21	SL Navy	SLN		4, 55, 50	50, 55	
22	Mahaweli Authority Sri Lanka	MASL	18, 50	50		4, 12, 18, 25, 50
23	Ministry of Agriculture	MOA	12, 1, 4	12, 4, 50		50
24	Department of Irrigation	DOI	4, 25, 50, 9, 7, 22, 1, 50	50, 7, 22, 4		50
25	Ceylon Electricity Board	CEB	50	24, 22		
26	Geological Survey & Mines Bureau	GSMB		4, 21	1, 21	
27	Indian Ocean Tsunami Warning Centre	IOTWC		4,		
28	National Aquatic Reservation Authority	NARA		50,	1, 50	
29	Sri Lanka Airport and Aviation Services	SLAAS	2, 47, 50	50, 2	2, 47, 50	2, 47
30	SL Ports Authority	SLPA				

31	Pacific Tsunami Warning Centre	PTWC		4		
32	Coast Conservation Department	CCD				
33	Meteorology Climatology and Geophysical Agency	BMKJ		4		
34	Indian National Centre for Information Services	INCOIS		4		
35	Joint Australian Tsunami Warning Centre	JATWC		4		
36	Regional Integrated Multi-Hazard Early Warning Systems	RIMES		4		
37	California Integrated Seismic Network	CISN		26		
38	Coast Police Stations	CPS		7, 50	50, 7	
39	Non-Governmental Organization	NGO				
40	International NGO	INGO				
41	Fishing Community	FC				
42	Department of Fisheries	DOF				
43	Office of the Chief Defence Staff	OCDS				
44	National Disaster Relief Services Centre	NDRSC				
45	Sri Lankan Telecom	SLT				
46	Public Health Inspector	PHI	50	50	50	50

47	Airports	AP		29		
48	Sri Lanka Coast Guard	SLCG		4		
50	General Public	GP				
52	Department of Agrarian	DAS		50		50
54	Japan Meteorological Agency	JMA		4		
55	Sri Lanka Railway	SLR	50	50		
56	Indian Meteorology Department	INDO - MET		4		
57	Australian Meteorology Department	AUS - MET		4		

ANNEX C

Governance and leadership			
Indicator	**Sub indicators**	**Reference**	**Remarks**
National policy and legislations	National health policy and plan	(UNDRR, 2020)	National Health Policy is active / National Health Policy covers the health disaster and emergency management for possible hazards in the country
	Integration of biological hazards into disaster risk reduction planning	(UNDRR, 2020)	The full spectrum of public health functions including biological hazards routinely provide input to the country's disaster resilience governance mechanism, meetings, disaster resilience programs, and documents.
	Inclusion of health aspects in urban planning	(UNDRR, 2020)	A comprehensive set of health issues related to disasters and emergencies is fully included in its urban planning scenarios. The likely impact on staff availability, health facilities, water and sanitation, treatment and care is planned for and modelled, including immediate impact and for long-term physical and psychological health issues.
Compliance with international regulations	Implementation of International Health Regulations	(Nuclear Threat Initiative & Johns Hopkins School of Public Health, 2019)	The country has an IHR focal point and has submitted the IHR reporting timely
	Joint External Evaluation		The country has completed and published either a National Action Plan for Health Security (NAPHS) to address gaps identified through the Joint External Evaluation (JEE) assessment or a national GHSA roadmap that sets milestones for achieving each of the GHSA targets within the last five years

	Participation in International agreements		The country has cross-border agreements, protocols, or MOUs with neighboring countries or as part of a regional group, with regards to both public health or animal health emergencies
Stakeholder coordination	Decentralization and Representation of health sector in DRR different jurisdictions	Desk study	Public health administration is decentralized to the village level in align with the disaster management governance in the country
	Availability of multi sectoral coordination	Desk study	Public health officials are representing the health sector in disaster management platforms both at national and local levels and organizing multi sectoral platforms at both levels
Political and security risk	Government effectiveness	(Nuclear Threat Initiative & Johns Hopkins School of Public Health, 2019)	Government effectiveness score > 2
	Public confidence on government		
	Risk of terrorism and conflicts		
	International tension		There is no threat that international disputes/ tensions could have a negative effect
Monitoring and evaluation	Availability of performance monitoring frameworks	(WHO, 2019)	Assessments are carried out at both national and regional levels with
	Policy Reviewing	(WHO, 2019)	Policy reviewing is carried out in a regular manner and based on lessons from emergencies
	Benchmarking with regional and international indicators	(WHO, 2019)	Measures to increase the national health sector disaster preparedness after comparing the national status of health

