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# TOWARDS HEALTH SYSTEMS RESILIENCE TO EXTREME WEATHER EVENTS: MANAGING HEALTH NEEDS DURING FLOODS IN CAMBODIA

Dell Saulnier

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**TOWARDS HEALTH SYSTEMS RESILIENCE TO EXTREME WEATHER EVENTS: MANAGING HEALTH NEEDS DURING FLOODS IN CAMBODIA**

THESIS FOR DOCTORAL DEGREE (Ph.D.)

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To my 100-year-old grandmother, Barbara,
who gave me my first definition of resilience: *challenge, choice, change*.

Time changes the nature of the whole world.

Everything passes from one state to another and nothing stays like itself.

– Lucretius, *On the Nature of Things*

# ABSTRACT

**Background:** Extreme weather events like floods are expected to become more common as climate change continues, putting health at risk. Knowledge on what health needs are expected after such events is needed for health systems to be able to provide health services. Resilient health systems have the capacity to maintain their functions and change when experiencing events like floods which enables them to continue delivering essential health services. Enabling resilience in health systems requires an understanding of what capacities create resilience.

**Aim:** To assess the effects of flooding on health and the capacity of the public health system to manage health needs during floods in Cambodia, with a view to identifying capacities that foster health systems resilience to extreme weather events.

**Methods:** Study I was a systematic review of epidemiologic articles (n=113) to identify changes in health outcomes of affected people after flood or storm disasters globally, analysed by narrative synthesis. Study II was a time series analysis of monthly visits to public healthcare facilities in eleven districts in Cambodia for acute respiratory infections, diarrhea, skin infections, noncommunicable diseases, injuries, and vector-borne diseases between 2008 and 2013. Poisson regression models were used to quantify their relationship with the extent of flood water in each district. In Study III, focus group discussions (n=8) and semi-structured interviews (n=17) with community members who had experience with pregnancy or childbirth during floods were used to understand if and how the public health system's capacity to absorb, adapt, or transform is linked to the community's own capacity when managing antenatal and childbirth care needs during seasonal and occasional floods. The data were analysed by thematic analysis. In Study IV, 23 semi-structured interviews were conducted with public sector staff with experience providing or managing antenatal or childbirth care services during floods. They were analysed by thematic analysis to generate knowledge on the influences on public sector health service delivery in Cambodia during seasonal and occasional floods that are related to the system's capacity to absorb, adapt, or transform.

**Results:** There is some evidence that flood and storm disasters affect health for up to two years, and that floods and storms may affect health differently (Study I). In Cambodia, visits to healthcare facilities for diarrhea, acute respiratory infections, and skin infections increased immediately and up to three months after seasonal and occasional floods (Study II). The community was primarily capable of absorbing the impact of seasonal and occasional floods on their antenatal and childbirth care needs, which was linked to their responsibility to balance the expectations placed on them to receive care during floods but with limited support and help (Study III). Collaboration and relationships have created boundaries around decision-making that allow a stable but flexible approach to public antenatal and birth health services in Cambodia when regularly exposed to floods (Study IV).

**Conclusions:** Floods had a prolonged effect on health, increasing new and routine health needs globally and increasing new health needs in Cambodia for up to three months after repeated seasonal and occasional floods. The public sector of the Cambodian health system appeared to have the capacity to absorb and adapt in order to manage antenatal and childbirth health needs during seasonal and occasional floods. They were aided by the community's own capacity to absorb that helped relieve the health system's responsibility to manage health needs. Strategies that enhance stability and flexibility in contexts where extreme weather events are perceived as strains rather than shocks may enhance system capacities for resilience. Public health system support to communities during floods and involvement in decision-making may generate resilience capacities in the community, strengthening the health system's resilience to repeated extreme weather events.

# LIST OF SCIENTIFIC PAPERS

I. Saulnier DD, Ribacke Brolin K, Von Schreeb J. No calm after the storm: A systematic review of human health following flood and storm disasters. *Prehospital and Disaster Medicine*. 2017; 32(5):1-12

II. Saulnier DD, Hanson C, Ir P, Alvesson HM, von Schreeb J. The effect of seasonal floods on health: Analysis of six years of national health data and flood maps. *International Journal of Environmental Research and Public Health*. 2018;15:665.

III. Saulnier DD, Hom H, Thol D, Ir P, Hanson C, von Schreeb J, Mölsted Alvesson H. Staying afloat: A qualitative study of community perspectives on health system resilience explored through the management of pregnancy and delivery care during floods in Cambodia. *BMJ Global Health.* 2020. [Accepted]

IV. Saulnier DD, Hom H, Thol D, Ir P, Hanson C, von Schreeb J, Mölsted Alvesson H. Generating knowledge on health systems resilience: A qualitative study of health worker perspectives on antenatal and childbirth services during floods in Cambodia. *[Manuscript*]

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| CRED | Centre for Research on the Epidemiology of Disasters |
| FGD | Focus group discussion |
| HMIS | Health Management Information System |
| MODIS | Moderate Resolution Imaging Spectroradiometer |
| NASA | National Aeronautics and Space Administration |
| NCDM | National Committee for Disaster Management |
| NIPH | National Institute of Public Health |
| PRISMA | Preferred Reporting Items for Systematic Reviews and Meta-analyses |
| WHO | World Health Organization |

# OPERATIONAL DEFINITIONS

- **Absorb** — The resources and capacity to continue functioning using existing strategies and resources
- **Adapt** — The resources and capacity that allows a system to make short-term changes to how it uses resources
- **Care** — Formal and informal care during pregnancy and birth, from self-care to community-based or facility-based care
- **Climate change** — A change in the mean and/or variability of the climate that persists for extended periods of time
- **Disaster** — A serious disruption in the functioning of a society or community that is caused by a combination of a hazardous event, the exposure and vulnerability of the community or society, and their capacity to cope, and leads to human, material, environmental, or economic losses or impacts
- **Extreme weather event** — Weather events that are more unusual, unseasonal or severe than they have previously been
- **Health need** — The need for promotive to curative health services as perceived by an individual or recognized by a professional
- **Transform** — The resources and capacity that lets a system fundamentally rearrange its function or structure in the long-term to avoid shocks
- **Vulnerability** — Interacting environmental, economic and social factors that can make a population or health system more susceptible to the impact of a hazard like an extreme weather event

# 1 PREFACE

The first time I visited Cambodia in May 2016, the country was in the middle of its worst drought in fifty years. As I drove north to Battambang, we passed brush fires burning along the roads and riverbeds down to the last few centimeters of water. The image of desiccated rice fields sat in my mind next to what I had been taught about malnutrition and hunger gaps.

A year and a half later, I was standing in the middle of a flash flood. As I perched on a concrete rise—one eye on a frantic dog swimming towards me, the other on a live powerline in the water half a block away—nothing seemed routine. I wondered if people ever got used to such extremes, if people from all strata of life could plan for all the tossibilities. I had seen nurses working alone in remote health centers, with few resources at their disposal and responsible for the welfare of their neighbors. What did she need to know, need to do, need to have, to be able to take care of them in all situations? Each time I went back to Cambodia, I learned a little more.

My own interest in resilience to disasters stemmed from this wonder about how people and systems deal with shocks. It seemed apparent to me that it required more than individual efforts and single actions at a few points in time. Systems were integral somehow but there seemed to be so little understanding about what that meant. This thesis is my own small contribution to that knowledge, and I hope  it is one more stepping stone towards protecting people's health when they are faced with extreme weather events and disasters.

# 2 BACKGROUND

## 2.1 CLIMATE CHANGE AS A GLOBAL PUBLIC HEALTH ISSUE

By the end of this century, the health, security, and prosperity of most of the world's population will be affected by climate change [1]. Climate change came to the forefront as a cross-cutting issue for health and development in 2015 with the adoption of the Sustainable Development Goals, which called climate change the greatest threat to sustainable development [2]. Two other congruent international agreements were adopted in the same year. The 2015 Paris Agreement to limit the increase in global average temperature to a total of 1.5 degrees Celsius to promote sustainable development. The Sendai Framework for Disaster Risk Reduction 2015-2030 aimed to shift thinking away from managing disasters, some caused by climate change, to investing in resilience in order to reduce disaster risk and protect health [3]. All three agreements call for action to meet their targets by 2030.

The release of greenhouse gases from human activity has raised the earth's observed global temperature by approximately 1 degree Celsius compared to pre-industrial times [4]. If global warming continues at its current rate, the global mean surface temperature will rise by 1.5 degrees Celsius compared to pre-industrial times by the middle of this century and there will be profound impacts on natural and human systems (Box 1) [4]. One projected consequence is the continued rise in the frequency or intensity of extreme weather events, such as extreme temperatures, heat waves and cold waves, floods, and tropical cyclones [5].

### 2.1.1 The impacts of climate change and extreme weather events on health

Climate change amplifies risks to health through its impacts on society, the environment, economic security, health systems, and other human systems [6]. The direct impacts of climate change and its influence on natural and human systems can affect human health. Heatwaves, for example, can directly cause heat stroke or exacerbate underlying illness [7]. The main intermediate pathways to poor health are complex and multitudinous. New populations will be exposed to vector- and rodent-borne diseases, impacts on agriculture will compound food insecurity, and displacement and migration means populations may lack access to clean water, sanitation facilities, and essential services [1, 4, 7, 8]. A further threat to health are extreme weather events. Besides the direct morbidity and mortality caused by these events, they can disrupt, damage, and destroy infrastructure and societal systems: infrastructure for transport, communications, electricity, water supply, and sanitation systems; agricultural systems and crops, livestock, and food supplies; households and community buildings; or economic activities [1, 8-10]. This has been shown to lead to lost livelihoods, billion-dollar economic losses, poor sanitation and hygiene, food and water insecurity, displacement, and mental and physiological stress [1, 8-10].

**Box 1.** Examples of expected impacts on natural and human systems by the end of the century at a global mean temperature rise of 1.5 degrees Celsius compared to the pre-industrial average [4]

| | |
|---|---|
| **Water resources** | The quantity and quality of available fresh water will decrease. River flooding will increase.<br>*In context:* 1.3 billion people will be exposed to water scarcity; chronic water scarcity for populations living in river basins; higher temperatures over agricultural land will strain groundwater supplies. |
| **Land ecosystems** | Plant and animal ecosystem ranges and phenology may change. Extinction risks will increase. Coastal systems (e.g. mangroves, coral reefs) shrink or die off.<br>*In context:* Plant-insect pollination cycles are uncoupled; 8% of plant species, 4% of animals, and 6% of insects lose >50% of their habitat ranges; frequency of forest fires could increase by nearly 40% globally. |
| **Ocean ecosystems** | Coastal systems (e.g. coral reefs) shrink or die off. Marine food systems are disturbed.<br>*In context:* Coastal protection from e.g. mangroves is reduced; coastal tourism slows. |
| **Sea level rise** | Sea levels will continue to rise globally. Coastal flooding will increase.<br>*In context*: An additional 31-69 million people will be exposed to coastal flooding; coastal flood damages will cost 0.3-5% of global gross domestic product per year; freshwater can become salinated. |
| **Food systems** | Crops no longer suited to current growing regions. Crop yields and food production are reduced in some regions, increase in others. Livestock and fishery productivity will fall.<br>*In context:* Nutrient content of food declines; crop yields from wheat, rice, and maize fall by 6%, 3.2%, and 7.4% for each degree Celsius increase in temperature; livestock numbers decline by 7-10%; marine fisheries will catch 3 million metric tons less fish for each degree of warming. |
| **Urban areas** | Urban areas exposed to extreme heat, greater precipitation, and sea level rise.<br>*In context:* Heat stress in twice as many megacities like Lagos, Nigeria will expose an additional 350 million people to deadly heat. |
| **Economies** | Tourism destination popularity and viability changes. Heating and cooling will increase energy demands. Sea transport increases.<br>*In context:* Of 900 coastal resorts in 19 Caribbean countries, 29% projected to be completely inundated by a sea level rise of 1 meter, and 49-60% vulnerable to coastal erosion; ice-free Arctic waters extends the shipping season. |

In addition, extreme weather events can reduce access to the health system and health services, destroy health system buildings and infrastructure, interrupt supply chains, and cause the loss or diversion of human, economic and physical resources [8, 11]. All these impacts can indirectly affect health, creating and exacerbating health needs in an affected population. For example, extreme weather events have been associated with increases in infectious diseases from overcrowded shelters after displacement, and water and scarce sanitation facilities [12]. However, despite their potential to affect health, the difficulty in establishing a causal relationship between an event and health outcomes means the scope and burden of indirect health effects after extreme weather events remains unclear [9]. Potentially, the true burden of health needs following extreme weather events has been largely underestimated [9].

The impacts on health from climate change and extreme weather events are unequally distributed to the vulnerable. Social, environmental, and economic factors like poverty, access to health services, and education all drive vulnerability. The World Health Organization (WHO) has estimated that climate change will cause an additional 250 000 deaths from heat exposure, diarrhea, malaria, and undernutrition each year between 2030 and 2050 [13]. Vulnerable groups like the elderly and children are expected to bear the brunt of these deaths, with an additional 38 000 deaths among elderly people from heat exposure and 95 000 deaths among children from undernutrition. Out of the approximate 48 000 annual deaths from diarrheal disease, 44 500 are projected to occur in low- and middle-income countries in south Asia and Sub-Saharan Africa. People living in poverty and socially marginalized groups are more likely to be exposed to extreme weather events, have inadequate access to essential services like healthcare, or have fewer resources to cope [8, 10, 14]. Within the health system, a high level of health needs, a low capacity to manage an extreme event, and limited resources can all make the system more vulnerable to extreme weather events and less able to cope in response [15]. If the vulnerability of a society exposed to an extreme weather event means they are unable to cope, the event can become a disaster.

### 2.1.2 Implications for the health system

Climate change is endangering health now and will in the future [16]. It is challenging health system performance and undermining progress towards goals like universal health coverage, when events like extreme weather events can test a system's ability to provide quality, accessible essential health services to all people without financial hardship [17]. Health systems may need to prioritize services, functions, and resources based on the expected health needs of the population when an extreme weather event occurs [15], a challenge that can be more difficult for low-resource systems [15]. Knowledge about expected demands on the system has been called for to help systems adapt and change, for example to help manage increased demands for ambulance services during extreme heat, or to plan how to divert resources during small-scale infectious disease outbreaks that can follow floods [18, 19]. Generating knowledge on the expected health risks and needs of climate change can help inform health system adaptation to climate change [20]. In addition, the literature has discussed how responsiveness to a diverse range of health needs is key to enhancing trust and utilization of services in the health system during times of crisis, and ultimately, improving health outcomes [21-23].

## 2.2 THE RELEVANCE OF FLOODS

Floods are the most common extreme weather event. Floods affect more people globally each year than any other kind of extreme event, the majority of whom live in Asia [24]. Between 1995 and 2015, 2.3 billion people were affected [25], and over 23 million people in 2018 [26]. Generally defined, floods refer to water that is covering an area where it is not usually found. However, definitions for floods are not uniform and can be a mix of frequency, speed, depth, impact, location, or length of time [27]. The subjectivity of definitions has been an issue for scientific research where it can preclude comparisons between events [27] and in the perception of risk by populations who have been or are potentially exposed to floods [28].

There are a variety of causes for flooding, such as dam breaks and tidal waves. In this thesis, the focus is on floods caused by heavy precipitation which can result in flash floods and inundation floods. Flash floods are often smaller in scale than inundation floods and shorter in duration but associated with severe damage because of the rapidity of onset. Inundation floods can cover vast areas, as seen along river floodplains, can last for weeks to months, and often have a slower onset than flash floods [27]. Climate change is expected to cause more frequent and extreme precipitation and longer monsoon seasons, particularly in tropical regions such as Southeast Asia. As a result, floods are expected to become more frequent and more extreme over time [5]. The potential for exposure to floods is high worldwide, with more than one billion people in 155 countries living in areas potentially exposed to floods [29].

As with extreme weather events in general, floods can affect health directly and indirectly through their impact on society. Earlier research on the health effects of floods shows direct effects from contact with flood waters as drowning, minor injuries, and water-borne infectious diseases like leptospirosis [30-32]. Floods have been shown to destroy crops and livestock, leading to higher food prices and food shortages [30, 33, 34], cause economic losses, lost livelihoods, and unemployment [10, 24], and damage housing, local buildings, and infrastructure [9, 10, 27]. These impacts can indirectly affect health through food insecurity, displacement and overcrowded shelters, contaminated drinking water, increased stress, and greater exposure to vectors. Observed health outcomes include malnutrition, infectious diarrhea, malaria and other vector-borne diseases, cardiovascular events, worsened chronic illnesses, and poor mental health [27, 30-32].

Not all floods are extreme and the impact of a flood depends on how frequent and severe it is [35, 36]. Expected seasonal inundation flooding that occurs in floodplains along rivers can be beneficial to agriculture and aquaculture and their associated livelihoods [37]. But regular or repeated flooding can still be harmful, particularly in low- and middle-income countries that have limited resources. To date, the research on the health outcomes of repeated exposure to floods has focused mostly on mental health outcomes, some of which have shown a higher risk of poor mental health [38, 39]. Yet repeated events have been shown to cause damage and wear down economic and development resources within the population and health systems, increasing their vulnerability and leading to an accumulation of risk to more severe events [24, 40]. Smaller-scale, repeated events may also contribute more to morbidity than more extreme events, as has been seen with small-scale floods and extreme temperatures [41, 42]. For instance, a few studies have shown a link between malnutrition in children after floods [33] and experiences of continued exposure to risk factors for infectious disease and chronic illnesses, such as sewage and mold [43]. At the same time, repeated exposure to floods can generate knowledge about how to cope with and respond to floods, possibly creating adaptive capacity to future events [44, 45]. They also provide an opportunity to study the effects of floods on health and health systems because they are predictable.

## 2.3 HEALTH SYSTEMS AS SYSTEMS FOR HEALTH

The ultimate goal of a health system – "all people, organizations or actions whose primary intent is to promote, maintain, or restore health" – is to improve health [46]. To do this, it must be able to provide health services to the population. In the WHO building blocks framework, the health service delivery building block's aim is to deliver safe, quality services to people who need them, when and where they are needed [46]. 'Services' generally refers to the types of care that are delivered, such as health protection, promotion, prevention, treatment, or management [47]. They are delivered at the primary, secondary, and tertiary levels, through public and private providers [46]. The organization and management of health services, such as designing service packages, interpreting policies, or deciding on the strategic direction of the system, is mostly performed at the meso (district and regional) and macro (national and global) levels [47].

Health service delivery is where the remaining five building blocks of the health system—medicines and technologies, information, governance, the health workforce, and financing—converge in order to provide health services (Figure 1) [48, 49]. This perspective highlights the importance of service delivery in achieving the desired goal of improved health, as part of a responsive and efficient system that protects against social and financial risks. If people should be the center of the health system [46], then health service delivery plays an important role as the main entry point to the system for the majority of the population.

The benefit of the health system dynamics framework [49] is that it illustrates the dynamics between the components of the system. Health systems are, by name and nature, complex and adaptive *systems* [50]. The interactions between diverse, interconnected components and their effects on one another are what create complex adaptive systems like health systems [51]. They are able to continually learn from experience, organize themselves, and adapt in response to interactions among their parts and with other systems [50, 52]. These changes and the way the system's components interact are complex, nonlinear, and not easily predicted. Importantly, health system behavior and structure is influenced by the context of the system, including its history, values and principles, networks of actors, and the trust and relationships between individuals, groups, and the population [50, 52, 53]. It is the sum of these relationships, dynamics, and components that create a functioning health system [50, 54].