			disaster risk management with regional and international capacities (ex; Implementing IHR)
	Capacity development	(WHO, 2019)	Capacity enhancement strategies are enriched with regional and international support. Capacity development strategies are included within the national health policy.

Health Finances			
Indicator	**Sub indicators**	**Reference**	**Remarks**
Funds for Health EDRM programs	Staff activities and supplies	(WHO, 2019)	The percentage of staff activities and supplies that are provided with funds, required for health sector preparedness planning [Recommended level is more than 80%)
	Hospitals and infrastructure safety	(WHO, 2019)	The percentage of healthcare facilities that are provided with funds, required for preparedness and response planning [Recommended level is more than 80%)
	Specific programs for HDRM at community level	(WHO, 2019)	Funds are allocated for community HDRM programs covering all risky areas in the country for potential hazards
Emergency management	Contingency funds for emergency response and recovery	(WHO, 2019)	Availability of a contingency fund for immediate preparedness and response activities in forecasted emergencies.
	Financial arrangements for emergency care	(WHO, 2019)	Financial arrangements are available to address sudden financial requirements of community for emergency care (Ex; cost waiver policies)
	Monetary resource mobilization	(WHO, 2019)	Plans are available for monetary resource mobilization at both national and local levels without power struggles and delays
Community needs	Household out-of-pocket payments	(World Health Organization, 2010)	The number of households in each region where direct out-of-pocket payments to providers for health during the past 12 months was more than 10% of their total income. [Recommended value is fewer than 20% of total households in the country]

Health Information Systems			
Indicator	**Sub indicator**	**Reference**	**Remarks**
Surveillance and early warnings	Indicator and event-based surveillance systems	(World Health Organization, 2018)	Indicator and event-based surveillance system(s) are in place to detect public health threats in the country and use international links to identify possible threats to the country. In addition to surveillance systems in country, using expertise to support other countries in developing surveillance systems and provide well-standardized data to WHO and OIE for the past five years without significant external support
	Inclusion of public health concerns into national multi hazard early warning system	(WHO, 2019) UNDR 17	Comprehensive and effective monitoring exists and will deliver effective early warnings to address the health risks and impacts pertaining to all hazards that the country faces. They will allow time for reaction (as far as technology permits). Warnings are seen as reliable and specific to particular high-risk areas in the country
	Transparency and ethic consideration of surveillance data	(Nuclear Threat Initiative & Johns Hopkins School of Public Health, 2019)	Provisions exist to ensure the transparency in the collection and storing surveillance data. Rules and regulations are in practice to address ethical considerations in data sharing.
	Real Time Reporting	(World Health Organization, 2018)	Country has in place an inter-operable, interconnected, electronic real-time reporting system, including both the public health and veterinary surveillance systems which is sustained by the government and capable of sharing data with relevant stakeholders according to country policies and international obligations.