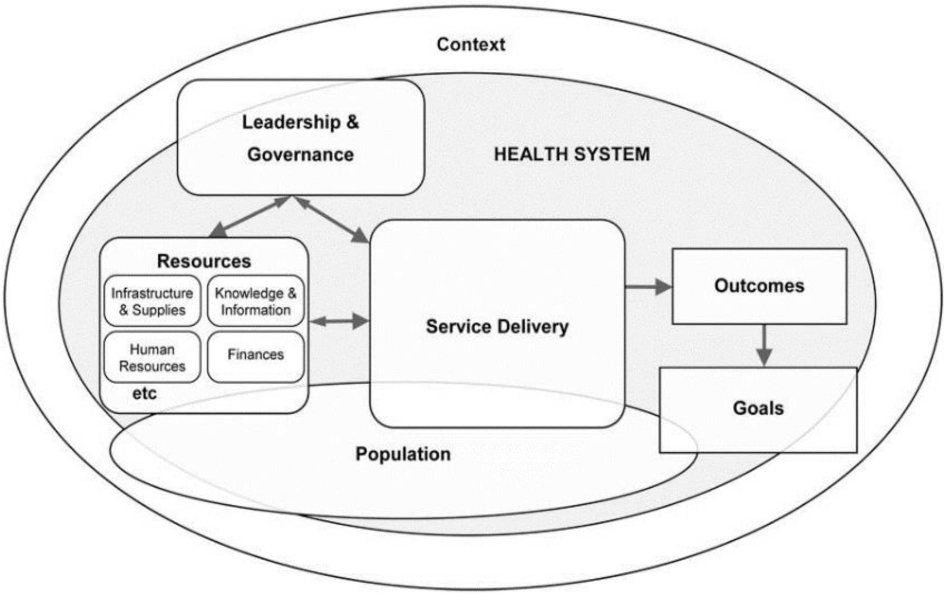


**Figure 1.** The health system dynamics framework [49]

## 2.4 THE ROLE OF HEALTH SYSTEMS IN PROTECTING HEALTH DURING FLOODS

Health systems play a key role in protecting health and minimizing the health consequences of extreme weather events like floods [55]. Floods can create health needs, the need for promotive to curative health services as perceived by an individual or recognized by a professional [56]. New health needs will emerge that are caused by the flood and its impact on society, as described earlier (e.g. leptospirosis). Concurrently, people will continue to experience routine health needs that persist regardless of flooding (e.g. routine vaccinations, chronic disease management) and may form the highest burden for care [57, 58]. In this thesis, we have used antenatal and childbirth care to proximally represent typical routine and new health needs, although neither pregnancy, childbirth, nor emergency complications are causally linked to floods. Maternal health services – essential to maintaining health and likely to be affected by shocks [59] – can be seen as an indicator of a health system's ability to cover both new and routine health needs during floods. Pregnancy is representative of routine health needs that do not change because of floods but still require preventive and promotive care that can be planned in advance. Childbirth and complications are representative of new health needs that can emerge during floods, occur suddenly or unexpectedly, and require skilled management and emergency care [59, 60]. Previous research has also taken similar approaches when studying health system service provision during crises [60-62].

People need to be able to rely on the health system to provide the necessary preventive, promotive, and curative care and skilled management for their changing health needs during floods, from community-based care to primary and higher level care at health centers and hospitals [57, 63, 64]. However, how and why people interact with health services stems from multiple factors beyond the need for care, such as trust [53]. Trust in the health system has been acknowledged as more complicated than delivering competent services through positive interactions which might play a role in people's interactions with systems during emergencies, but this remains unclear [65]. A recent literature review found that trust in the health system appears more fragile when services are distributed inequitably and inefficiently or the system is unable to address the population's range of health needs [66].

Floods can shock health systems by affecting healthcare facilities and other infrastructure, damaging or diverting resources, and interrupting health service provision [11, 27]. With an increase in the frequency of extreme weather events, health systems may experience multiple or repeated shocks [67]. Shocks are defined here as events that can decrease the availability of system resources and/or increase the demand for health services, using the definition from Mladovsky et al. (2013) [68]. This perspective views shocks through their impact on demand and resources, as significant, often sudden external events. Shocks have been more widely described as sudden or extreme external phenomena that challenge the system, such as storms or pandemics, although no communal definition exists yet [69]. There is also a growing body of literature around the concept of stresses, or chronic, internal strains on system functioning, like persistent underfunding [69]. In this thesis, floods are conceptualized as shocks.

During shocks, populations may no longer have access to functioning health services to receive care for new or routine health needs [58, 63, 70]. When health services are disrupted, the health needs of the population are unmet, and health service delivery cannot achieve its aim. This can cause additional harm, as seen during the West Africa Ebola outbreak [71-73], when the epidemic caused a major reduction in health service delivery, leading to significant morbidity and mortality. Health systems should be able to manage and change if needed when they are exposed to a shock, so that they are able to continue delivering health services. In other words, they should be resilient.

## 2.5 HEALTH SYSTEMS RESILIENCE

### 2.5.1 Health systems resilience as a concept

Resilience has been generally recognized as the ability of a system to absorb a shock while still retaining its fundamental functions and characteristics [74]. It rose to prominence in multiple disciplines from psychology to economics and disaster risk reduction after its initial development in the field of ecology [75, 76]. From there, a more dynamic interpretation of resilience arose that incorporated adaptation and transformation [77]. Including the capacity to adapt and transform moved the concept of resilience away from the idea that systems can and should maintain their original state, since the original state may be a vulnerable one [78, 79]. Instead, systems can adapt by adjusting or changing to mitigate future shocks but still retain their basic structure, or they can transform by fundamentally changing their structure to eliminate a risk altogether [77, 80]. Resilience can then be an emergent property of complex adaptive systems like health systems, as they adjust in response to shocks and new structures and behaviors appear [81, 82].

The concept of resilience was applied to health systems during the 2014-2016 Ebola outbreak in West Africa and swiftly gained popularity. The systems in Guinea, Liberia, and Sierra Leone were viewed as vulnerable and resilience was taken up as a way to strengthen health systems for acute shocks in the future, including extreme weather events [22, 83, 84]. Since then, the focus has broadened to include the idea of 'everyday resilience', or resilience to stresses that continually challenge the system or its ability to adapt [82]. Despite the quick adoption of resilience in the global health and health systems literature [69, 85], there remains little consensus on what it actually means or how it is interpreted and conceptualized [69, 83]. Perhaps as a result of its newness, the literature to date has focused on concepts and principles with fewer studies on how resilience is generated or strengthened in health systems in reality, a crucial step to developing strategies to promote resilience [82, 86].

### 2.5.2 Capacity for resilience and the Dimensions of Resilience Governance framework

There is recognition that understanding resilience as an ability rather than an outcome is in line with the idea of health systems as dynamic systems that evolve, change, and adapt [80]. With this has come a focus on the capacities that sustain health systems resilience [84, 87-89]. What behaviors, processes, and structures are needed to keep health systems functional and able to deliver services when faced with a shock and let resilience emerge? The literature has pointed to a variety of capacities, from cognitive and behavioral capacities for problem solving and identifying possible actions, to organizational resilience factors such as leadership capacity [82, 84, 90].

In a conceptual framework by Blanchet et al. (2017) [88], the authors propose that a system's macro-level capacities to absorb, adapt, or transform when exposed to a shock are derived from the system's ability to manage four other capacities: knowledge, uncertainty, interdependence, and legitimacy (Figure 2).

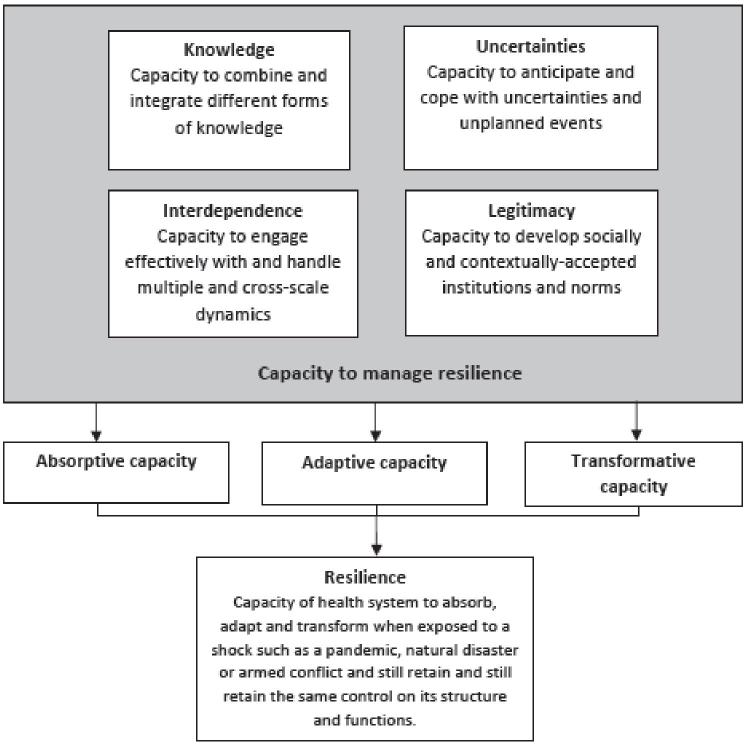


**Figure 2.** The Dimensions of Resilience Governance framework [88]

If a system can integrate and process knowledge about their resources, risks, and health needs, anticipate and cope with uncertainty, manage interactions with other systems beyond the health system, and create a legitimate system that provides socially acceptable and contextually appropriate care, then it is capable of absorbing, adapting, or transforming. The framework can therefore be used to explore the characteristics of resilient health systems and understand what creates the capacity to manage resilience [69, 88].

### 2.5.3 Governance and context

The concept of resilience has been criticised for neglecting to consider context [79, 80, 83, 91, 92]. The definitions and thinking around health systems resilience have drawn heavily from ecology, which does not account for the social, political, and economic reality of human systems [69, 83, 92]. Haldane (2017) and Martineau (2016) argue that health systems resilience needs to be reframed as more than a single state measured through health outcomes and acknowledge "that each health system is unique, influenced by context and circumstances" [83] and shaped by factors, relationships, and actions beyond the system [93]. Qualitative interpretations are needed to make sense of these factors and analyze resilience in a given context [80, 94].

As dynamic systems, health systems are also shaped by the variety of interactions and decisions that actors in the system are able or willing to take [49]. Key to the Dimensions of Resilience Governance framework is the concept of governance to manage resilience, defined by Blanchet et al. as "the implicit and explicit rules and institutions that shape power, relationships between actors, and the actions of these actors" [88]. These interactions and rules will depend on the people, their agency, and the power structures in a health system's context [67, 93]. In line with the capacity thinking described above, governance is then useful for understanding what it is a system does that gives it the capacity to absorb, adapt, or transform to different kinds of shocks, rather than what the system has [80].

Health systems resilience has similarly been criticized for ignoring issues of power and returning systems to a state of vulnerability without addressing the underlying causes that created the vulnerability in the first place [79, 95]. Understanding how governance and issues of power influence resilience capacity will depend on the perspective it is being viewed from, which has so far not been widely explored in health systems resilience literature [86]. This includes the perspective of the population as both the beneficiaries of health services and co-producers of health [96, 97]. The actions of the population when they are exposed to extreme weather events—how they care for their health and their own capacity and resources to manage a shock—will have implications for the health system [67, 93, 98, 99].

# 3 THESIS RATIONALE

Extreme weather events present a growing threat to human health and can challenge the ability of health systems to function and deliver health services. As the trend for global warming continues with climate change, populations and systems may be faced with shocks like floods, and health systems will need to be able to manage the changing health needs after such events. If health systems should be able to continue to deliver health services for new and routine needs when shocked, it is necessary to know what health needs are expected. Yet to date, there is limited information on how floods can affect human health or how health systems cope with repeated shocks [67]. Although research on how floods affect some aspects of health exists, research on the long-term changes in morbidity and from low-income settings is lacking [9, 27, 100]. The relationship between floods and direct or indirect health outcomes has not been well-quantified [31, 101]. Different extreme weather events are likely to affect health in different ways, yet floods are often conflated with storms (hurricanes, typhoons, and cyclones) in the literature on health effects, when storms have the additional hazard of strong winds. In addition, the impact of seasonal floods on health may be different than the impact of less frequent floods, but this is rarely distinguished [32]. Assessing the impact of floods on health can help identify the expected health needs after future shocks (Study I, II), and build understanding about what health systems should be resilient to.

The concept of resilience has been co-opted as a way to strengthen health systems for shocks [22, 83, 84], but the concept is in its infancy and few studies have addressed what strategies or processes can foster resilience in health systems. If health systems are expected to be resilient, there must first be a better understanding of how resilience is generated or strengthened in health systems in reality [82, 86]. Studying how existing health systems manage when exposed to a shock is one way to build understanding on what resilience actually entails. Three studies in this thesis are set in Cambodia, a country that is regularly exposed to seasonal flooding in the Mekong River flood plains and occasional floods in the coastal regions, and highly vulnerable to climate change [102]. Cambodia then provides an opportunity to not only study the effects of repeated flooding on health, but also to examine how the health system manages health needs during floods and assess what capacities for resilience currently exist. Examining the capacity of the health system (Study III, IV) to manage health needs during floods (in this case, using pregnancy and childbirth as proxies for new and routine health needs) can then contribute to a better understanding of what strategies might help build resilience to extreme weather event shocks like floods in the future.

# 4 AIM AND OBJECTIVES

With a view to identify capacities that foster health systems resilience to extreme weather events, the overall aim of the thesis is to assess the effects of flooding on health and the capacity of the public health system to manage health needs during floods in Cambodia.

The specific aims were:

- To identify the changes in health outcomes of affected people that occur after flood and storm disasters at a global level. (Study I)
- To quantify the short- and long-term effect of seasonal and occasional floods on health problems seen at public healthcare facilities in two provinces in Cambodia. (Study II)
- To understand if and how the public health system's capacity to absorb, adapt, or transform is linked to the community's own capacity to absorb, adapt, or transform when managing antenatal and childbirth care needs during seasonal and occasional floods in Cambodia. (Study III)
- To generate knowledge on the influences on public antenatal and childbirth health service delivery in Cambodia during seasonal and occasional floods that are related to the system's capacity to absorb, adapt, or transform. (Study IV)

# 5 METHODS

## 5.1 SCOPE OF THE THESIS

When studying resilience, the starting point is to identify the resilience *of what* (the system and context) and *to what* (the shock) [81]. This thesis studies the resilience *of* public sector antenatal and childbirth health services in Cambodia *to* seasonal and occasional floods. The four studies address the context, the shock, and the system's capacity to deal with the shock, as generally outlined in (Figure 3). Study I focuses on the shock by identifying changes in health after exposure, in this case to isolate the health effects of flood disasters as compared to storm disasters. Using the changes in health identified after floods during Study I, Study II assesses their effect on health in a specific health system context that is exposed to repeated flood shocks. The study quantified the effect of seasonal and occasional floods on the health outcomes identified in Study I in two provinces in Cambodia. Studies III and IV examine the capacity of the health system in the Cambodian context to manage new and routine health needs when exposed to repeated flood shocks. This was done by understanding influences on public sector antenatal and childbirth health services when they are exposed to seasonal and occasional floods, and how the community's capacity to manage antenatal and birth care is linked to the public sector's capacity. Studies III and IV expand on the framework's original term 'adaptive capacity' by including absorptive and transformative capacities, under the assumption that resilience emerges from all three capacities [80].

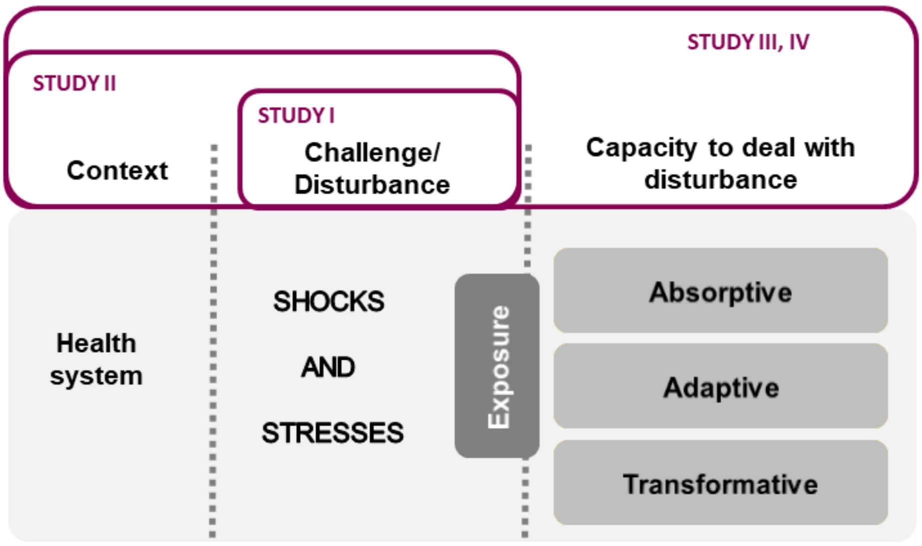


**Figure 3.** The four studies as they related to the adapted WHO conceptual framework for resilience [15]

## 5.2 OVERVIEW OF THE STUDIES

The thesis uses a mix of approaches, outlined in Table 1. Primary data was collected for Studies III and IV. Secondary data was used for Studies I and II.

**Table 1.** Overview of thesis methods

| | **Study I** | **Study II** | **Study III** | **Study IV** |
|---|---|---|---|---|
| **Study type** | Systematic review | Time series | Qualitative | Qualitative |
| **Data sources** | Six scientific literature databases | Monthly national health information system reports; remote sensing flood maps | Focus group discussions (n=8), semi-structured interviews (n=17) | Semi-structured interviews (n=23) |
| **Period** | 1980 – 2015 | 2008 – 2013 | 2018 | 2018 |
| **Setting** | Any country that experienced a flood or storm disaster | Eleven flood-exposed districts Prey Veng and Kampot provinces, Cambodia | Two flood-exposed districts Prey Veng and Kampot provinces, Cambodia | Two flood-exposed districts Prey Veng and Kampot provinces, Cambodia |
| **Study population** | Epidemiologic articles on health after flood or storm disasters (n = 113) | All visits to public health facilities for six health problems, extent of flood water in each district | Community members with experience managing antenatal or birth care during floods | Public sector staff with experience providing or managing antenatal or birth care services during floods |
| **Main analysis** | Narrative synthesis | Poisson regression models | Thematic analysis | Thematic analysis |

## 5.3 STUDY SETTING

Studies II, III and IV were conducted in the Kingdom of Cambodia, a country of approximately 15 million people in Southeast Asia [103]. Cambodia experienced conflict, genocide, and civil war from the 1960s to 1990s that destroyed much of the social and economic infrastructure. The country has developed substantially since the 1990s and became a lower middle income country in 2015 [104] (Table 2). The national poverty rate fell from 53.2% of households in 2004 to 20.5% in 2011 [105].

Cambodia has been undergoing a transition to a double burden of disease. In 2017, the most common causes of years of life lost from premature death were lower respiratory infections, neonatal disorders, stroke, cirrhosis, and road injuries [106]. An earlier estimate of diabetes prevalence ranged from 5 to 11% [107], and in 2012, it was estimated that more than half of people with diabetes remain untreated [108]. Risk factors for heart failure, like hypertension and smoking, remain highly prevalent [109]. At the same time, dengue and malaria are endemic in Cambodia, although malaria incidence has been reduced [110, 111]. Access to safe drinking water and sanitation facilities, both risk factors for diarrheal disease, remain limited in rural areas: 27% of the rural population in 2017 used surface water or unimproved water supplies, and 41% used no sanitation facilities [112].

**Table 2.** Country and health indicators for Cambodia

| Indicator | 2000 | 2014 | 2017 | Source |
|---|---|---|---|---|
| Population growth (annual %) | 2.2 | | 1.5 | [104] |
| Life expectancy at birth (years) | 58.4 | | 69.3 | [104] |
| Maternal mortality ratio per 100 000 live births | 488 | | 160 | [113] |
| Gross National Income per capita (in US dollars) | 300 | | 1 240 | [104] |
| Rural population (% of total population) | 81.4 | | 77.0 | [113] |
| Adult literacy rate (% of people aged 15 and above) | 67.3[a] | 78.0 | | [104] |
| Access to improved drinking water source during rainy season (% households)[b] | 43.1 | 83.3 | | [114, 115] |
| Households (%) possessing a boat with or without a motor | 8.9 | 9.4 | | [114, 115] |
| Out-of-pocket health expenditure per capita (in US dollars) | 13.6 | | 49.6 | [113] |
| Density of medical doctors per 10 000 population | 1.6 | 1.6 | | [113] |
| Density of nurses and midwives per 10 000 population | 9.1 | 9.5 | | [113] |
| First treatment for illness or injury sought in private sector (%) | 32.9 | 67.1 | | [114, 115] |
| Sought antenatal care in public sector for most recent live birth (%) | -- | 89.8 | | [114, 115] |
| Attended antenatal care at least once for most recent live birth (%) | 44.8 | 95.5 | | [114, 115] |
| Delivered at a public or private health facility for most recent live birth (%) | 9.9 | 83.1 | | [114, 115] |

[a] for 1998; [b] Piped water, public tap, tube well or borehole, protected well or spring, rainwater, or bottled water

### 5.3.1 The Cambodian health system

The Cambodian health system is pluralistic, with a large, widely unregulated private for-profit and not-for-profit sector that provides the majority of outpatient curative care [116, 117]. In rural areas in 2014, half of all providers were unlicensed and non-medical, such as drug vendors, traditional or spiritual healers [*kru khmer*], and traditional birth attendants [118]. In the same areas, 29% were private licensed health workers. This thesis focuses only on the public sector of the health system, because of the difficulty in accessing and collecting consistent, reliable data from providers and facilities in the private sector. The Ministry of Health, institutionalized as the government health ministry in 1997, is responsible for all aspects of public sector health care. The national and provincial levels oversee and support service delivery at the lower levels (Figure 4). Operational district health departments are responsible for most service delivery, although the districts remain highly accountable to higher levels of the health system and have limited decision-making power [116].

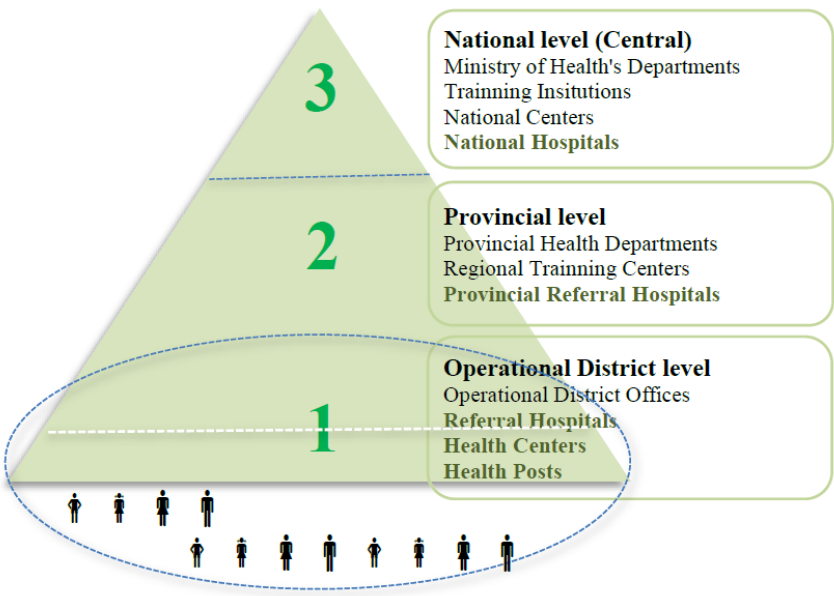


**Figure 4.** The three levels of the public health system in Cambodia taken from [119]

Health centers are the primary healthcare structure and were designed to be the first point on the patient pathway [116]. They provide a minimum package of preventive and curative primary care activities, including antenatal care and services for normal deliveries, and provide outreach once a month per village [120]. District, provincial, and national referral hospitals provide a progressively higher levels of complementary treatment activities [121]. District and provincial hospitals provide advanced antenatal care for high-risk patients and care for normal deliveries, obstetric emergencies, and complicated deliveries. Antenatal and childbirth services are also available at private clinics and hospitals. Monthly data on health service utilization at public health facilities is collected and monitored by the Department of Planning and Health Information and the Ministry of Health through the web-based Health Management Information System (HMIS) [122]. Approximately one-third of private facilities have reported data to HMIS since 2017, although reporting is sporadic and not from all provinces.

However, care seeking often does not follow the intended pathway due to a variety of challenges in the public sector. There is a lack of trust in perceived low-quality services, an inadequate number and mix in the health workforce, a lack of supplies and medicines, and limited competency of health workers [116, 119]. Still, uptake of maternal health services is high in the public sector, with nearly 90% of antenatal visits performed at public health centers and deliveries at public hospitals (Table 2). The government has been investing widely in maternal health services to strengthen emergency obstetric care, improve skilled birth attendance rates, change health seeking behavior, and remove barriers to care. This included policies to promote facility-based antenatal and childbirth care and prevent the use of traditional birth attendants [123-125].

The health system has also been prioritizing emergency preparedness and response capacities over the last decade. The National Committee for Disaster Management (NCDM) is the hub for disaster management, including weather events and emergencies. NCDM brings together other government ministries and development partners with the Humanitarian Response Forum for preparation and response activities. NCDM committees extend from the national down to commune and village level. The Ministry of Health has identified the potential risks to health from climate change and the continued limited capacity of the public sector to deal with public health emergencies, disaster preparedness, and disaster response as key priorities. They have developed several strategic plans to reduce morbidity and mortality and enhance preparedness and response from extreme weather events, including floods [119, 126, 127]. This has included developing preparedness and response plans for disasters and emergencies at all levels of the health system and for all types of healthcare facilities.

### 5.3.2 Study areas

Studies II, III, and IV were set in Prey Veng and Kampot provinces in southern Cambodia along the Vietnam border (Figure 5). Prey Veng is bordered by the Mekong River and is in its flood plains. The province experiences seasonal inundation floods during the rainy season (June to November) when excessive rainfall across the region causes the Mekong to overflow its banks. The floods can last for several months with depths up to three meters [37, 128]. Floods in Prey Veng were defined by the local population as either ‘small water’ [ទឹកតូច] that flooded rice fields, small roads, and land around villages but did not affect national roads, and ‘big water’ [ទឹកតូច] that flooded into villages and covered national roads, making boats a necessity for travel.


Kampot is a coastal, mountainous province at the edge of the Mekong Delta that sometimes experiences shorter flash floods from rainfall and occasional inundation floods [37, 128]. The local population defined floods in different ways among themselves in Kampot. They generally defined floods as when water damaged rice fields, entered villages, or covered roads. Both provinces experienced flood disasters in 2000, 2011, and 2013, with Prey Veng more severely affected [129-131].

**Figure 5.** Map of Cambodia with the two study provinces circled (map by UN Office for the Coordination of Humanitarian Affairs (OCHA) licensed under CC BY 3.0, circles added)

The flood terminology described above was initially developed for the project during field work at the end of the rainy season in 2017. The terms used for the studies are based on conversations with the local population in the two provinces during the field work. They were later deepened and double-checked when recruiting study sites and collecting data for Studies III and IV.

Both provinces are predominantly Buddhist and of Khmer ethnicity with agriculture as the primary occupation [132]. Prey Veng has a population of approximately one million spread over twelve districts and Kampot approximately 600 000 over four districts [103] (Table 3). Studies III and IV were set in one district in each province. There were eight health centers in the Prey Veng district, sixteen health centers in the Kampot district, and one referral hospital in each. The districts are equivalent to the administrative communes. The communes link the districts to other sectors, social services, and municipal representative committees, such as the commune disaster management committees. Elected commune chiefs and commune council members oversee villages, led by village chiefs who are responsible for the well-being and administration of the villages.

**Table 3**: Indicators for the two study provinces in 2014 [114]

| **Indicator** | **Prey Veng** | **Kampot** |
|---|---|---|
| Women and girls aged 6 years and older who had no completed education (%) | 22.1 | 15.9 |
| Women with at least one problem accessing healthcare (%)[a] | 48.0 | 85.1 |
| Received antenatal care from a skilled provider for most recent live birth (%) | 99.0 | 93.9 |
| Delivered at a public sector health facility for most recent live birth (%) | 69.4 | 72.2 |
| Delivered at home for most recent live birth (%) | 10.0 | 18.2 |

[a] Getting permission to go for treatment; getting money for treatment; distance to health facility; not wanting to go alone

## 5.4 STUDY DESIGN AND METHODS

### 5.4.1 Study I

The study was designed as a systematic review to identify the changes in health outcomes of affected people that occur after flood and storm disasters at a global level. We chose to study disasters to capture the widest range of possible outcomes after extreme weather events. We opted to use the Centre for Research on the Epidemiology of Disasters (CRED) definition of a disaster of either 10 people reported killed, 100 people affected, or a state of a declaration of emergency because it covers different disaster severities [133]. The type of research that can be conducted on disasters and health is limited, for practical, logistical, and ethical reasons [134]. Research on the relationship between disasters and health outcomes is often observational with a variety of designs, and populations, measures of exposure, and outcomes differ. Narrative synthesis analysis was used to capture the wide variety of research on disasters and health outcomes. The review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines [135]. The study protocol was registered in the PROSPERO International Register of Systematic Reviews [136].

We searched six scientific literature databases in 2015 (Appendix 1) for epidemiologic studies on human morbidity and mortality following flood or storm disasters. After screening by two authors, articles published in English between 1980 and 2015 were included if they had a clear outcome and met the CRED definition of a disaster [133]. We excluded studies on interventions, risk factors only, disaster response populations, mental health, and outcomes greater than two years after the disaster.

Data was extracted on study design, data sources and collection, disaster type and location, time from disaster to the outcome (<2 weeks, 2-4 weeks, >4 weeks post-disaster), study population, comparison groups (if any), and health outcome effect estimates or descriptive results. Health outcomes were grouped into i) injuries and poisonings, ii) infectious and parasitic diseases, iii) noncommunicable diseases and chronic illnesses, iv) contact with health services (defined here as contact for a factor influencing health status such as need for dialysis, to receive services for a current health condition, or to receive prophylactic care), and v) other signs and symptoms, according to the International Classification of Diseases and Related Health Problems 10th Revision [137]. Noncommunicable diseases, chronic illnesses, and contact with health services were included as outcomes to capture the indirect effects of disasters on health that are associated with the disaster's impact on society, such as displacement, that can cause stress, exacerbate existing conditions, or prevent access to healthcare [58].

We used a narrative synthesis to analyse the data because of the considerable heterogeneity in study designs, populations, and outcomes, following the UK's Economic and Social Research Council's guidance [138]. First, we did a preliminary synthesis of the data to observe initial differences and patterns, done by tabulating the data across health outcome group and by type of disaster. Then, we explored the groups further by differentiating by timing of the effect to highlight the possible relationship between timing of the outcome and the type of outcome and disaster. We also closely observed and described opposing results in the same outcome groups.

Throughout the first two steps, we checked the robustness of the synthesis by relating the quality of the studies to the trustworthiness of the synthesis. We assumed a priori that the studies would be at risk for bias (e.g. selection and publication bias) because of their heterogeneity and the challenges to doing research in disasters. However, we chose to still include studies with bias risk because of the descriptive approach of narrative synthesis and to discuss the limitations of including them. We emphasized comparative articles (60 out of 113 included articles) as key articles of higher quality. We considered surveillance system studies as key comparative articles because they use statistically defined thresholds to generate alerts for certain diseases. We also included articles that used surveillance systems that generate alerts from single cases of diseases with epidemic potential. We recognized that results from these studies that reported no alerts were likely more valid than results with alerts because of the risk for false positives [139]. We judged studies without a control or comparison to be very low quality and summarized their data in table format, based on our assessment that the level of quality was too low to include them in the final synthesis and draw reliable conclusions. We rated the quality of the key articles as good, fair, or poor, following the National Heart, Lung, and Blood Institute's approach to assessing quality in observational study designs [140].

### 5.4.2 Study II

The study is a time series analysis [141] to quantify the short- and long-term effect of seasonal and occasional floods on health problems seen at public healthcare facilities in two provinces in Cambodia. Time series are often used to investigate whether variation in an outcome can be explained by changes in exposure over time. Based on the findings of Study I, we hypothesized that there would be an association between the extent of flood water in the eleven districts in the provinces and the number of visits to facilities for six health problems: diarrhea, acute respiratory infections, skin infections, injuries, vector-born disease (malaria or dengue fever), and noncommunicable diseases (heart disease or diabetes).

Our exposure was the extent of flood water each month in the eleven districts. Flood water data was obtained from the National Aeronautics and Space Administration (NASA) Moderate Resolution Imaging Spectroradiometer (MODIS) global flood mapping project, which produces daily water maps of the earth's surface and has performed well in detecting flood events [142, 143]. Composite images were created of the extent of flood water for each month between January 2008 and December 2013 and converted into the number of square kilometres of flood water per month in the eleven districts.

The outcomes were visits to public facilities for diarrhea, acute respiratory infections, skin infections, injuries, vector-born disease, and noncommunicable diseases. Monthly inpatient and outpatient visit counts per district for the six health problems were obtained from Cambodia's national HMIS [144] (Box 2). Counts were imputed for 29 months that had extreme outlier counts, by averaging the counts from the months before and after. We also obtained the total number of outpatient consultations, facility deliveries, and home deliveries per month to use as proxies for access to health centers and hospitals  during floods.

**Box 2.** Overview of Cambodia's Health Management Information System [116]

The HMIS was developed in 1993 to collect routine health data from public health facilities. It was scaled up to all provinces in 1994. A web-based version was launched in 2011, based on the District Health Information Software 2 health information platform [145]. Subsequent evaluations of the system have shown good to excellent internal consistency of the data and completeness of reporting [146, 147]. The data is used at the subnational level for performance reviews, technical working group meetings, and annual budgeting purposes.

The system covers public national, provincial, and district referral hospitals and health centers but does not systematically collect data from private facilities. Facilities tally counts for laboratory examinations, vaccinations, antenatal consultations, deliveries, family planning services, inpatient discharge diagnoses, and outpatient consultations from written registration logbooks for each month. The data is entered into a template in the online system. Health centers without access to the internet send their paper data to the operational district offices for entry. Cases that are referred between facilities are counted in the system at both facilities.

Poisson regression models with robust standard errors were chosen to analyze the count data [148]. Sixty-six models were constructed (one for each of the six health problem in each district), controlling for season (rainy or dry) and year. Three lag months were included in all the models except those for injuries, where we did not expect a delay between exposure to flooding and the health outcome. To check access to facilities, an additional thirty-three Poisson regression models controlling for season and year were built. Models with three lag months were used for the total number of consultations in each district and models without lag months for the number of deliveries. The results for all models are presented as the ratio of incidence rates for each health problem for an increase of ten square kilometers in flood water.

### 5.4.3 Study III

The study uses the qualitative methods of focus group discussions and semi-structured interviews to understand if and how the health system's capacity to absorb, adapt, or transform is linked to the community's own capacity to absorb, adapt, or transform when managing antenatal and childbirth care needs during seasonal and occasional floods. Antenatal and childbirth care were used as proxies to represent typical routine and new health needs. In Cambodia, maternal health services and pathways to care are well established, unlike services for other routine or new health needs, like dengue fever or noncommunicable diseases [149, 150]. Using antenatal and childbirth services allowed us to more easily identify participants with the experiences we were seeking, and structure the focus groups and interviews around concrete, well-known examples and experiences.

Using the findings from Study II, we focused in this study on community members as active contributors to the health system's capacity to manage health needs during floods. We chose a qualitative approach because we wanted to understand the capacity of the health system to deal with shocks in a specific setting. Using qualitative methods allowed us to focus on how and why community members in the Cambodian health system dealt with care during floods, and describe and interpret their experiences [151]. Thematic analysis was chosen because it allows patterns of meaning in the data to be identified and interpreted [152]. In this study and Study IV, we defined the terms: i) *absorb* as the resources and capacity to continue managing health needs using existing strategies and resources, ii) *adapt* as the resources and capacity that allows a system to make short-term changes to how it uses resources to manage health needs, and iii) *transform* as the resources and capacities that let a system fundamentally rearrange their function or structure in the long-term to avoid shocks. The term 'care' was used to capture different formal and informal types of care during pregnancy and birth, from self-care to community-based or facility-based care.

The study was conducted at the end of the rainy season in 2018 in eight villages in two districts that had experienced flooding that year (Figure 6). It was first introduced to the provincial and district health departments and health centers to confirm flooding. Flooding in the villages was confirmed through discussion with village leaders. We purposively selected adults living in the village to create a heterogeneous sample of gender- and age-based perspectives on managing pregnancy and birth care during floods. After enrolling health centers and villages, a list of potential participants was identified from the antenatal, birth, and vaccination logbooks at the health centers. Village chiefs and village health support group workers helped identify other potential participants who did not receive care at a facility. We conducted eight focus group discussions (FGDs) with women who were pregnant or gave birth during the most recent flood, or men whose partner met the same criteria (41 participants in total). The method was chosen to discover the shared knowledge and social commonalities around managing care for pregnancy and birth [151]. To triangulate the focus group discussion findings, seventeen semi-structured interviews [153] were conducted with village chiefs, village health support groups, traditional birth attendants, paternal or maternal grandmothers, and commune administrators for women's affairs. These participants were identified through discussion with village chiefs, health support group workers, and informal discussion with other villagers.

We developed topic guides (Appendix 3) for the focus groups and interviews based on the Dimensions of Resilience Governance framework [88]. The framework focuses on the capacity of health systems to manage resilience and suggests that a system's ability to successfully manage knowledge, interdependence, legitimacy, and uncertainty can enable the system to absorb, adapt, and transform when faced with a shock. The framework therefore provides a useful entry point to research the behaviors and strategies that create these capacities. For the topic guides, the theoretical dimensions were adapted into concrete questions about experiences managing antenatal and childbirth care during floods. The guides were adjusted and readjusted during two weeks of training and piloting and during data collection as relevant topics were raised, although the overall structure of the guides remained the same.

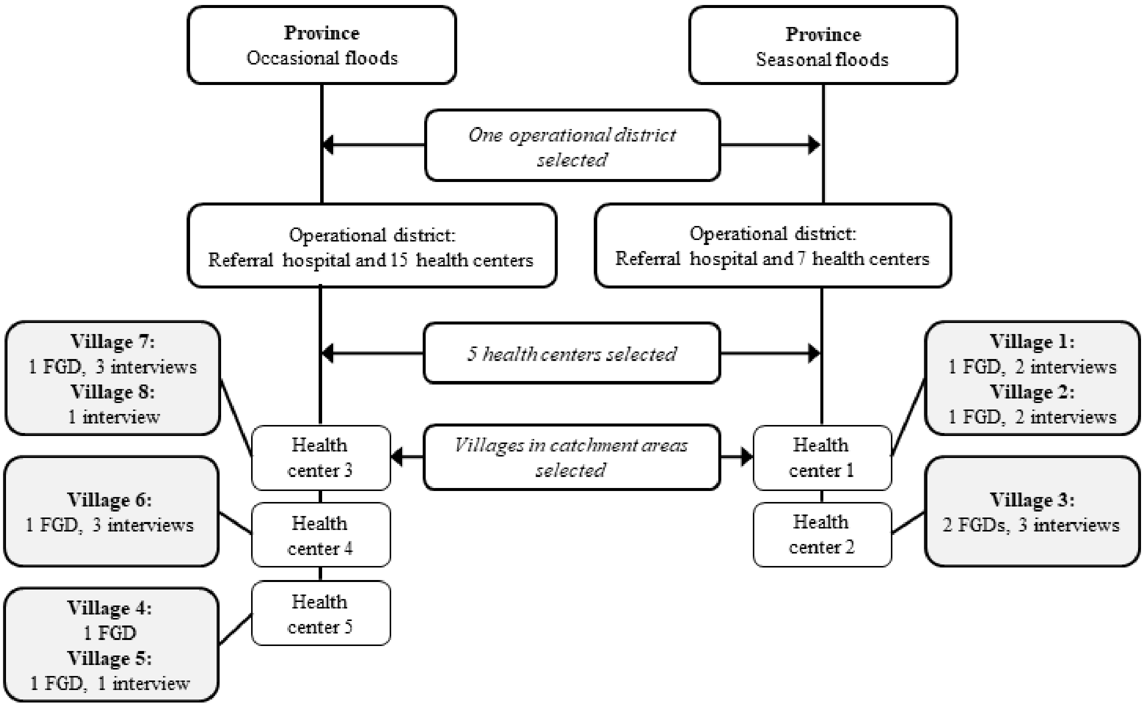


**Figure 6.** Site selection and formal data collected for each village in Study III

Two female data collectors conducted the focus groups and interviews in private, neutral spaces. One data collector was an older qualitative researcher with a background in medicine, and the other was a younger public health student with a midwifery background. The data collectors, a project coordinator, and I spent four weeks visiting the villages and health centers to get more acquainted with each village setting, build trust, and understand the daily management of health in the villages. I informally interviewed other community members with the project coordinator, seeking out perspectives we may not have captured in the formal discussions, such as mothers living in the poorest households, and deepening our understanding of floods and their definitions. The team met in private after each focus group and interview to discuss what was said, to assess how it fit into the larger picture that was being developed from the formal and informal discussions, and to identify any new topics that could be explored further. Descriptive and reflective notes about the data collection were written throughout. We used information power to guide the sample size [154], or the idea that if a sample holds a high degree of information, a smaller the number of participants will be needed. We determined a preliminary sample size of eight focus groups and fourteen interviews based on the study's broad aim and expected variation in the data across cases, plus the participant's expected specific information on the topic, quality of the dialogue, and use of a theory. We judged the final sample sizes for the studies as sufficient after adding three additional interviews.