Risk assessments	Comprehensive disaster risk assessment at national and local level	(WMO, 2018)	Assessment and quantification of exposed people, services and critical infrastructure conducted and mapped for all relevant hazards [including biological threats], secondary risks associated with these impacts are evaluated, and risk management solutions considered to increase resilience at both national and local levels
	National health surveys and resource tracking	(World Health Organization, 2010)	National health survey and resource tracking procedures are conducted in required frequency covering the entire country
	Use of technology in risk assessments	(UNDRR, 2020)	The level of usage of technological applications in assessing main drivers of disaster risks; hazard, exposure, and capacity
Information management	Availability of databases for risk information and their safety	(UNDRR, 2020)	Health records of citizen/victims of a disaster (health conditions, prescription records) are safe, and also accessible by emergency response workers (for example those providing healthcare in shelters, hospitals where people may be taken if injured).
Information products	Development of guidelines/ protocols/ good practices	(WHO, 2019)	A plan is available for good practices/ guidelines/ protocols to be developed based on collected information.
	Availability of information sharing procedures	(Nuclear Threat Initiative & Johns Hopkins School of Public Health, 2019)	Publicly available plan or policy for sharing information related to health of citizens/victims (Ex; health records, genetic data, clinical specimens, and/ or isolated specimens) It is important to note that data is shared in accordance with the Pandemic Influenza Preparedness (PIP) Framework and other available ethical frameworks.

	Data from other critical systems shared with public health sector	(UNDRR, 2020)	Relevant data and feeds for other critical systems [electricity, transportation, food, etc.] are identified; quality data is reliably distributed to all public health stakeholders who need it.
Research and development	Availability of research and development agenda in health sector	(WHO, 2019)	A comprehensive national research agenda is functioning, and international collaborations are also included and promotes the institutionalization of research outcomes

Risk communication			
Indicator	**Sub indicators**	**Reference**	**Remarks**
Public communication	Availability of a guiding document to outline public communication	(Nuclear Threat Initiative & Johns Hopkins School of Public Health, 2019)	Publicly available standard operating procedures, guidelines, memorandums of understanding (MOUs), or other agreements between the public health and security authorities to respond to a potential deliberate biological event. Public evidence that public health and national health authorities have carried out an exercise to respond to a potential deliberate compound hazard event amidst a biological outbreak
	Use of conventional media platforms to risk communication	(Nuclear Threat Initiative & Johns Hopkins School of Public Health, 2019)	Evidence that the authorities utilize conventional media platforms such as radio, TV, announcements, etc. for risk communication during every phase of a disaster
	Use of technological platforms such as social media, messenger, etc for risk communication	(Nuclear Threat Initiative & Johns Hopkins School of Public Health, 2019)	Authorities use these technological platforms for risk communication during every phase of a disaster
	Inclusion of people with special needs in communication methods	Desk Study	All the followings have been incorporated in the public communication strategies • Elderly people • Differently abled people with hearing and visual disabilities • Children • Women • Language barriers • Cultural barriers • People in remote areas with no access to media platforms

Stakeholder communication	Platforms for internal stakeholder communication	(World Health Organization, 2018)	Effective, regular and inclusive communication coordination with partners and stakeholders including definition of roles, sharing of resources and joint action plans
	Regular testing of coordination platforms	(World Health Organization, 2018)	Regular testing by a simulation exercise or tested by a real health emergency
	Coordination with officials from DRR planning	UNISDR	Coordination is available with DRR officials at both national and local level platforms/ Health agencies represent disaster management committees, units, meetings, etc. which are coordinated, organized by disaster management authorities
	Coordination with non-government organizations/donor agencies/ private sector	(WMO, 2018)	Health agencies have developed mechanisms to maintain links with non-government agencies, donor agencies, and private sector agencies who are engaged with disaster management and health and well-being of community, before and after a disaster event
Risk communication system management	Risk Communication plan	(World Health Organization, 2018)	Fully operational national system established meeting criteria of all previous levels, with reasonable skilled and/or trained personnel and volunteers, and financial resources and arrangements for scale-up as evidenced by a simulation exercise or tested by a real health emergency
	Effectiveness of EWs and risk communication system	(WMO, 2018)	Regular mechanisms are in place to test the EWs and risk communication systems at both national and local levels

Rumour monitoring and management	Dynamic listening and Rumour monitoring system	(World Health Organization, 2018)	Strong system for listening and rumor management on a permanent basis which is integrated into the decision-making and response actions for public communication, communication engagement with affected communities, as well as for internal and partners communications
Community engagement	Community compliance to risk information	(UNDRR, 2020)	Health agencies are maintaining systems to monitor the public compliance to risk information shared by agencies and take necessary actions accordingly. [Availability of evidence that depicts these systems have functioned in the past]
	Public awareness programs	(WMO, 2018)	Public awareness and education programs take place including special needs of vulnerable communities and tested and updated regularly covering all the risk areas in the country and other areas if necessary
	Two-way communication systems	Desk study	Health agencies use two-way communication systems for assessing community grievances, needs, damages, and rumors.