All interviews and FGDs were transcribed verbatim into Khmer by the data collectors or trained transcribers from the National Institute of Public (NIPH) in Cambodia. A single translator translated the transcripts into English. The translator took part in the study training and piloting prior to data collection to ensure she was familiar with the concepts and terminology that would be used. Any questions she had about the content of the interviews or transcripts were discussed with me and the data collectors. We used a data-driven thematic approach, led by me and with regular input from the co-authors of the study. I first created a code list that reflected descriptions or ideas about managing care during floods in the data, then checked them across characteristics of the data, for example between antenatal care and childbirth care. The codes were regularly revised as the analysis progressed. After coding, I used the dimensions in the resilience framework to review the data for new ideas and explored the relationship between the codes. The subcategories and categories were then created from observed patterns of meaning in the data plus the theoretical understanding gained during the previous step. I identified a theme that brought together the meaning and association between the categories, and then the findings were mapped back onto the framework to show how they contributed to its capacities.

### 5.4.4 Study IV

This study was designed and conducted in conjunction with Study III to understand the health system's capacity to deal with shocks from the health service delivery perspective. It used the qualitative methods of semi-structured interviews to generate knowledge on the influences on public antenatal and childbirth health service delivery in Cambodia during seasonal and occasional floods that are related to the system's capacity to absorb, adapt, or transform.

The data was collected immediately following data collection for Study III at the end of the rainy season in 2018, following a similar process. The study was introduced to the provincial and district health departments, hospitals, and health centers at the same time as Study III. Five health centers, two district referral hospitals, and four district or provincial health departments (Figure 7) with recent flooding in their catchment or management areas were enrolled, plus the Ministry of Health. We purposively sought out and selected a heterogeneous sample of public healthcare providers or health department staff who had been working in their current role at the time of the recent floods. We expected them to have experience providing or managing antenatal or childbirth services during floods. The chiefs of the facilities identified eligible participants. We developed a semi-structured interview topic guide (Appendix 4) of questions about experiences providing or managing antenatal and childbirth care during floods, based on the Dimensions of Resilience Governance framework [88]. The guide was adjusted as new ideas and topics arose during training, piloting, and data collection, such as the referral system between facilities. The two interviews with commune administrators from Study III were also included as data in this study, as they provided insight on the administrative link between the villages and the health system during floods.

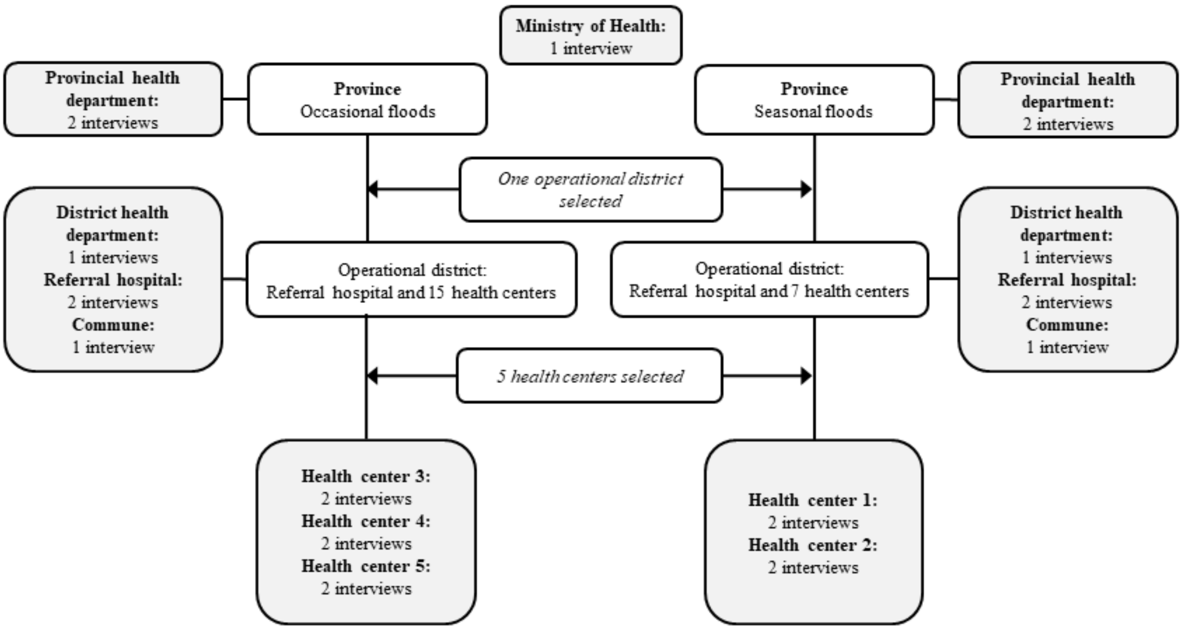


**Figure 7.** Site selection and formal data collected for study sites in Study IV

The same team of data collectors conducted and audio recorded 23 semi-structured interviews, held in private spaces. The team spent four weeks visiting the health departments, hospitals, and health centers to immerse ourselves in the working environments, build trust, and observe service delivery and management in practice. We did not observe or take part in any patient consultations or treatments or seek out interactions with patients at the facilities. The project coordinator and I continued to informally interview facility and health department administrators, such as the financial officers or drug supply managers, and other providers, to develop a fuller picture of health service delivery, management, and flooding. The team discussed all interviews afterwards in private, and we continued to take detailed notes throughout. After 21 interviews, we added two additional interviews with provincial health staff, and assessed that the final 23 interviews had enough power to capture the relevant and appropriate information.

The interviews were transcribed verbatim into Khmer and translated into English, using the same translator as Study III. Following the same approach as Study III, I led a data-driven thematic analysis with regular input from the co-authors of the study. Descriptions and ideas about managing and providing care during floods were coded and checked across perspectives and groups in the data (e.g. midwives versus chiefs, health departments compared to health centers). New ideas and the relationship between the codes was then explored through the dimensions in the framework, and subcategories and categories were developed. Finally, I identified a single, encompassing theme and mapped the findings back onto the capacities of the framework to visualize their relationship.

## 5.5 ETHICAL CONSIDERATIONS

Studies II, III, and IV were approved by the National Ethics Committee for Health Research in Cambodia (number 088, 206, and 207) and the Swedish Ethics Authority (number 2019-02458).

Study I used public data from published articles and did not require approval. However, a larger issue to consider for systematic reviews is whether the included studies were conducted in an ethical manner themselves [155]. Research on disasters is prone to ethical challenges such as power imbalances between affected populations and researchers, the potential benefit to the participant of taking part versus participation as an additional burden during a stressful time, and blurred lines between disaster assistance and research interventions or compensation [156]. We worked under the assumption that the included studies had passed a peer-review and publication process that considered or questioned the ethics of the studies, but it is not possible to know how fully ethical issues were considered and addressed during their conduct.

The data collected in the HMIS used in Study II is routine clinical data that does not require patient consent to collect and cannot be traced to an individual (all data is aggregated and reported at the healthcare facility level). The greatest risk was to health facility confidentiality. To protect it, the minimum data needed to complete the analysis was accessed and obtained from the information system, and data was analysed at the district level rather than the healthcare facility level.

For Studies III and IV, we took the additional step of presenting the study and asking permission to conduct it at all levels down to the village, which we considered important for the context [157]. We received permission from the provincial health departments, district health departments, commune chiefs, hospital and health center chiefs, and village chiefs, followed by individual participant consent. Sensitive topics emerged during the discussions. For the community members, this was around experiences coping with floods, delivering during floods, or about seeking care. All participants were reminded that they were free to withdraw from the study at any time, although none did. For the providers and health department staff, the sensitive issues were mostly around working relationships and management. These were considered highly sensitive, and as a result, the original plan was changed from conducting focus group discussions to conducting interviews only. The sensitive nature was evident when one participant asked to have part of their interview withdrawn from the study after the interview was complete because they felt they had spoken too critically about management. This section of the interview was removed. When contacting participants, we explicitly expressed that we would not share anything the participants said outside of the research team. We attempted to minimize the visibility of who was participating by holding all interviews in private in less public areas (e.g. in secondary buildings on hospital campuses). However, since the chiefs of the health facilities and departments gave permission for the study to be conducted and were asked to help identify eligible staff, it was not possible to keep participation confidential; we did not share the names of staff who ultimately participated with the chiefs. This might have caused participants to not convey the full extent of their experiences or thoughts with us, and triangulation between participants' perspectives was considered important to ensure high quality.

## 5.6 PROJECT COLLABORATION AND FIELDWORK OBSERVATIONS

The thesis project was developed as the cornerstone of a collaboration between NIPH in Cambodia and the Department of Global Public Health, Karolinska Institutet. A few members at each institution had worked together previously and in 2015, they began discussing how to create a formal collaboration. In 2016, we wrote a grant for building research and education capacity for public health and health systems in disasters. My PhD was intended to bring together the institutions through joint supervision and involving other students and staff in the research. The education component included workshops, seminars, and teaching exchanges. We received the grant from the Swedish Research Council and I began the PhD project two months later.

Even with the enthusiasm and commitment on both sides, there were challenges to conducting research within such a new collaboration. It takes time to build working relationships and trust. The collaboration is a small one with only a handful of people involved, and we began without a collaboration structure in place. The research project did not belong to any larger research programs or projects, and as the only PhD student in the collaboration, I had to build many things from the ground up or figure them out as I went. For example, there was a limited pool of available data collectors or research assistants that could work on our project. My counterpart at NIPH and I invested a great deal of time in finding and training NIPH students and other staff to work as data collectors or help with the project, and did double duties managing and overseeing the collaboration, the research, and our other work. I believe this work has paid off, as some of them continue to be involved in our research and collaboration, and I hope they have benefitted from the experience.

Research needs oversight plus buy-in and acceptance from participants. We had originally planned a fairly ambitious cohort study for the PhD project. During the relatively short amount of time from the start of the collaboration to the proposed study start date, it became apparent to us that we did not have the relationships with the participants in place or the human and financial resources to make it feasible. The cohort study was replaced with the systematic review that had been conducted during the formative phase of the collaboration and PhD.

There were also logistical and contextual challenges to doing research in a new and distant country. As someone who doesn't speak Khmer, my most obvious challenge was around collecting data. I managed the data collection together with a project coordinator, and I trained and employed data collectors for Studies III and IV. These were my first qualitative studies, and it meant I missed part of the experience of interviewing, although I still informally interviewed other people with our project coordinator as a translator during data collection. I doubt we would have gotten the same depth and openness in the data had I tried to conduct the focus groups and interviews with a translator, or if we had not been able to discuss each focus group and interview together afterwards as a team in the field, and triangulate with the informal interviews we had just finished.

Making decisions about the studies required first-hand information of the setting. For instance, none of us in the collaboration were familiar with the HMIS data, and it became apparent that I would need to understand what was happening at the health facilities to understand the potential weaknesses of the data. I spent three weeks with an NIPH student as translator, travelling to villages, health centers, hospitals, and health departments in the two study provinces. I talked to villagers, parents, drug sellers, traditional medicine practitioners, private and public providers, and health department staff, trying to get a picture of the different patient pathways, how the health problems we wanted to work with are diagnosed and referred, and how data was collected and entered into the information system.

This was also the time when I got a better understanding of what floods are and what they mean to people. I visited at the end of the rainy season and was able to get a firmer grasp on their reality: the concrete ways they change daily life in the villages and at health facilities, the nuances in terms used and the ways their severity is perceived, and the multitude of ways people have learned to live with them.

# 6 RESULTS

## 6.1 THERE IS SOME EVIDENCE THAT FLOODS AND STORMS HAVE DIFFERENT AND PROLONGED EFFECTS ON HEALTH (STUDY I)

*Objective:* To identify the changes in health outcomes of affected people that occur after flood and storm disasters at a global level

The systematic review included 113 articles out of 6 223 screened. Twenty-three articles studied floods. Seventy-seven were set in high-income settings, nineteen in upper or lower-middle income countries, and fourteen in low-income countries. Fifty-three articles did not include a comparison or control group or indicate a change in health. They were judged as very poor quality.

There were sixty key articles that did include a comparison or control and indicated a change in health. These are summarized in Appendix 2. We rated 37 as good quality, 12 as fair quality, and 11 as poor quality. Twelve key articles studied floods and seven were good quality. Thirty-five were set in high-income settings, thirteen in upper or lower-middle income countries, and nine in low-income countries. Forty-five studies used healthcare facility data as the primary data source. The remainder used data collected from household, school, or workplace surveys or telephone hotlines. The systematic review provided some evidence that floods have a different effect on health than storms. Table 4 and Table 5 summarizes the health outcomes where key articles indicated that the outcome increased post-flood or storm.

**Table 4.** Summary of the main increases in health outcomes observed after floods over time. The number of studies refers to the number of studies reporting the observed estimates given on each line.

| *Time* | *Outcome* | *No. of studies* | *Summary of change estimates* |
|---|---|---|---|
| < 2 weeks | Diarrhea | 1 | Cholera outbreak identified |
| 2-4 weeks | Diarrhea | 1 | Cryptosporidiosis outbreak identified |
| | Leptospirosis | 1 | 1 outbreak identified |
| | Dermatitis | 1 | Higher proportion dermatitis diagnoses among households in flooded (96.5%) versus non-flooded areas (57.9%) ($p<0.05$) |
| | Hypertension | 1 | Higher proportion of worsened hypertension among households in flooded (42.9%) versus non-flooded areas (20.3%) ($p<0.05$) |
| >4 weeks | Diarrhea | 1 | Surveillance system alerts for acute water diarrhea and bloody diarrhea within seven weeks |
| | Acute respiratory infections | 1 | Relative risk among households increased within six months (relative risk: 1.25, 95% CI: 1.06-1.47) |
| | Leptospirosis | 1 | 1 outbreak identified more than four weeks post-storm |
| | Worsened diabetes outcomes | 1 | Mean HbA1C in diabetic patients living in flooded households rose from 7.6% (95% CI: 7.5-7.7) pre-flood to 7.9% (95% CI: 7.7-8.0) at 6 to 9 months post-flood ($p=0.002$) |
| | Stunting and underweight | 1 | Children in flooded villages more likely to be stunted and underweight than children from non-flooded villages (adjusted prevalence ratio: 1.86; 95% CI: 1.05-2.44) at 2 to 3 years post-flood |

Following floods, three surveillance studies reported outbreaks of cholera and other infectious diarrhea after one to seven weeks, yet a fourth study of a health and demographic surveillance site found no increase in diarrheal illness in the two years after flooding. The health and demographic surveillance site study also reported an increase in acute respiratory infections during the same time period. Two studies identified two outbreaks of leptospirosis after one month. Within one year post-flooding, two studies indicated worsened hypertension and glycaemic control in diabetic patients. A community-based study of children reported a higher likelihood of stunting and underweight in the three years after flooding. Lastly, one study observed an increase in the proportion of diagnosed dermatitis in the month following a flood.

After storms, eight studies reported increases in the number of visits to healthcare facilities for wounds for up to three weeks. Six studies documented more visits and calls for poisonings (predominantly from carbon monoxide) to facilities and poison control hotlines in the first two weeks post-storm.

For infectious diseases after storms, four studies reported an increase in the number of diarrhea cases in households and at facilities and for the risk for infectious diarrhea within one week of storm landfall. Another four studies identified outbreaks of cholera, norovirus, and acute water diarrhea up to three months post-storm. An additional five facility-based studies observed increases in the number of visits to facilities and incidence of diarrhea in the five weeks to one year post-storm. However, two surveillance system studies and one facility-based study observed no change in gastrointestinal illness at any point post-storm. Three studies identified outbreaks of leptospirosis and one indicated an increased risk for leptospirosis at a treatment facility between two weeks to two months post-storm. Three studies showed significant increases in visits to treatment facilities for cellulitis and other skin or soft tissue infections one week post-storm, but another study indicated no increase in visits for the same conditions

Four studies reported increases in the incidence of cardiovascular complaints and events at facilities up to two years post-storm, apart from a fifth study which indicated no relationship between storms and visits to facilities for cardiovascular disease. Another two studies documented more evaluations of diabetic foot at facilities and worsened glycaemic control from four weeks to sixteen months after storms. Two community-based studies of children indicated more stunting and underweight three months to one year post-storm.

The remaining storm studies demonstrated more frequent contact with health services for health maintenance within one week after storms (three studies), an increase in visits to facilities for dermatological complaints within two weeks (two studies), and an increase in mortality primarily from cardiovascular events and diabetes during and 30 days after landfall (three studies).

**Table 5.** Summary of the main increases in health outcomes observed after storms over time. The number of studies refers to the number of studies reporting the observed estimates given on each line.

| *Time* | *Outcome* | *No. of studies* | *Summary of change estimates* |
|---|---|---|---|
| < 2 weeks | Carbon monoxide poisoning | 1 | Proportion of carbon monoxide intoxications increased from 0% to 1.1% of all facility visits (p=0.015) |
| | | 5 | Increases in carbon monoxide, gasoline, and hydrocarbon poisoning or exposure from baseline values |
| | Wounds | 5 | Facility visits increased for lacerations (p=0.0014 and p<0.001), corneal abrasions (p<0.05), and open wounds (p=0.001 and relative risk: 17.3; 95% CI: 13.0-23.0) |
| | Diarrhea | 2 | Cholera and norovirus outbreaks identified |
| | | 2 | Facility visits for diarrhea or gastroenteritis increased post-storm (p<0.001), rose from 9.7% pre-storm to 12.9% post-storm at another facility (p=0.05) |
| | | 1 | Higher odds for shigellosis or other infectious diarrhea in 1 week post-storm (odds ratio: 3.56; 95% CI: 2.98-4.25) |
| | | 1 | Higher odds of diarrhea in flooded homes (odds ratio: 1.4, 95% CI: 1.4-28.0) |
| | Skin or soft tissue infections | 1 | Facility visits for cellulitis rose 1 week post-storm (relative risk: 2.8, 95% CI: 2.0-2.4) |
| | | 2 | Facility visits for cellulitis increased from 0.3% of total visits to 1.2% 2 weeks post-storm (p=0.05), and for impetigo (0.2% to 0.5% 1 week post-storm) (p=0.05) |
| | Health maintenance visits | 1 | Increase in facility visits for medication refills, oxygen therapy, dialysis, and vaccinations (p<0.05) |
| | Dermatologic complaints | 1 | Increased from 2.2% of all facility visits pre-storm to 4.5% of visits post-storm (p=0.01) |
| 2-4 weeks | Cardiopulmonary complaints | 1 | Increased from 2.3% of all facility visits pre-storm to 7.3% of visits post-storm (p=0.03) at four weeks after |
| | | 1 | Increase in facility visits (relative risk: 2.73, 95% CI: 1.51-4.95) at 2 weeks after compared to before |
| | Wounds | 1 | Proportion of facility visits for lacerations rose from 8.6% pre-storm to 11.3% post (p<0.01) and for puncture wounds from 1.1% to 2.5% (p<0.001) |
| | | 1 | Facility visits for infected wounds increased within 1 month (p=0.0066) |
| | Leptospirosis | 1 | 1 outbreak identified |
| >4 weeks | Diarrhea | 2 | Cholera and acute watery diarrhea outbreaks identified after 3 months and 6 weeks, respectively |
| | | 1 | Proportion of facility visits for diarrhea elevated post-storm (p<0.05) for 5 weeks |
| | | 1 | Facility visits for diarrhea elevated 5 weeks post-storm (relative risk: 2.0; 95% CI: 1.4-2.8) |
| | | 1 | Higher risk of diarrhea in 2 storm-affected areas (odds ratio: 1.6; 95% CI: 1.52-1.65 and odds ratio: 1.3; 95% CI: 1.21-1.32) within 5 weeks |
| | | 1 | Incidence of acute diarrhea and dysentery increased (p<0.05) in 8 months post-storm |
| | | 1 | Average number of visits for intestinal infections rose from 6.5 to 13.1 cases per month (p<0.01) in the year after a storm |
| | Leptospirosis | 2 | 2 outbreaks identified between 6 and 8 weeks post-storm |
| | | 1 | Risk of leptospirosis increased by 1 month (relative risk: 4.4, 95% CI: 1.6-12.4) |
| | Myocardial infarction | 1 | Incidence of myocardial infarction visits rose at facilities (attributable rate ratio: 1.22, 95% CI: 1.16-1.28) during the first year post-storm |
| | | 1 | Percentage of facility admissions for acute myocardial infarctions increased from 0.71% pre-storm to 2.18% within 2 years post-storm (p<0.0001) |
| | Stroke | 1 | Incidence of stroke visits rose at facilities (attributable rate ratio: 1.07, 95% CI: 1.03-1.11) during the first year post-storm |
| | Worsened diabetes outcomes | 1 | Evaluations for diabetic foot increased at a facility by 4 weeks post-storm (p=0.007) |
| | | 1 | Mean HbA1C values among diabetic patients rose from 7.7% pre-storm to 8.1% post-storm (p<0.01) 6 months after a storm |
| | Stunting and underweight | 1 | Less height (p<0.002) and weight (p<0.03) gained in nutritionally at-risk children 3 months after |
| | | 1 | Increase in the stunting/underweight among children 1 year after (p<0.05) |

## 6.2 DIARRHEA, ACUTE RESPIRATORY INFECTIONS, AND SKIN INFECTIONS CAN INCREASE IMMEDIATELY AND UP TO THREE MONTHS AFTER SEASONAL AND OCCASIONAL FLOODS IN CAMBODIA (STUDY II)

*Objective:* To quantify the short- and long-term effect of seasonal and occasional floods on health problems seen at public healthcare facilities in two provinces Cambodia

Between January 2008 and December 2013, there were 5 748 237 outpatient consultations and inpatient discharge diagnoses in the two provinces. Flood water followed a seasonal pattern in nine districts across both provinces although the scale differed between them. The greatest extent of flood water in one month in Prey Veng was 2 434 square kilometres and 195 square kilometres in Kampot. Angkor Chey and Chhouk districts in Kampot had an average of less than one square kilometre of flood water per month and produced imprecise estimates for all health problem models (Appendix 5).

We found some evidence for an association between the extent of flood water and visits for diarrhea, acute respiratory infections, and skin infections (Table 6). In six districts, we found fifteen positive associations at lag months 0 or 3 between the extent of flood water and the incidence rate for these three outcomes. The largest increase in incidence rates occurred in Kampong Trach district in Kampot. The incidence rate of diarrhea increased by 55% (95% CI: 1.33-1.80) and the incidence rate for skin infections rose by 182% (95% CI: 2.41-3.29), both at lag month 0. Significant increases in incidence rates in the other district ranged from 3% at lag month 0 (95% CI: 1.00-1.05) to 44% at lag month 3 (95% CI: 1.28-1.62) for acute respiratory infections, and 5% at lag month 0 (95% CI: 1.02-1.08) to 28% at lag month 3 (95% CI: 1.14-1.44) for skin infections.

At lag months 1 and 2, incidence rates for diarrhea declined by 6% (95% CI: 0.90-0.99) to 21% (95% CI: 0.71-0.89). The skin infection incidence rate declined significantly in one district at lag month 1 (IRR: 0.77, 95% CI: 0.67-0.89). There was no evidence for a decline in acute respiratory infections at lag month 1 or 2.

Injuries both increased and decreased: there was a significant increase in one district (incidence rate ratio [IRR]: 1.17, 95% confidence interval [CI]: 1.02-1.34) and decrease in another (IRR: 0.94, 95% CI: 0.90-0.98). We found similar results for vector-borne diseases. Out of seven significant associations, the incidence rate declined at lag months 0, 1, and 2 for five associations, ranging from a decline of 82% (95% CI: 0.04-0.96) to a decline of 13% (95% CI: 0.60-0.99). Incidence rates rose for the remaining two associations in different districts, by 107% (95% CI: 1.39-3.10) at lag month 0 and 135% (95% CI: 1.28-4.34) at lag month 3.

We found no declines in the incidence rate of normal or complicated deliveries at health facilities as flood water increased. The incidence rate of home deliveries increased in one district in Prey Veng (IRR: 1.39, 95% CI: 1.20-1.60), but there were no other significant associations. For outpatient consultation visits, we observed a significant decline in the incidence rate at lag month 1 (IRR: 0.95, 95% CI: 0.91-0.99 and IRR: 0.90, 95% CI: 0.82-0.99) in two Prey Veng districts and at lag month 2 (IRR: 0.88, 95% CI: 0.79-0.98) in a district in Kampot.

The mean number of visits per month for noncommunicable diseases was one in both provinces, and the median was zero. The small quantity of visits produced imprecise estimates in all districts except for Peam Ror, Peareaing, and Svay Antor in Prey Veng province. Only one of the associations in those three districts was significant (IRR: 1.57, 95% CI: 1.21-2.03 at lag month 3), and it lost significance when using the imputed data (IRR: 0.94, 95% CI: 0.82, 1.08).

**Table 6**. Significant incidence rate ratios and 95% confidence intervals for diarrhea, acute respiratory infections, skin infections and vector-borne diseases at lag months 0 to 3 by district, corresponding to a ten square kilometer increase in flood water and controlled for season and year

| District | Lag month 0 | Lag month 1 | Lag month 2 | Lag month 3 |
|---|---|---|---|---|
| **Diarrhea** | | | | |
| Kampong Trach | 1.55 (1.33, 1.80) [a] | 0.79 (0.71, 0.89) | | |
| Kampong Trabek | | 0.88 (0.82, 0.94) | 0.87 (0.80, 0.95) | 1.17 (1.05, 1.29) |
| Peam Ror | | 0.94 (0.90, 0.99) | | 1.06 (1.02, 1.11) |
| Svay Antor | | | | 1.09 (1.01, 1.16) [a] |
| Prey Sdach | 1.05 (1.00, 1.09) | | | |
| **Acute respiratory infections** | | | | |
| Peareaing | 1.04 (1.01, 1.07) [a] | | | 1.03 (1.00, 1.05) |
| Kampong Trach | 1.44 (1.28, 1.62) | | | 1.20 (1.05, 1.38) |
| Svay Antor | | | | 1.11 (1.02, 1.22) |
| **Skin infections** | | | | |
| Peareaing | 1.05 (1.02, 1.08) [a] | | | 1.05 (1.02, 1.09) [a] |
| Prey Sdach | 1.09 (1.02, 1.16) | | | |
| Svay Antor | 1.14 (1.02, 1.28) | 0.77 (0.67, 0.89) | | 1.28 (1.14, 1.44) [a] |
| Kampong Trach | 2.82 (2.41, 3.29) | | | |
| Peam Ror | | | | 1.10 (1.01, 1.20) |
| **Vector-borne diseases** | | | | |
| Peareaing | 0.77 (0.60, 0.99) | 0.75 (0.58, 0.97) | | |
| Svay Antor | 2.07 (1.39, 3.10) | | | |
| Kampong Trach | 0.48 (0.26, 0.88) | 0.30 (0.14, 0.61) | 2.35 (1.28, 4.34) | |
| Kampot | | | 0.18 (0.04, 0.96) | |

[a] Value is from imputed data

## 6.3 THE COMMUNITY MAINLY DESCRIBED THEIR ABSORPTIVE CAPACITY FOR MANAGING THEIR OWN ANTENATAL AND CHILDBIRTH CARE NEEDS DURING SEASONAL AND OCCASIONAL FLOODS, HELPING TO RELIEVE THE BURDEN ON THE HEALTH SYSTEM (STUDY III)

*Objective:* To understand if and how the public health system's capacity to absorb, adapt, or transform is linked to the community's own capacity to absorb, adapt, or transform when managing antenatal and childbirth care needs during seasonal and occasional floods in Cambodia

The fundamental theme of the study, *'Responsible for the status quo',* revealed the responsibility placed on the community to have the capacity to manage antenatal and childbirth care during seasonal and occasional floods. The theme represents the balance community members had to find when they received little additional support or help in managing their antenatal or childbirth care during floods. At the same time, they still wanted antenatal and birth care and felt that village leaders and healthcare providers expected them to continue receiving care during floods. Four categories informed the theme: 1) *'Depending on others but ready to be alone',* 2) *'Women navigating a shrinking space for choices about care',* 3) *'A personal trade-off between mistrust and the benefits of formal care',* and 4) *'Mitigating difficulty during floods'.* The findings are visualized in Figure 8..

Community members lived in a changing context where solutions for pregnancy care came and went. For example, community members described the growth of available maternal health services in the private sector compared to the public sector and the loss of community-based resources like traditional birth attendants and traditional medicine (category *'depending on others but ready to be alone')*. They described floods as an unpredictable force that made managing pregnancy and birth more difficult. Community members felt they needed to be ready to manage their care themselves, without the expectation of help:

> *It's hard to ask them [other villagers] because we can only ask for help one or two times. What if someday they don't have anything either? If we ask them too often, we might be troublesome to them, so we have to accept that.* (FGD 1, women)

Men and women learned strategies to cope with pregnancy and birth through experience and shared knowledge (category *'mitigating difficulty during floods'*) and prepared to implement these primary strategies during floods. However, community members reported how a lack of resources, not enough help from others, and social pressure sometimes meant they needed to use secondary strategies, such as skipping antenatal care or going into debt for care. They also described how the strategies they used did not always eliminate the challenges they encountered during floods.

Public health centers and village leaders strongly espoused messages about appropriate pregnancy care. Women felt that their ability to make a choice about how to care for pregnancy had been reduced to one correct option: getting facility-based antenatal and birth care (category *'women navigating a shrinking space for choices about care')*.

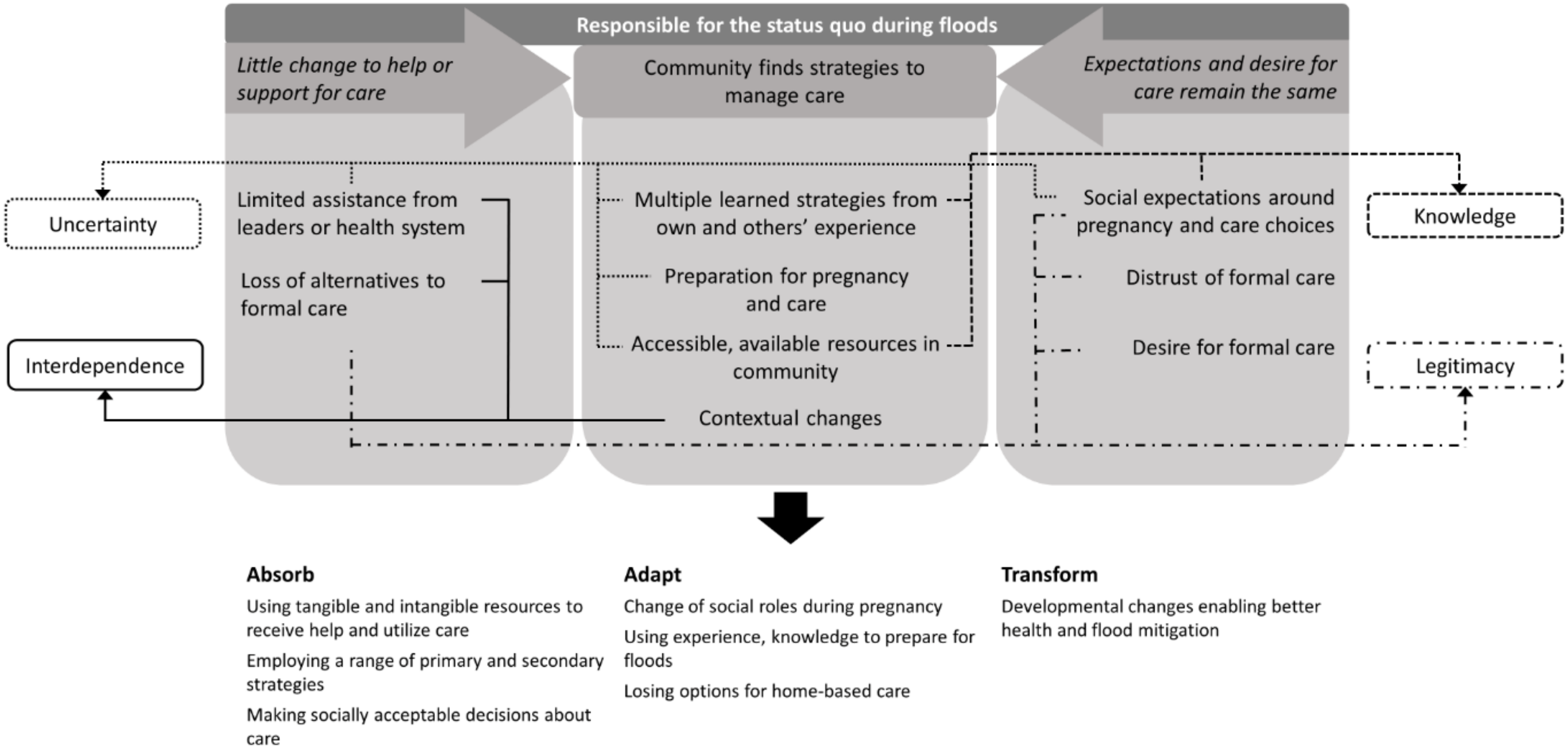


**Figure 8.** Representation of the findings as they contribute to the four dimensions of resilience governance and lead to the community's capacity to absorb, adapt, or transform during floods. The theme is represented in the dark grey boxes. Results from across the four categories are represented in light grey. The four different line types represent the connections between the findings and the four dimensions in the framework.

*Yes, we must go. In short, we have to go and get a check-up every month. The doctor will check us and tell us when to go next month. We have to go regularly. [You] cannot miss this, it's a must that pregnant women go there.* (FGD 4, men)

Women and men could seek assistance and resources from within the community to help them navigate care during floods, such as borrowing a boat. They also described regaining power over their decisions by actions such as clandestinely seeking informal care from traditional birth attendants or seeking help from the village chief.

Community members wanted to feel secure during floods by getting formal antenatal and birth care, despite misgivings about the quality of care from the public health facilities (category *'a personal trade-off between mistrust and the benefits of formal care')*. Pregnancy during floods was a more uncertain time than pregnancy when there was no flood and women described a desire for more security. The fear of delivering, experiencing complications, or missing the benefits of antenatal care during floods outweighed the mistrust in the public sector.

*If we do not go then it could be very risky for us. Sometimes, [women] have the pain in the night. And there's no one to take them there because the flood was here all around, there's no boat or anything at all. It's risky.* (FGD 3, women)

The community described their capacity to deploy absorptive strategies to manage their antenatal and birth care when exposed to seasonal and occasional floods but were less able to employ adaptive strategies or engage in transformative processes

## 6.4 COLLABORATION AND RELATIONSHIPS SET LIMITS ON DECISION-MAKING TO ALLOW A STABLE BUT FLEXIBLE APPROACH TO PROVIDING PUBLIC ANTENATAL AND BIRTH SERVICES IN CAMBODIA, ENABLING THE SYSTEM TO ABSORB AND ADAPT (STUDY IV)

*Objective:* To generate knowledge on the influences on public antenatal and childbirth health service delivery in Cambodia during seasonal and occasional floods that are related to the system's capacity to absorb, adapt, or transform

The main theme, *'collaboration across the system creates adaptability in the response'*, describes how collaboration and social relationships appeared to create clear boundaries to decision-making around antenatal and birth care among public healthcare providers and health department staff. Providers and staff discussed seasonal and occasional floods as strains rather than shocks. With a firm understanding of the boundaries, providers and staff reported their ability to prepare and respond to these floods in a flexible but stable manner, resulting in absorptive and adaptive capacity.

Five categories created the main theme: 1)'*Floods just another strain on service delivery'*, 2) *'Facilities and health departments able to calibrate and manoeuvre to make flood routines work for them'*, 3) '*Working in the same direction during floods'*, 4) '*Engaging in local governance to fulfil a duty to the community during floods'*, and 5) '*Creating relationships to* *successfully respond to floods'*. Figure 9 illustrates the results using health outreach services at health centers as an example.

According to the participants, seasonal and occasional floods did not have a serious impact on the health of the population in their catchment areas or on antenatal or birth services (category *'floods just another strain on service delivery')*. Instead, providers and staff expressed flooding as just one of many consistent challenges to providing services. Providers and staff in the occasionally flooded district described floods as a less of a threat to health and their work than the participants in the seasonally flooded district:

> *The floods are not so big that we have to focus on them so much. They're not big to the point of an emergency.* (Interview 7, provincial health department)

Standard routines and plans to prepare for and respond to floods existed at the health departments and facilities, with clear roles and responsibilities (category '*facilities and health departments able to calibrate and manoeuvre to make flood routines work for them'*). Based on previous experiences with floods, facilities and health departments were able to capitalize on the available decision-making space within their role or responsibility to adjust their routines and plans to fit flooding conditions.

During floods, providers and staff recognized collaboration across public health sector levels and with other government ministries, groups, and external actors as key to keeping health services functional (category *'working in the same direction during floods'*). Participants discussed the limits they had in solving problems and making decisions outside their roles and responsibilities during floods. They relied on direct contact with higher level decision-makers who could take responsibility for decisions and a sense of teamwork:

> *When there's a big flood, the OD [district health department] will have to visit the flooded areas every day to see the people's situation, how they are living, is there any clean water for them to use, any diarrhea, are there any health center staff to help them with their health problems or not? Everyone is enthusiastic when there's a big flood, both the provincial level and district level.* (Interview 10, district health department)

Providers and staff, particularly health center providers, expressed how creating relationships made it possible for them to share information and continuing providing services during floods (category *'creating relationships to successfully respond to floods'*). The relationships between community and health center providers helped the health response to floods by facilitating information sharing and access to the affected villages. Providers and staff noted information sharing between them as open and accessible but could be influenced or hampered by personal and social relationships:

> *Before they [the health center] transfer a case here, they will call us. They call the hospital, there's a telephone there. Sometimes they contact [the hospital chief] directly. Sometimes they call any staff that they know here.* (Interview 20, referral hospital midwife)

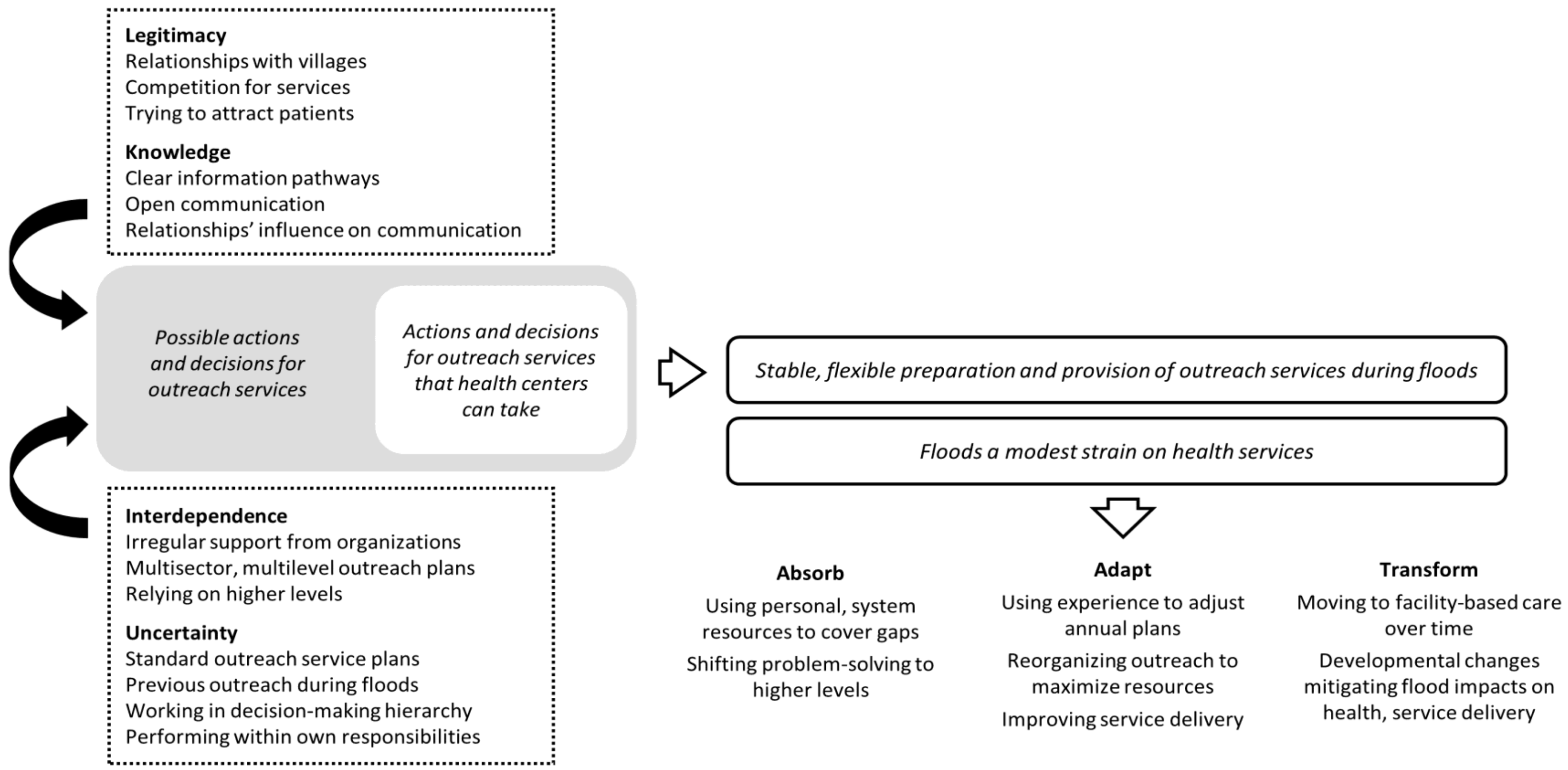


**Figure 9.** Representation of the four dimensions of resilience and the system's capacity to absorb, adapt, and transform as they relate to the main theme, using health center outreach services for antenatal and childbirth care during a big floods as an example.The dotted line boxes contain ideas from the five categories as they relate to the four dimensions of the resilience governance framework. The midline boxes and arrows illustrate their contributions to the main theme and to the public sector's capacity to absorb, adapt, and transform in response to floods.