Health services			
Indicator	**Sub indicators**	**Reference**	**Remarks**
Healthcare facility capacities	Resilience of public healthcare facilities	(UNDRR, 2020)	Procedures and plans are developed and implemented to ensure that all public health infrastructure – including the services on which it depends – are protected during disasters and rated capable of dealing with “most severe” scenario with minimal loss of service.
	Surge capacities of hospitals and emergency care centres	(UNDRR, 2020)	Surge capacity exists to deal with additional health needs likely to arise from “most severe” scenario and is tested either via actual events or practice drills – can be activated without major time delays [can be specified by professionals based on risk profile of the healthcare facilities]
	Availability and continuity of healthcare services for non-affected patients	HRDM 28 (UNDRR, 2020)	Care could be maintained in “most severe” scenario for all categories of existing patients. If patients need to be moved, transportation facilities and routes are known to have required capacity and resilience.
	Operability of the network of healthcare facilities during disasters	(UNDRR, 2020)	All key public health facilities are in locations and conform to codes that will allow them to survive in the “most severe” disaster scenario.
Laboratory system	Laboratory capacity for detecting priority diseases	(Nuclear Threat Initiative & Johns Hopkins School of Public Health, 2019)	A national laboratory system equipped with national procurement protocol is available and have capacity to conduct at least five out of 10 WHO-defined core tests and tests are named. Private sector laboratories are available to connect during major outbreaks [Plans are available to maintain the coordination]

	Laboratory quality [accuracy] systems	(Nuclear Threat Initiative & Johns Hopkins School of Public Health, 2019)	A national laboratory quality assurance system is in place and a national laboratory that serves as a reference facility which is accredited and subjected to external reviews is available. [A special attention should be paid on accuracy of laboratory tests]
Emergency health response	Public health sector and professionals integrated with the emergency management team	(UNDRR, 2020)	Public health sector is fully represented and engaged on the emergency management team and integrated into all emergency decision taking including emergency case management. Engagement has been tested via drills (within the last year) or live response.
	Health emergency operations program	(Nuclear Threat Initiative & Johns Hopkins School of Public Health, 2019; World Health Organization, 2018)	A national health EOP is available and regularly updated after evaluation and testing/ Regional health EOPs are available and regularly updated
Preventive health services	Medical counter measures during an emergency	(World Health Organization, 2018)	Plans are drafted and one response OR a formal exercise or simulation within the previous year in which medical countermeasures were sent or received by the country
	Immunization	(WHO, 2019)	Plans are available to immediately publish vaccination procedures in an outbreak and update the procedures based on lessons learned and new knowledge on the outbreak.

	Public health and security authorities	(World Health Organization, 2018)	A legal agreement, policy is available for the coordination among health officials and security forces, coordination is tested through a simulation exercise or real scenario, and written reports are shared among, and joint training programmes are available
	Infection control practices and availability of equipment	(Nuclear Threat Initiative & Johns Hopkins School of Public Health, 2019)	A plan, strategy, or similar document to address personal protective equipment (PPE) supply issues for during a public health emergency is publicly available and is tested via simulation exercise or real scenarios
	Environmental Health	(WHO, 2019)	Policies and action plans are in place and practiced for all the following areas. • Water, sanitation, hygiene • Vector control • General and health care waste management
	Food and nutrition	(WHO, 2019)	A plan is available to assess and measure food and nutrition requirements of citizens/victims and take necessary actions to ensure the needs
Post disaster planning	Mitigating long term impacts on public health and well-being	(UNDRR, 2020)	Fully comprehensive plans exist addressing longer term public health needs after “most probable” and “most severe” scenario
	Recovery planning	(World Health Organization, 2019)	Plans and policies have been drafted for recovery planning at both at national and local levels for a multi sectoral approach and strategies are taken to strengthen post event health system with the community engagement