According to the participants, health centers were losing their relevance and struggling to provide comparable, competitive services to those offered at private facilities and public hospitals (category *'engaging in local governance to fulfil a duty to the community during floods'*). In response, health center staff worked to improve the quality of services at their facilities, and during floods, drew on their belief in the good of their work and in the public health system's ability to function as it should.

The antenatal and birth health services managed by the public facilities and health departments appeared to have the capacity to absorb and adapt to seasonal and occasional floods, which they perceived as strains rather than shocks.

# 7 DISCUSSION

The results show that floods can have a sustained impact on new and routine health needs (Study I, II). In the context of the Cambodian health system, these impacts present as an increase in new health needs at public facilities that may last for up to three months; with no evidence of change, the impact on routine health needs remains unclear (Study II). The public sector of the health system appeared to have the capacity to absorb and adapt to manage antenatal and birth health needs during seasonal and occasional floods. The system's capacity was influenced by collaboration and relationships across the system and between actors and sectors that enabled stability and flexibility in their approach to preparing and responding to floods (Study IV). The public sector's capacity was aided by the community's own capacity to absorb, helping to relieve the burden of managing health needs on the health system during floods (Study III).

## 7.1 FLOODS AS A SHOCK TO HEALTH AND THE PUBLIC HEALTH SYSTEM

The findings for Study I showed that there is some evidence that floods can have a prolonged effect on health for up to two years. Associations were observed between both floods and storms and changes in new and routine health needs, like leptospirosis and worsened diabetes outcomes. Although relatively few studies addressed outcomes after four weeks, there was evidence that diabetes outcomes remained worse for up to two years post-flood and storm. When studying repeated floods rather than disasters, increases in flood water could affect visits to public healthcare facilities up to three months later for acute respiratory infections, diarrhea, and skin infections (Study II). This links to the importance for health systems to be able to maintain and provide health services for both types of needs when faced with shocks. For instance, key articles in Study I linked worsened diabetes outcomes to lack of access to care or medications, as well as other factors like physiological stress. Previous research from other shocks has highlighted the implications of disrupting health services for new or routine needs, such as the potential benefits of maintaining cancer screening during financial shocks [158] and the negative impacts on maternal health and chronic health conditions during the West Africa Ebola outbreak [71, 72].

The difference in some of the observed health outcomes after floods and storms (Study I) supported our initial hypothesis that the effects of floods on health has been conflated with storms in previous literature. The findings demonstrate that there is value in disaggregating the health effects of the two types of extreme weather events to view the impacts of floods alone. Systematic reviews of health after floods conducted prior to Study I considered floods and storms as a single type of event, using the rationale that storms can cause flooding [30, 31, 101]. However, storms have the added hazard of strong winds that can cause direct morbidity (e.g. injury from falling tree limbs) and substantially damage the environment, housing, and other infrastructure, leading to indirect morbidity (e.g. carbon monoxide poisoning from generator use). The additional hazard may be related to the differences in health outcomes between floods and storms seen in Study I. It may also be part of the reason that all the comparative studies on injuries and poisonings included in the study were for storms. However, out of the sixty key articles, only twelve were from floods and these studied seven different outcomes in ten different settings. No key articles examined injuries, poisonings, or contact with the health services after floods. This highlights a remaining evidence gap in our understanding of floods and their impact on health and the health system, an issue that has been raised in flood research over the last twenty years [32, 159].

When thinking of floods as a shock to health systems, the findings from the thesis show that further differentiating between the concepts of shocks and stresses may be beneficial. It could be a helpful future step in understanding what health systems need to be resilient to and if resilience characteristics vary depending on the kind of shock systems face [82, 90]. The health systems resilience literature has broadly described shocks as sudden or extreme external phenomena that challenge the system, such as pandemics or financial crises [69]. This is in line with our study of flood and storm disasters (Study I), which viewed them as events that substantially impact a society and its functioning [160]. The results of this study are an indication of the range of potential outcomes when a population and health system are exposed to severe floods. Moving beyond the idea of sudden crises, health systems stresses have been discussed as internally generated, chronic, everyday challenges to the system, such as political instability or chronic underfunding [69]. The floods in Studies II, III, and IV were repeated external shocks that ranged in scope and severity and aggravated health services, falling between the concepts of shocks and stresses. Seasonal and occasional floods were not perceived as a major challenge to the health services (Study IV) and were described as overwhelming but expected natural phenomena by the local population (Study III), which could be the result of repeated exposure to the same shock. In addition, a flood disaster in the year 2000 was repeatedly described as the greatest shock to the community and health services in memory (Study III, IV), suggesting that the normal seasonal and occasional floods are not perceived as a major challenge to the health services in comparison. As climate change is expected to gradually increase the frequency of floods, it may be worthwhile to apply the principles of everyday resilience—building resilience to chronic challenges—to repeated seasonal and occasional flood shocks. This may in turn promote resilience to more acute, extreme events [22, 84].

## 7.2 FLOODS AS A SHOCK IN CONTEXT

In the Cambodian context, the increase in visits to public healthcare facilities for diarrhea, acute respiratory infections, and skin infections immediately and three months following increases in flood water may be related to poor sanitation, contact with contaminated flood water, and changing living conditions (Study II). All of these risk factors have been linked with floods in other settings, and remain high in Cambodia [112, 161-163]. Noncommunicable and vector-borne diseases made up the smallest proportion of visits to public facilities yet in Cambodia, dengue fever is endemic [110, 164] and cardiovascular disease and diabetes are prevalent [107, 165]. Other studies have found that public facilities are the second choice of care for these conditions because communities lack confidence in the quality of care and availability of medications [150, 166, 167]. Understanding the full scope of new and routine health needs following floods in the Cambodian context would require drawing on other sources of data, such as private facility records, and investigating the population's relationship with the private sector. For instance, participants identified the main challenge to health services during floods as difficulty delivering the appropriate quality or quantity of care because floods exacerbated the usual limitations and lack of resources in the public sector (Study IV). The public sector also chose to prioritize new health needs in their community outreach services during floods, leaving community members responsible for seeking facility-based antenatal care and dissatisfied with the outreach services (Study III, IV). This was coupled with a perceived decline in demand for routine services at public health centers (Study IV). If the community does not trust the public sector, they may be more inclined to visit private providers for new and routine needs during floods, when access to care was described as more difficult. Visiting private providers may also be an active choice to exert control over health-related decisions, as seen in other studies from Cambodia [168-170].

The delay in increases until three months post-floods may also be related to previous exposure to flooding (Study II). The flood mapping data shows that districts in both provinces had been repeatedly exposed to floods. District- and facility-level strategies to respond to health needs during floods are already in place in the public health system in Cambodia, for example clinical outreach during floods and health education prior to floods [127]. Experiences from previous exposure may have generated strategies in the population for managing infections and diarrhea in the short-term without seeking or receiving care at public facilities. The idea is partially supported by our findings that: i) the rates for all consultations at facilities, births at facilities, and home births remained stable during floods (Study II), ii) community members, healthcare providers, and health department staff reported that maternal health services remained functional throughout floods (Study III, IV) and iii) community members reported being able to seek out and access care during floods, although with more difficulty (Study III). The results suggest that the availability of services at public facilities and the population's ability to seek and access services are not greatly restricted by floods in these districts in Cambodia.

## 7.3 CAPACITIES OF THE PUBLIC HEALTH SYSTEM IN CAMBODIA TO MANAGE ANTENATAL AND CHILDBIRTH HEALTH NEEDS DURING SEASONAL AND OCCASIONAL FLOODS

The findings from Studies III and IV show that the public sector of the health system had some capacity to absorb and adapt when managing health needs during seasonal and occasional floods, aided by the community's own capacity to absorb. Transformational capacity was comparatively difficult to observe and interpret.

Based on the findings of Studies III and IV, we considered the capacities of the public health services and the community to be linked. The community took on the responsibility of managing their antenatal and birth care during floods, relieving some of the burden on the health services to respond to their needs (Study III). For example, they referred themselves to and between facilities when they had pregnancy-related emergencies during floods (Study III, IV). In the community's experience, the health system had few strategies to help the community manage care during floods, though antenatal and birth services continued to function at public facilities (Study III). To the community, this meant the responsibility for managing care lay with them rather than the health system. Mladovsky et al (2012) understood shocks from the perspective of their impact, as events that had a substantial negative impact on the availability of health system resources or a substantial positive impact on the demand for health services [68]. Neither a substantial increase in demand for antenatal and birth services during floods nor a decrease in available resources were noted (Study II, III, IV). The unchanged demand for services during floods may be linked to the community's capacity to manage their own health needs, that appeared to allow the health services to function and continue providing health services as normal during floods. However, the ability of the public sector antenatal and birth services to continue functioning as normal may be at risk if future floods exceed the community's ability to absorb and adapt, and the responsibility to manage health needs is fully shifted to the public sector system. Investment by the health system in adaptive or transformative measures over time that could relieve the responsibility on the community during floods were not described, leaving the community vulnerable to more severe floods and different shocks if their absorptive and adaptive capacities are exceeded [79]. There is a clear need to further understand the community's potential role in building resilience in health systems and how community capacities influence the health system's capacities for resilience [83, 93, 171].

The Dimensions of Resilience Governance framework used in Study III and IV gives four overlapping dimensions that allow a health system to manage resilience: interdependence, knowledge, uncertainty, and legitimacy. The findings of this thesis identified two intersecting areas that crossed the dimensions: trust and ownership between the community and health system, and decision-making in the context of relationships among the community, system, and actors.

### 7.3.1 Trust and ownership between the community and health system

Trust and ownership affect the community's involvement in decision-making and interactions with the health system [65, 67]. Men and women reported feeling powerless to choose the antenatal and birth care they wanted during floods because of top-down interactions with the public sector, and as a result, lost trust and the sense of ownership in the public system (Study III). Health service providers and staff also reported that they felt the community had a low degree of trust in public facilities, which they described when talking about the relationships between health centers and communities and how community members utilized public facilities normally and during floods (Study IV). Providers and health department staff were actively engaged in trying to improve the quality and reliability of everyday services in order to attract community members to their services (Study IV). Providers and health department staff also strongly believed in the value of their work and the system's capability to function during floods. The public sector participants' work to improve services, and their belief in their work and the system during floods, could be a starting point for developing strategies to build trust between the community and the public health system. This would be especially relevant during floods when relationships between the community and public facilities played a vital role enabling health services to function smoothly (Study IV). For antenatal and childbirth health services, this might be helped by the fact that community members saw maternal health service as more trustworthy than care for other kinds of health needs (Study III and [116, 172]). The Ministry of Health has invested heavily in maternal health reforms which have improved them to a greater degree than other services [116, 149, 172], which has likely influenced the community's belief in these services.

### 7.3.2 Decision-making in the context of relationships

The relationships, choices, and interactions between actors inside and outside the system have been identified as influencing resilience [80, 82, 84, 173, 174]. Limits on decision-making seemed to influence the community and health system differently. Restricted decision-making plus limited support were described by the community as influencing their capacity to primarily absorb rather than adapt (Study III). Throughout the study, participants highlighted how a top-down approach to information sharing from village leaders and health centers to the men and women living in the village seemed to force them onto a single pathway for actions and decisions about their care. This pushed out community-based knowledge and strategies for managing pregnancy and birth in the community, and affected the community's sense of trust and ownership in the public health system, similar to other findings from Cambodia [168-170]. The lack of alternative knowledge and strategies may have created a risk to the health system if the community and health system are exposed to shocks that do disrupt health services and these alternative strategies for coping have been lost. Being excluded from the decision-making process and losing the power to make decisions may be what is influencing the community's capacity to absorb, adapt, or transform, rather than having a limited set of decisions. This has been described in organizational resilience [82].

For the health services, collaborations and relationships across the system put known limits on decision-making and actions by the facilities and health departments. It created a stable but flexible process for preparing and responding to floods and appeared to give them the capacity to adapt and absorb in response to floods (Study IV). The findings support the idea that understanding the boundaries of the decision-making space is a key component to taking action [175]. The top-down hierarchies that exist in the Cambodian health system might have helped to counteract uncertainty in the flood response by letting participants have the power to make choices in their domain and in collaboration with and supported by other levels and actors in the health system. This may be a prominent factor in the public system's apparent stability and flexibility when preparing and responding to floods, together with the existing plans and routines [80, 82, 174]. However, hierarchical decision-making is normal in the Cambodian health system [176, 177] and its potential influence should not be taken out of context.

### 7.3.3 Examining capacities and the factor of time

The studies in this thesis offer insight into the Cambodian health system as it existed in the recent past. Our studies cannot provide a full picture of resilience because they cannot explain how and why the system reached its current state [91, 92]. This was evident in some of the findings from Study III and IV, particularly in relation to the dimension of interdependence and capacity to transform. As noted in Studies III and IV, Cambodia has undergone numerous and rapid economic and developmental changes in the last twenty years that were described as fundamentally changing the landscape for managing health needs after floods. For example, the construction of better roads was described as improving access to facilities during floods (Study III, IV). We interpreted this as a change in the infrastructure sector that had a transformative effect on the health system and the community, therefore also highlighting the interdependence between systems. However, how changes in the past are influencing current capacities remains unclear. For instance, at what point in time or degree of change do better roads become a transformative versus adaptive or absorptive capacity? Has interdependence in the past between the health system and infrastructure system reduced the need for current transformative capacity?

A similar difficulty was encountered when trying to determine where one capacity might begin and another end, when viewing them at multiple health system levels and also comparing them between the community and the health system. For example, the policy to limit the use of traditional birth attendants [125] could be considered transformative for the health system by fundamentally changing how services would be delivered, a change perhaps most prominent at the facility level. For the community, however, it may have been the impetus behind some of their absorptive and adaptive capacity by creating a need to seek care beyond the community during floods at their own expense (Study IIII). A wider and deeper exploration of the context and capacities is needed to better explain how capacities are developed and intersect. Future iterations framework may wish to consider incorporating scales of time or system levels.

## 7.4 METHODOLOGICAL CONSIDERATIONS

The studies in the thesis are subject to biases, particularly selection bias, that can affect their generalizability and transferability. The terms generalizability and transferability in quantitative and qualitative research refer to the extent that the findings of a study can be applied in another population or setting [178, 179]. In Study I, the most common setting for the articles was an emergency healthcare facility in a high-income country, The conclusions that can be drawn about health outcomes in other contexts, such as low-income countries, are therefore limited. The articles were also open to selection bias based on care-seeking behavior. Because emergency facilities are at the peak of the health service delivery pyramid [180], the health outcomes of those without accessible, affordable, or available care, those who sought or received primary care, or those with less acute health needs are not well-represented in the results. Applying the results to specific settings would also depend on other contextual factors, such as burden of disease. For these reasons, we see Study I as an indication of potential changes in health after floods over time that need to be considered if a flood occurs in a given setting. Because Study II used data from all public facilities in the districts, the results are a reasonable estimate of what health needs public facilities could expect after floods in other districts in Cambodia. It is possible that the findings on diarrhea, acute respiratory infections, and skin infections could be generalized to other middle-income contexts with similar flood patterns and care-seeking behavior in the public and private sectors.

The prominent findings from Studies III and IV center around social relationships and power. We have therefore provided a thick description of the setting to let readers consider whether they believe specific results may apply to their own contexts and health systems. However, because we used a framework that acknowledges context and relational dynamics, we assume that the more conceptual findings may be useful for other health systems. For instance, we found in Study IV that understanding the decision-making space could be a factor that helps health system actors act in response to floods. This may be a useful contribution to understanding the general characteristics that build resilience in health systems.

This thesis focuses only on the public sector of the health system. As described earlier, the private sector of the Cambodian system is widely unregulated. The public sector, in comparison, provided the opportunity to study a clearly structured organization that was accessible through our collaboration with the National Institute of Public Health, and access to consistent and reliable health facility data. Excluding the private sector likely had an impact on the result, primarily for Studies II and IV. Study II is likely to have underestimated the impact of floods on vector-borne and noncommunicable diseases as private providers are known to be the primary source of care for such health needs. In Study IV, the results reflect only the perspectives and experiences of public providers. It is highly likely that the private sector experiences floods in a different way and has different strategies and capacities for managing health needs during floods. Further exploration of their perspectives as well as the intersection between the public and private sectors during floods would be an important contribution to understanding resilience in this context. We did not limit the discussions in Study III to the public sector. Private sector providers like traditional birth attendants and maternity clinics arose as important resources for managing care, further supporting future explorations of the private sector and its role in creating resilience capacities during floods.

The thesis defined and measured floods in three commonly used ways that differed by study: human impact, frequency, and spatial boundaries [27]. Each of these definitions and measurements are open to different interpretations across studies. For instance, the criteria used in Study I set a numerical threshold to what is considered human impact (e.g. at least 100 people affected) for a flood disaster. The local populations in Studies III and IV regularly described 'big water' floods as affecting more than 100 people but did not consider them disasters. Similarly, we were not able to link the extent of flood water spatially mapped in Study II to the local definitions of flooding around severity and depth. It was then unclear if either the community or the health system considered the extent of flood water in the districts to be floods. The benefit of using multiple approaches meant that the floods could be contextualized as a shock in the local setting. This was apparent in Studies III and IV, although few differences between seasonally and occasionally flooded districts were described. Floods of both seasonal and occasional frequency were described from the health system perspective as strains rather than shocks and as often overwhelming events by the communities in both districts. We confirmed the local definitions of flooding that we developed before each interview or focus group in Study III and IV to help control the scope of how they were interpreted.

The findings from Studies III and IV offer insight into how the community and health system manage new and routine health needs during floods through the example of antenatal and childbirth care. The idea to use antenatal and birth care was drawn from Study II, where we found evidence to suggest that the number of deliveries at facilities or at home did not change during floods. However, antenatal and birth care are not directly representative of all new and routine health needs, and these services have undergone reforms and received investments to improve quality, health outcomes, and functioning. It is likely that the findings in these studies would differ, particularly around the concept of legitimacy, had we used other new and routine needs or specific health services.

### 7.4.1 Quantitative and review methods (Studies I and II)

The systematic review generated new information by disaggregating the spectrum of changes to health expected after flood and storm disasters over time. However, the low overall quality of the articles in Study I affected the quality and usefulness of the review, limiting the conclusions that can be drawn. The articles were subject to several methodological problems. The most common ones identified in the key articles were selection bias based on care-seeking behavior, potential misclassification of exposure (e.g. assuming all patients seeking care were exposed or not confirming the exposure occurred before the outcome), and poorly defined control groups or time periods. Furthermore, potential confounders such as age were only measured in 24 of the 60 key articles. Health outcome definitions were incongruent between articles, and articles lacked information on the severity of the outcome. This variety in quality, outcomes, and study designs made it difficult to synthesize the data and meant studies and outcomes could only be compared and contrasted at a low level of detail.

In addition, there may be publication bias among the included studies towards results that highlight a significant or adverse impact on health. During the conduct of the review, we included only studies written in English and potentially missed eligible studies (particularly from non-English speaking countries), introducing a degree of selection bias to the review. Some associations between a disaster and a health problem were limited to one study. Therefore, it is difficult to draw definitive conclusions from the review.

In Study II, a strength was the ability to use data from all public facilities across two districts, including primary care facilities which was in contrast to the majority of emergency facilities articles ain Study I. The study thus gave a realistic picture of health problems seen at public facilities during floods, but the data was subject to selection bias. It did not include private facility data and relied on the care seeking behavior of the population for multiple health problems. Also, facilities do not use standardized diagnoses and the data may be subject to classification issues across providers. Still, the internal consistency and completeness of the HMIS data were rated as good during the study period [146, 147]. The study may have been strengthened if private facility data, in addition to other potentially confounding factors like temperature, were included.

The flood water data was unable to capture flash floods because of the number of daily images needed to positively detect water and was therefore a valid indicator for inundation floods only. In addition, cloud cover obscured an average of 29.3% of map pixels per month in Prey Veng and 32.6% in Kampot. This may have resulted in an underestimation of flood water per month in both provinces.

### 7.4.2 Qualitative methods (Studies III and IV)

We used information power to guide the sample size for these studies [154]. We assessed that the final sample of eight focus groups and 37 interviews was sufficient, based on the broad aims and expected variation in the data across cases, plus the participant's expected specific information on the topic, quality of the dialogue, and use of a theory.

Both studies used a conceptual framework to guide the study development and data analysis. A strength of using the framework was that it enabled us to structure two perspectives of health needs during floods around the same concepts. By using the framework throughout study development, data collection, and analysis, the concepts were consistently applied across both studies. However, there were challenges to using such a framework. First, the relatively abstract concepts in the framework needed to be interpreted by both the researchers and the participants. We dealt with this by working to develop a common understanding of the concepts among the researchers. Prior to data collection, the team members and translator spent time translating concepts like 'uncertainty' from English to Khmer, to ensure that they were understood in equal terms by all members and would be consistently used with participants. The topic guides were written as straightforward questions about participants' experiences with health needs during floods to help make the concepts more concrete. During data analysis, a certain degree of abstraction from the data is required, so we chose a data-driven approach during coding and creating categories to ensure that the theoretical concepts did not eclipse other information in the data. Second, the framework was initially developed to explore characteristics of resilient health systems. We applied it to the community in Study III because of its focus on interactions that create the capacity to manage resilience, with the belief the interactions between the community and health system will affect the system's resilience. This allowed us to triangulate ideas between studies. Still, we encountered some difficulty in interpreting and drawing boundaries around the dimensions in the framework, like 'interdependence', as they related to both the health system and the community and the interactions between them.

We sought to enhance trustworthiness in the studies using multiple strategies. For credibility, or whether the findings correctly reflect the participant's views and the data [179], the research team members stayed in the districts during data collection and repeatedly visited the study sites. We used data collectors who were familiar with health service delivery at multiple levels in the rural Cambodian context. Data was triangulated by gathering information from multiple sites, across different strata of the community and the public health system and using additional methods like informal interviews. The team also discussed ideas and information as they came up during data collection. However, a key consideration is social desirability bias, or whether the participants felt able to share the full extent of their experiences with the data collectors. This is particularly relevant to Study IV, where we found it difficult to capture informal or deeper views from participants working at higher levels of authority. We may have had different results had we incorporated observations at facilities during floods into our methods or spent a longer amount of time at the health facilities to build trust.

An audit trail was kept from the studies' planning stages through data collection and analysis to record the paths of the studies and the decisions and their rationale along the way. This was done to keep track of the study processes, influences on the researcher's understanding of the data and research, and how these may have affected the analysis or findings [179]. For example, all iterations of the analysis were documented in a spreadsheet with notes on why changes were made. This was a valuable resource during manuscript writing to understand how our thinking about the relationship and relevance between codes and categories, for instance, had developed over time and after discussions among the authors.

Reflexivity centers on understanding how the researcher may influence the study and its findings [179]. My own background in global health and work in the research group on healthcare in disasters greatly informed the project's development, although the context and floods were new to me. Getting familiar with the context is a process that continues today, and was especially important for the qualitative studies, as I had never done qualitative research before. As an immigrant myself, I feel the process of learning a new context is essentially lifelong, and that my understanding of the Cambodian context, including its health system and communities, is relatively superficial. The team of researchers and data collectors working on the studies was a diverse group with different experiences of Cambodia, floods, resilience, and health systems. This opened up different perspectives on the context, interpretations of the data during analysis, and the studies' findings.

# 8 CONCLUSIONS

- There is evidence that flood disasters can increase new and routine health needs for up to two years (Study I). In the Cambodian context, repeated seasonal and occasional floods had a prolonged effect on new health needs, as visits to public healthcare facilities for diarrhea, acute respiratory infections, and skin infections increased immediately and up to three months afterwards; the impact on routine health needs was indeterminate (Study II).

- The public sector of the Cambodian health system appeared to have the capacity to absorb and adapt in order to manage antenatal and birth health needs during seasonal and occasional floods (Study IV). The public sector's capacity was aided by the community's own capacity to absorb, helping to relieve the burden of managing health needs on the health system during floods (Study III).

- Collaboration across health system levels and sectors and relationships that set boundaries on decision-making were described as a fundamental component of the public sector's capacity to adapt antenatal and childbirth health services when exposed to seasonal and occasional floods. Strategies that enhance stability and flexibility in contexts where extreme weather events are perceived as strains rather than shocks may enhance system capacities for resilience. (Study IV)

- Greater support for the community from the public health system during floods and involvement in decision-making may generate resilience capacities in the community and in turn strengthen the health system's resilience to repeated extreme weather events (Study III).

# 9 IMPLICATIONS FOR RESEARCH AND PRACTICE

**Further differentiate between extreme weather events and their impacts on new and routine health needs over time**

- Research should address health outcomes and healthcare utilization in the months following the events, with a focus on routine health needs and linking indirect outcomes to the event.
- Such information can be applied by health systems at the local and national level to prepare for and respond to health needs over time after extreme weather events.
- Using data from sources other than health facilities, when possible, can help to identify the full scope of health needs after such events.

**Recognize and incorporate context as a driving factor in developing health systems resilience**

- Knowledge on the transversal capacities that build resilience remains mostly theoretical. Studying system capacities and how they link to social, political, economic, and environmental contextual factors—for example, comparative case studies—could be one step towards identifying cross-contextual strategies to build resilience.
- Health systems should consider whether suggested strategies from other contexts for building resilience capacities will be effective or acceptable in their own context.

**Acknowledge and address the role of the community in managing health needs and its interlinkages with health systems resilience**

- Research could further investigate how community resilience contributes to health systems resilience to identify joint capacities and the limits to them in both the community and health system.
- At the local level, health systems are encouraged to work with communities to understand how community management of health needs could be incorporated into the health system response or to recognize existing gaps in community management of health needs that could be filled by the health system during extreme weather events like floods.
- Incorporating the community into planning processes for shocks may enable a greater sense of trust and ownership in the health system

**Learn from repeated exposure to shocks**

- Future research should consider the role of repetition of shocks in creating the capacity for the community and health system to absorb, adapt, and transform, as seen in Studies II, III, and IV. This may be of particular use if climate change increases the frequency of extreme weather events.
- The idea of shocks needs further clarification to enable health systems to know what they need to be resilient to. Classifying the characteristics of shocks and stresses by their source, duration, severity, frequency of exposure, and expected impacts would be a useful first step.
- Strengthening the definitions and classifying shocks and stresses could help identify events that fall between shocks and stresses, like the idea of strains raised in Study IV.

**Promote resilience as a process rather than a fixed set of capacities**

- Considering how health systems have developed and changed over time may illuminate the processes and pathways that have led to a system's capacity to manage resilience or not.
- Understanding changes over time may also help to further distinguish the boundaries between absorptive, adaptive, and transformative capacities.

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## APPENDIX 1: SYSTEMATIC REVIEW DATABASE SEARCH STRATEGIES

### Medline (Ovid)

1. exp Floods/
2. exp Cyclonic Storms/
3. (floods or flooding* or stormwater* or cyclon* or typhoon* or hurricane*).tw.
4. or/1-3
5. exp Vital Statistics/
6. Time Factors/
7. exp "Wounds and Injuries"/
8. exp Acute Disease/
9. exp Chronic Disease/
10. exp Disasters/
11. exp Disease Outbreaks/
12. Epidemiology/
13. exp Nutrition Disorders/
14. Health Status/
15. (injur* or morbid* or mortal* or wound* or epidemiolog* or stunting* or diseas* or nutrition* or fracture* or rupture* or burn* or death* or infect* or communicab*).tw.
16. (health adj2 (status or effect* or impact or outcome*)).tw.
17. or/5-16
18. 4 and 17
19. limit 18 to yr="1980 -Current"
20. remove duplicates from 19

### Cinahl (Ebsco)

| | |
|---|---|
| 1 | TI ( floods or flooding* or stormwater* or cyclon* or typhoon* or hurricane* ) OR AB ( floods or flooding* or stormwater* or cyclon* or typhoon* or hurricane* ) |
| 2 | (MH "Vital Statistics+") |
| 3 | (MH "Time Factors") |
| 4 | (MH "Wounds and Injuries+") |
| 5 | (MH "Acute Disease") |
| 6 | (MH "Chronic Disease") |
| 7 | (MH "Disasters+") |
| 8 | (MH "Disease Outbreaks") |
| 9 | (MH "Epidemiology+") |
| 10 | (MH "Nutrition Disorders+") |
| 11 | (MH "Health Status+") |
| 12 | TI ( injur* or morbid* or mortal* or wound* or epidemiolog* or stunting* or diseas* or nutrition* or fracture* or rupture* or burn* or death* or infect* or communicab* ) OR AB ( |

injur* or morbid* or mortal* or wound* or epidemiolog* or stunting* or diseas* or nutrition* or fracture* or rupture* or burn* or death* or infect* or communicab* )

13 TI ( health N2 (status or effect* or impact or outcome*) ) OR AB ( health N2 (status or effect* or impact or outcome*) )

14 S2 OR S3 OR S4 OR S5 OR S6 OR S7 OR S8 OR S9 OR S10 OR S11 OR S12 OR S13

15 S1 AND S14

Limit to 1981 - Current

**Global Health (Ovid)**

1. exp hurricanes/
2. exp floods/
3. (floods or flooding* or stormwater* or typhoon* or hurricane*).tw.
4. cyclon*.tw.
5. 1 or 2 or 3 or 4
6. exp vital statistics/
7. exp wounds/ or exp lesions/ or exp wound infections/ or exp wound treatment/
8. exp chronic diseases/
9. exp disasters/
10. epidemiology/
11. exp nutritional disorders/
12. (injur* or morbid* or mortal* or wound* or epidemiolog* or stunting* or diseas* or nutrition* or fracture* or rupture* or burn* or death* or infect* or communicab*).tw.
13. (health adj2 (status or effect* or impact or outcome*)).tw.
14. 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13
15. 5 and 14
16. limit 15 to yr="1980 -Current"

**Web of Science Core Collection**

# 5 **2,046** #2 AND #1

**Refined by:** [excluding] **RESEARCH AREAS:** ( ENVIRONMENTAL SCIENCES ECOLOGY OR OPERATIONS RESEARCH MANAGEMENT SCIENCE OR PLANT SCIENCES OR AGRICULTURE OR ENGINEERING OR SOCIOLOGY OR GEOLOGY OR MARINE FRESHWATER BIOLOGY OR WATER RESOURCES OR METEOROLOGY ATMOSPHERIC SCIENCES OR BUSINESS ECONOMICS OR MECHANICS OR FORESTRY OR URBAN STUDIES OR MATERIALS SCIENCE OR ZOOLOGY OR GOVERNMENT LAW OR CONSTRUCTION BUILDING TECHNOLOGY OR SCIENCE TECHNOLOGY OTHER TOPICS OR VETERINARY SCIENCES OR BIODIVERSITY CONSERVATION OR OCEANOGRAPHY OR FOOD SCIENCE TECHNOLOGY OR PHYSICAL GEOGRAPHY OR ENTOMOLOGY OR IMAGING SCIENCE PHOTOGRAPHIC TECHNOLOGY OR THERMODYNAMICS OR ENERGY FUELS OR MATHEMATICS OR MINING MINERAL PROCESSING OR FISHERIES OR MATHEMATICAL METHODS IN SOCIAL SCIENCES OR INSTRUMENTS INSTRUMENTATION OR COMPUTER SCIENCE OR HISTORY OR INFORMATION SCIENCE LIBRARY SCIENCE OR EDUCATION EDUCATIONAL RESEARCH OR TELECOMMUNICATIONS OR AUTOMATION CONTROL SYSTEMS OR ARCHAEOLOGY OR NUCLEAR SCIENCE TECHNOLOGY ) AND

**PUBLICATION YEARS:** ( 2014 OR 2015 OR 1995 OR 1983 OR 2011 OR 2000 OR 1993 OR 2013 OR 1996 OR 1994 OR 2009 OR 2002 OR 1992 OR 1984 OR 2007 OR 2004 OR 1991 OR 1980 OR 2010 OR 1999 OR 1981 OR 2012 OR 2001 OR 1990 OR 2008 OR 2003 OR 1987 OR 2006 OR 1998 OR 1988 OR 2005 OR 1997 OR 1986 )

# 3 **6,790** #2 AND #1

# 2 **5,695,385 TOPIC:** (injur* or morbid* or mortal* or wound* or epidemiolog* or stunting* or diseas* or nutrition* or burn* or death* or infect* or communicab*) OR **TOPIC**: (health NEAR/2 (status or effect* or impact or outcome*))

# 1 **122,669** **TOPIC**: (floods or flooding* or stormwater* or cyclon* or typhoon* or hurricane)

### Embase (embase.com)

**#18** #4 AND #16 AND [1980-2015]/py

**#17** #4 AND #16

**#16** #5 OR #6 OR #7 OR #8 OR #9 OR #10 OR #11 OR #12 OR #13 OR #14 OR #15

**#15** (health NEAR/2 (status OR effect* OR impact OR outcome*)):ab,ti

**#14** injur*:ab,ti OR morbid*:ab,ti OR mortal*:ab,ti OR wound*:ab,ti OR epidemiolog*:ab,ti OR stunting*:ab,ti OR diseas*:ab,ti ORnutrition*:ab,ti OR fracture*:ab,ti OR rupture*:ab,ti OR burn*:ab,ti OR death*:ab,ti OR infect*:ab,ti OR communicab*:ab,ti

**#13** ‘health status’/de

**#12** ‘nutritional disorder’/exp

**#11** ‘epidemiology’/de

**#10** ‘epidemic’/exp

**#9** ‘disaster’/exp

**#8** ‘chronic disease’/exp

**#7** ‘acute disease’/exp

**#6** ‘injury’/exp

**#5** ‘vital statistics’/exp

**#4** #1 OR #2 OR #3

**#3** floods:ab,ti OR flooding*:ab,ti OR stormwater*:ab,ti OR cyclon*:ab,ti OR typhoon*:ab,ti OR hurricane*:ab,ti

**#2** ‘hurricane’/exp

**#1** ‘flooding’/exp

### PubMed (non-indexed references)

(((((floods[Title/Abstract] OR flooding*[Title/Abstract] OR stormwater*[Title/Abstract] OR cyclon*[Title/Abstract] OR typhoon*[Title/Abstract] OR hurricane*[Title/Abstract])))

AND

((injur*[Title/Abstract] OR morbid*[Title/Abstract] OR mortal*[Title/Abstract] OR wound*[Title/Abstract] OR epidemiolog*[Title/Abstract] OR stunting*[Title/Abstract] OR diseas*[Title/Abstract] OR nutrition*[Title/Abstract] OR fracture*[Title/Abstract] OR rupture*[Title/Abstract] OR burn*[Title/Abstract] OR death*[Title/Abstract] OR infect*[Title/Abstract] OR communicab*[Title/Abstract]))))

NOT medline[sb]

## APPENDIX 2: SUMMARY OF MAIN FINDINGS AND QUALITY RATING OF THE SIXTY KEY ARTICLES

Abbreviations: RR: relative risk; OR: odds ratio; MOR: matched odds ratio; ARR: attributable rate ratio; APR: adjusted prevalence ratio; CI: 95% confidence interval (unless otherwise specified); CO: carbon monoxide; CDC: Centers for Disease Control and Prevention; WHO: World Health Organzation

Notes: * = no confidence interval given

| Author and quality | Disaster | Study objective | Study population, data sources, and comparison | Main findings |
|---|---|---|---|---|
| Hendrickson (1997)<br>**Quality:** Good | Storm<br>1992<br>USA | To measure increases in injuries and other health outcomes among an entire population in the impact zone of a storm | Record review: all patient visits<br>All primary, emergency care facilities on a Hawaiian island<br>2 weeks pre-/post-storm | Significant increase in injuries, asthma and cardiovascular diseases but no change in proportion of patients needing hospitalization<br>- Incidence of injuries increased post-storm (1 461 visits/100 000 people/week) from pre-storm (213/100 000/week)<br>- Higher risk of being injured post-storm (RR: 6.86, 95% CI: 5.98, 7.87)<br>- No change in proportion of injured needing admission between the two time periods (RR 0.97, 95% CI: 0.44, 2.12)<br>- Visits for cardiovascular complaints (RR 2.73, 95% CI: 1.51, 4.95) and asthma increased (RR 2.81, 95% CI: 1.93, 4.09) |
| Miller (2013)<br>**Quality:** Good | Storm<br>2011<br>USA | To characterize nonfatal injuries seen in emergency departments following a storm | Record review: patient visits for externally caused injuries<br>114 acute care facilities<br>Severely affected/affected counties, 2010 reference period | - Visits for injuries increased, primarily due to falls, cutting, or piercing<br>- In all counties, increases in proportion of injuries caused by falls or recreational activities (p=0.001) one week post-storm<br>- In severely affected counties, increases in proportion of injuries caused by cutting or piercing (p=0.012) one week post-storm |
| Platz (2007)<br>**Quality:** Good | Storms (n=3)<br>2004<br>USA | To evaluate the effect of three consecutive storms on emergency departments | Record review: all patient visits<br>2 hospital emergency departments<br>3 days pre-/post-storm, previous year reference period | - Significant increases in visits for injuries, CO poisoning, lack of oxygen/electricity/hemodialysis after the first storm<br>- Increase in visits for lacerations (p=0.0014), multiple/blunt trauma (p=0.0026) between control year and first storm<br>- No significant change in visits for medication refills<br>- Increase in visits for lack of oxygen, electricity, or hemodialysis (p=0.0015) and CO intoxication (p=0.0156) between control year and first storm |
| Chen (2013)<br>**Quality:** Good | Storm<br>2012<br>USA | To examine CO exposures in the two weeks following a storm | All phone calls, patient visits coded for exposure<br>Poison control hotline, hospital emergency departments<br>2008-2011 reference period | - Significant increase in CO exposure following the storm and destruction of infrastructure<br>- Calls about CO exposure increased (p<0.001) during study period |
| Kim (2013)<br>**Quality:** Poor | Storm<br>2012<br>USA | To describe gasoline exposure following a storm | All calls coded for exposure<br>Poison control hotline<br>2008-2011 reference period | - Calls for gasoline exposure increased post-storm<br>- 18 to 283-fold increase in exposure one-month post-storm compared to reference years (p<0.001) |
| CDC (1986)<br>**Quality:** Poor | Storms (n=2)<br>1985<br>USA | To determine the impact of the storms | Record review: all patient visits<br>4 hospital emergency departments and emergency call line<br>1 week pre-/post-storm | - Injuries, especially bee stings, increased post-storm<br>- Greater proportion of visits for corneal abrasions (OR: 3.9, p<0.05*)<br>- |