Community engagement	Consideration of higher risk populations in healthcare	(UNDRR, 2020)	All citizens likely to require extra additional support or specific measures city-wide are identified and provisions exist to help them.
	Need assessments of vulnerable communities	(WMO, 2018)	Plans are available to measure needs of vulnerable communities during a disaster scenario. These plans can be customized based on specific needs in the area.
	Availability of community health services	(World Health Organization, 2019)	Primary health care, community-based clinical care is available in more than 80% of the population in country
	Mental health	(UNDRR, 2020)	Community organization(s), psychosocial support, schools, psychological trauma centres, and counsellors exist and are equipped to address full spectrum of mental health for every neighbourhood, irrespective of wealth, age, demographics, etc.

Health Workforce			
Indicator	**Sub indicators**	**Reference**	**Remarks**
Multidisciplinary workforce capacity	Available human resources for the broader healthcare system	(Nuclear Threat Initiative & Johns Hopkins School of Public Health, 2019)	Satisfying both Doctors: Population = 1:1000 & Nurse: Population = 3:1000 rations
	Competencies and skills of healthcare workers for disaster resilience	(UNDRR, 2020)	All relevant workforce competencies and skills identified and assessed to be adequate for disaster planning, health services and post disaster recovery, both in terms of skill depth and numbers.
	System for receiving foreign health personnel	(Nuclear Threat Initiative & Johns Hopkins School of Public Health, 2019)	A public plan is available in place to receive health personnel from other countries to respond to a public health emergency and plan is tested with scenario simulation
Workforce development	Analysis of training needs	(WHO, 2019)	Training needs assessment covers more than 80% of healthcare workforce
	Workforce development strategies	(WHO, 2019)	Workforce development strategies cover more than 80% of healthcare workforce

Staff contingency planning	Contingency planning for staff deployment	(WMO, 2018)	Contingency planning developed in a scenario- based manner with provision of funding for early action and response options and Strategies implemented to maintain preparedness for longer return-periods and cascading hazard events / A system in place for public health workers to communicate within themselves and cover all the other stakeholders who act as first responders
	Safety and security of HCW	(WHO, 2019)	Measures are taken to provide security for more than 70% of healthcare workers in emergencies / Legislation, a policy, or a public statement committing to provide prioritized healthcare services to healthcare workers who become sick as a result of responding to a public health emergency is available and practiced during last health emergencies

Medicine, equipment, and vaccines			
Indicator	**Sub indicators**	**Reference**	**Remarks**
Procurement	Availability of procurement plans	(Tema, 2014)	Procurement plans are available to cover more than 80% healthcare facilities
	Budgeting for health emergency medical supplies	(Tema, 2014)	An approved budget is available for emergency medical supplies and procedures are in place to supply additional finances required adequately
Storages	Prepositioning of medical supplies	(WHO, 2019)	Measures are taken for prepositioning emergency medical supplies in more than 80% of divisions in the country
	Security of medical storages	(WHO, 2019)	Security measurements are reviewed frequently and updated accordingly.
Supply chain management	Ability to deliver public health supplies to people in need	(UNDRR, 2020)	A comprehensive list of required items exists, and tested plans are known to be adequate to deliver them rapidly to the entire population.
	Logistic supplies of (medicines, emergency kits, etc.)	(WHO, 2019)	Emergency medical logistic supply mechanisms cover more than 80% of divisions in the country
	Cold chain system for vaccines	(WHO, 2019)	Vaccine delivery (maintaining cold chain) is available in greater than 80% of districts within the country OR Vaccine delivery (maintaining cold chain) is available to more than 80% of the national target population; systems to reach marginalized populations using culturally appropriate practices are in place; vaccine delivery has been tested through a nationwide vaccine campaign or functional exercise; functional procurement and vaccine forecasting results in no stock-outs