| Author and quality | Disaster | Study objective | Study population, data sources, and comparison | Main findings |
|---|---|---|---|---|
| Forrester (2008)<br><br>**Quality:** Fair | Storm 2005 USA | To evaluate whether the evacuation and storm landfall affected the pattern of poison control center calls | All calls<br>Poison control hotline<br>1 month pre-/during/2 weeks post-storm | - Total call volume increased for gasoline and CO exposure<br>- Gasoline exposure calls higher than expected (n=68, baseline rate:11-30) during landfall<br>- CO (n = 11, baseline rate: -2-10) and gasoline (n = 40, baseline rate: 12-28) exposure calls higher than expected post-storm |
| Forrester (2009)<br><br>**Quality:** Fair | Storm 2008 USA | To evaluate whether the storm affected the pattern of poison control center calls | All calls<br>Poison control hotline<br>1 month pre-/during/2 weeks post-storm | - Total call volume increased for gasoline and CO exposure<br>- Gasoline exposure calls higher than expected (mean:3, baseline rate: -1, 2) during landfall<br>- CO (mean:3, baseline rate: -1, 1) and gasoline (mean:5, baseline rate:-1, 2) exposure calls higher than expected post-storm |
| Quinn (1994)<br><br>**Quality:** Good | Storm 1992 USA | To determine the effect of a storm on a pediatric emergency department | Record review: all pediatric patient visits<br>1 hospital emergency department<br>1 week pre-/2 weeks post-storm | - More diagnoses of open wounds, gastroenteritis, and skin infections observed<br>- Increase in total number of visits for injuries (17% to 22.6%, p=0.01), open wounds (5.6% to 12% p=0.001), dermatologic (2.2% to 4.5%, p=0.01), cellulitis (0.3% to 1.2%, p=0.05) two weeks post-storm<br>- Increase in total number of visits for gastroenteritis (9.7% to 12.9%, p=0.05) one week post-storm<br>- No change to visits for soft tissue wounds<br>- Decrease in visits for upper respiratory infections (6.5% to 4.1%, p=0.05) two weeks post-storm<br>- Decrease in genitourinary complaints (2.8% to 0.9%, p=0.001) and nonspecific abdominal pain (1.9% to 0.7%, p=0.05) one week post-storm |
| Alhinai (2011)<br><br>**Quality:** Poor | Storm 2007 Oman | To compare number of patients and pattern of illnesses between disaster and peace times | Record review: all patient visits<br>1 primary healthcare center<br>2006 and 2008 reference period | - Significant increase in infectious and trauma-related visits<br>- Trauma-related visits accounted for 6.7% of visits during storm period compared to 4% in 2006 and 4.4% in 2008 (p<0.0001) reference periods<br>- Visits for diarrhea and lacerations significantly increased (p<0.001) during storm period<br>- Visits for respiratory infections and orthopedic trauma decreased (p<0.001) during storm period |
| Sjöberg (2007)<br><br>**Quality:** Fair | Storm 2004 Grenada | To document the types of patients and medical problems faced by hospital surgical services as a result of the storm | Record review: all admitted patients<br>Surgical ward of 1 hospital<br>2003 reference period | - Significant increase in patients seen for diabetic feet, gunshot wounds and infections due to wounds<br>- Increases in patients evaluated for diabetic foot (p=0.0074), infections from wounds (p=0.0066) within one month post-storm<br>- Decrease in patients evaluated for abdominal and other symptoms (p<0.0001 and p=0.0281) within one month post-storm |
| Sheppa (1993)<br><br>**Quality:** Poor | Storm 1989 USA | To determine the impact on emergency department operations of the storm | Record review: all patient visits<br>2 hospital emergency departments<br>1987-1988 reference period | - Increase in lacerations, puncture wounds, stings and falls in the 3 weeks post event; attributed to clean up activities.<br>- Increases in the proportions of visits for lacerations (8.6 to 11.3%, p<0.01), puncture wounds (1.1 to 2.5%, p<0.001), and chain saw lacerations (0.2 to 2.0%, p<0.001)<br>- No change in visits for gastrointestinal illness |
| Waring (2002)<br><br>**Quality:** Good | Storm 2001 USA | To evaluate the community's immediate public health needs | Randomly selected household survey<br>420 households<br>Flooded and non-flooded areas | - Increased illness in persons living in flooded homes (OR 4.7, 1.8, 12.0)<br>- Higher odds of diarrhea or stomach condition in flooded homes (OR 1.4, 95% CI: 1.4, 28.0) |

| Author and quality | Disaster | Study objective | Study population, data sources, and comparison | Main findings |
|---|---|---|---|---|
| CDC (2000)<br><br>**Quality:** Fair | Storm 1999 USA | To describe morbidity and mortality during and following the storm | Coroner reports, record review: all patient visits<br>20 hospital emergency departments<br>1998 reference period | - Drowning the main cause of death. Increase in visits for hypothermia, dog bites, and asthma.<br>- Increases in febrile illness (RR 1.5, 95% CI:1.3-1.9) and dermatitis (RR 1.4, 95% CI:1.2, 1.6) one week post-storm. Increase in diarrhea (RR 2.0, 95% CI:1.4, 2.8)<br>- Increase in asthma (RR 1.4, 95% CI:1.2, 1.7) one month post-storm<br>- Increase in basic medical needs (oxygen, medication refills, dialysis, vaccinations) (RR 1.4, 95% CI:1.2, 1.8) one week post-storm |
| Longmire (1988)<br><br>**Quality:** Fair | Storm 1985 USA | To determine what additional support would be needed to manage such a disaster | Record review: all patient visits<br>1 hospital emergency department<br>1 week pre-/2 weeks post-storm and 1983-1984 reference period | - Significant increase in patients treated for trauma and psychiatric problems<br>- Increase in lacerations, chain saw injuries ($p<0.05$) post-storm<br>- Increase in gastrointestinal complaints ($p<0.05$) post-storm |
| Deng (2015)<br><br>**Quality:** Good | Storms, 2005-2011 China | To assess the impact of storms and grades of accompanied precipitation on infectious diarrhea from 2005–2011 | Infectious diarrhea surveillance system, storm and rainfall data<br>1 province<br>All days 2005-2011 | - Storms and precipitation could contribute to increased risk of bacillary dysentery and other infectious diarrhea<br>- Precipitation a risk factor for bacillary dysentery and other infectious diarrhea at 25 mm (OR 3.25, 95% CI: 1.45-7.27) and 50 mm (OR 3.05, 95% CI: 2.2, 4.23)<br>- Greater odds of infectious diarrhea on lag days 6 (OR 2.3, 95% CI: 1.81, 2.93), lag day 5 (OR 3.56, 95% CI: 2.98, 4.25) after storms<br>- Greater odds of infectious diarrhea on lag day 2 (OR 2.47, 95% CI: 1.41, 4.33) and day 6 (OR 2.46, 95% CI: 1.69, 3.56) after tropical storms |
| Panda (2011)<br><br>**Quality:** Good | Storm 2009 India | To examine if storm was responsible for increased reporting of diarrhea cases from one district | Questionnaires for patients admitted for diarrhea<br>2 hospitals, 1 primary healthcare center<br>2007 reference period | - Significant increased occurrence of diarrhea in two of four affected areas<br>- Occurrence of diarrhea post-storm compared to reference year was OR 1.6, 95% CI: 1.52-1.65 for one affected area and OR 1.3, 95% CI: 1.21-1.32 for second area<br>- No increase in other areas. Cholera identified in 54% of cases. |
| Myint (2011)<br><br>**Quality:** Good | Storm 2008 Myanmar | To assess the situation of communicable diseases under national surveillance before and after a storm | Monthly communicable disease reports<br>2 national surveillance systems<br>1 year pre-/during/1 year post-storm | - Incidence of diarrhea, dysentery and acute respiratory infections increased post-storm in affected areas<br>- Incidence of other diseases and mortality rates did not increase.<br>- Disease patterns returned to normal 1 year post-storm. |
| Setzer (2004)<br><br>**Quality:** Good | Storm 1999 USA | To examine the effect of flooding from a storm on medical visits associated with waterborne pathogens | Record review: all insured outpatient visits for illnesses associated with waterborne pathogens<br>96 affected counties<br>Severely/less affected counties | - Small increases in visits in severely affected counties for two pathogens, relative to unaffected counties.<br>- Increase in outpatient visits for T. gondii ($p<0.05$) and adenoviruses ($p<0.01$) in severely affected counties compared to non-affected counties |
| WHO (2000)<br><br>**Quality:** Poor | Storm 1999 India | To investigate the possibility of a leptospirosis outbreak post-storm | Villagers with febrile illness<br>4 affected villages | - 22 confirmed cases of leptospirosis and 22 suspected cases |

| Author and quality | Disaster | Study objective | Study population, data sources, and comparison | Main findings |
|---|---|---|---|---|
| Vilain (2015)<br><br>**Quality:** Good | Storm 2014 France (Reunion Island) | To describe short-term health effects of the storm | Record review: all diagnoses<br>All emergency departments, emergency medical services, general practice and infectious disease surveillance systems<br>Daily/weekly reference periods | - Significant increase in visits for trauma, burns, and carbon monoxide poisoning detected in all emergency departments<br>- 10 confirmed cases of leptospirosis identified |
| Greene (2013)<br><br>**Quality:** Good | Storm 2012 USA | To assess whether storm-affected areas had higher disease incidence than unaffected areas | Daily cases of 42 reportable diseases<br>1 regional surveillance system<br>Affected/unaffected areas, 2007-2011 reference period | - Reportable disease incidence was not elevated post-storm<br>- Only legionellosis significantly increased in flooded areas post-storm (p=0.04); only 1 case reported |
| Fredrick (2015)<br><br>**Quality:** Good | Storm 2011 India | To investigate an outbreak of diarrhea in order to identify causes and recommend control measures | Cases of cholera in affected areas; matched controls<br>Household case finding, health facility surveillance system<br>Exposure to storm-affected drinking water supply | - Outbreak of cholera due to ingestion of water contaminated by drainage post-storm<br>- Cases began within first week after storm, rapid increase then decline by end of 2 weeks<br>- Matched odds ratio of 25 (95% CI: 4.9-285) for consumption of public drinking water and 37 (95% CI: 4.5-269) for unboiled water |
| Palacio (2005)<br><br>**Quality:** Fair | Storm 2005 USA | To improve identification of acute gastroenteritis, investigate the outbreak, and identify infectious agent | Evacuees with gastroenteritis symptoms<br>1 evacuation shelter medical facility | - Large outbreak of norovirus affected evacuees one week post-storm'<br>- 1 169 cases of acute gastroenteritis (18% of all evacuees), peaked 7 days after event |
| Bhattacharjee (2010)<br><br>**Quality:** Fair | Storm 2009 India | To explore cause of diarrhea outbreak and epidemiology of cholera strain | Record review: all patients admitted for diarrhea, questionnaire: 100 sampled cases<br>Health facilities in affected area | - 91% of all village residents in affected residential area had diarrhea, 26% of those severe or moderate<br>- V. fluvialis was predominant pathogen |
| Bhunia (2011)<br><br>**Quality:** Good | Storm 2009 India | To identify the agent and source of the outbreak as well as to propose control measures | Cases of cholera admitted to healthcare facilities; matched controls<br>Exposure to storm-affected drinking water supply | - Outbreak of cholera due to ingestion of water contaminated by drainage post-storm<br>- Cases began just after storm, peaked two months post-storm<br>- Matched odds ratio of 16 (95% CI: 4.9-51 )for consumption of unchlorinated piped water |
| Trevejo (1998)<br><br>**Quality:** Good | Storm 1995 Nicaragua | To identify and characterize etiologic agent of nonfebrile illness outbreak | Cases of malaria-negative patients hospitalized at facilities in affected areas; randomly selected, matched controls<br>Exposure to storm water | - Leptospirosis epidemic likely resulted from exposure to flood waters contaminated by urine from infected animals<br>- Matched odds ratio of 25 for walking in creeks (95% CI: 1.7–132.3) |
| Sanders (1999)<br><br>**Quality:** Good | Storm 1996 USA (Puerto Rico) | To determine the increase in leptospirosis after storm-generated floods | Record review: all patients with a negative dengue test<br>All facilities on an island<br>1 month pre-/3 weeks post-storm | - 4-fold increase in lab confirmed leptospirosis post-storm<br>- Relative risk of 4.4 (95% CI 1.6, 12.4) for testing positive for post-storm compared to pre-storm |
| Engelthaler (2005)<br><br>**Quality:** Poor | Storm 2005 USA | To describe investigation of *vibrio* cases after a storm | Reported cases of *Vibrio* infection<br>1 national surveillance system | - 18 wound associated cases of *Vibrio* found; 4 non-wound associated |

| Author and quality | Disaster | Study objective | Study population, data sources, and comparison | Main findings |
|---|---|---|---|---|
| Lin (2013)<br>**Quality:** Good | Storm<br>2009<br>Taiwan | To evaluate the impact of a storm on the incidence of lower extremity cellulitis and bacteriological characteristics of the patients | Record review: all patients<br>2 hospital emergency departments<br>1 month pre-/post-storm | - Patients seen for lower extremity cellulitis increased for up to 3 weeks post-storm<br>- Number of cellulitis patients increased in week 1 (RR 2.8, 95% CI: 2-4), week 2 (RR 2.0, 95% CI: 1.4-2.9), and week 3 (RR 1.53, 95% CI: 1-2.3).<br>- Cases of lower extremity cellulitis increased 88% after flood, constituted 6% of all ED visits |
| Caillouet (2008)<br>**Quality:** Good | Storm<br>2005<br>USA | To determine whether cases of West Nile neuroinvasive diseases increased regionally after a storm | Reported cases of West Nile neuroinvasive diseases<br>1 national surveillance system<br>3 weeks pre-/post-storm, 2002-2005 and 2006 reference periods | - Areas directly affected by storm experienced increases in cases after the storm compared to before the storm<br>- Cases increased from annual average of 30 (2002-2005) to 45 in 2006 in one affected region, and from 23 to 55 cases in another<br>- Incidence rate ratio between 2002-2005 and 2006 for two affected regions was 2.09 (95% CI: 1.48, 2.94) and 2.45 (95% CI: 1.77, 3.47) |
| Beatty (2007)<br>**Quality:** Poor | Storm<br>2004<br>Haiti | To assess the incidence of vector-borne diseases in the wake of a storm | All febrile patients<br>1 regional surveillance system | - No outbreaks of mosquito-borne illnesses detected |
| Schwartz (2006)<br>**Quality:** Good | Flood (n=3)<br>1988, 1998, 2004<br>Bangladesh | To examine demographic and microbiologic features that characterize recent diarrheal epidemics | Record review: All persons with an episode of diarrhea<br>Health and demographic surveillance site<br>Same flood weeks in 1 year pre/post flood for each flood | - Cholera is predominant cause of flood-associated diarrhea epidemics<br>- Approximate doubling in proportion of patients with V. cholerae infection compared with the seasonally matched control period (1998: 42% from 20%, p<0.001; 2004 first epidemic: 23% from 11%, p<0.001)<br>- In the 1988 and second 2004 epidemics, there was a lower but still significant increase in the proportion of patients with V. cholerae compared with seasonally matched periods (1988: 25% from 15%, p<0.01; 2004 second epidemic: 41% from 32%, p=0.03) |
| Gertler (2015)<br>**Quality:** Good | Flood<br>2013<br>Germany | To investigate sources and modes for infection with cryptosporidiosis after flood | Cases of cryptosporidiosis in children; matched controls<br>Exposure to flood water | - Compared to controls, cases were more likely to report visits to previously flooded areas (OR 4.9; 95% CI: 1.4-18)<br>- In multivariable analysis visits to the floodplain remained the sole risk factor (OR: 5.5; 95% CI: 1.4-22) |
| CDC (2012)<br>**Quality:** Fair | Flood<br>2010<br>Pakistan | To describe disease early warning surveillance system results after flood | Cases of 13 defined conditions presenting at fixed and mobile health facilities in flood-affected areas<br>1 surveillance system | - Of the 130 outbreak alerts, 88.5% were for acute watery diarrhea, 5.4% for suspected measles, 1.5% for acute flaccid paralysis and 1.5% for meningitis |
| Milojevic (2012)<br>**Quality:** Good | Flood<br>2004<br>Bangladesh | To analyze the health effects of flooding in rural Bangladesh | All visits to facilities for acute respiratory infections, diarrhea; all registered deaths<br>Health and demographic surveillance site<br>Flooded/non-flooded areas | - Little evidence of increase risk of diarrhea or mortality post event (0-3 years) but a moderate elevation in risk of ARI during 2 years following flood<br>- No evidence of a significant increase in mortality or diarrhea<br>- No increase in risk of acute respiratory infections during flood, but increased 6 months after (RR 1.25, 95% CI: 1.06-1.47) |

| Author and quality | Disaster | Study objective | Study population, data sources, and comparison | Main findings |
|---|---|---|---|---|
| Smith (2013)<br><br>**Quality:** Poor | Flood 2010-2011 Australia | To describe leptospirosis outbreak after flooding | Confirmed cases of leptospirosis<br>1 regional surveillance system | - 9 confirmed cases of leptospirosis exposed to flood water<br>- 7 developed during flood or 2 in weeks following flooding<br>- Median number of days between first exposure to flood water and illness was 20.5 days (range: 13-31) |
| Dechet (2012)<br><br>**Quality:** Poor | Flood 2005 Guyana | To describe a leptospirosis outbreak following severe flooding | Questionnaire for patients admitted with suspected cases of leptospirosis<br>4 facilities in affected areas | - An outbreak of leptospirosis was confirmed after flooding<br>- 34 deaths: 11 confirmed leptospirosis, 10 probable, 13 suspected<br>- 236 suspected cases. Of 105 tested, 52 were positive for leptospirosis<br>- 89% of positive cases reported contact with flood water |
| Pradutkanchana (2003)<br><br>**Quality:** Poor | Flood 2000 Thailand | To determine etiology of acute pyrexia of unknown origin cases after a flood | All pediatric patients presenting with acute fever >1 day<br>1 hospital in flooded area | - Dengue was most common cause of fever, followed closely by leptospirosis<br>- 29.4% of cases had dengue infection. 27.2% had leptospirosis infection |
| Bich (2011)<br><br>**Quality:** Good | Flood 2008 Vietnam | To identify differences in mortality, injuries and morbidity between flood affected and non-flood affected households | Randomly selected household survey<br>781 households<br>Severely affected/less affected communes | - Higher incidences of dengue fever, pink eye, and dermatitis in communes severely affected by flood compared to less affected communes<br>- No significant difference in proportion of dengue cases between severely and less affected communes.<br>- Significant ($p<0.05$) difference in proportions of pink eye, dermatitis worsened hypertension in flooded households compared to non-flooded<br>- Access to usual health care or medications compromised in flooded households compared to non-flooded ($p<0.05$) |
| McCarthy (1996)<br><br>**Quality:** Fair | Flood 1998 Sudan | To determine the etiology and importance of arboviral and other infectious diseases as the cause of febrile illness following flooding | Cases of acute fever presenting at outpatient clinics; matched controls | - Acute malaria a cause of febrile illness in weeks after initial flood<br>- Among 192 of the 200 cases and all 100 controls, 43 (22%) of the cases and 2 of the controls were positive for P. falciparum, ($P < 0.001$)<br>- |
| Cookson (2008)<br><br>**Quality:** Fair | Storm 2005 USA | To assess morbidity and mortality among evacuees using an internet-based surveillance system after a storm | Storm evacuees seeking care at shelters or hospitals<br>7 hospital emergency departments, 13 shelters<br>8 months pre-/1 month post-storm | - Of all conditions seen, only a significant increase in cardiopulmonary complaints from 2.3% to 7.3% of emergency department visits ($p=0.03$) |
| Gautam (2009)<br><br>**Quality:** Good | Storm 2005 USA | To detect any long-term increase in the incidence of acute myocardial infarction after a storm | Record review: all patients admitted for acute myocardial infarction<br>1 hospital<br>2 years pre-/2 years post-storm | - A 3-fold increase in the incidence of acute coronary syndrome in the two years following the storm<br>- Significant increase in percentage of acute myocardial infarction admissions before and after the storm (0.71% to 2.18%, $p<0.0001$)<br>- The post-storm group had a significantly higher prevalence of unemployment ($p<0.0003$), lack of medical insurance ($p<0.0001$), medication noncompliance ($p<0.0001$), and living in temporary housing ($P=0.003$). |

| Author and quality | Disaster | Study objective | Study population, data sources, and comparison | Main findings |
|---|---|---|---|---|
| Fonseca (2009)<br><br>**Quality:** Good | Storm<br>2005<br>USA | To examine the impact of a storm on the health of individuals with diabetes | Record review: adults with diabetes<br>3 healthcare system facilities<br>6 months pre-/6-16 months post-storm | - Significant increases in A1C, blood pressure, and lipids after the storm<br>- A1C values increased significantly (p<0.001) for one health system from 7.7 +1.7 to 8.1 + 2.1.<br>- Mean systolic blood pressure increased in all 3 systems (p<0.009)<br>- Mean low-density lipoprotein levels increased in 2 systems (p<0.001) but high-density lipoprotein levels increased at one and decreased at 2 systems (p<0.001)<br>- Linear regression shows significant increase in A1C over time post-storm for all 3 systems (p<0.05). |
| Park (2013)<br><br>**Quality:** Good | Storm (n=3)<br>2003, 2006, 2007<br>South Korea | To determine whether typhoons and heavy rain increase allergic disease | Record review: outpatient visits for allergic disease<br>Outpatient clinics in 16 affected cities<br>2003-2009 reference periods | - Observed increase in allergic diseases but not asthma after storms<br>- For all storms combined, the rate ratio for asthma decreased by day 6 post-storm (RR: 0.900, 95% CI: 0.862-0.937) but allergic rhinitis increased by day 6 (RR: 1.191, 95% CI: 1.150-1.232) |
| Swerdel (2014)<br><br>**Quality:** Good | Storm<br>2012<br>USA | To examine changes in the incidence and mortality of cardiovascular events after a storm | Record review: all discharge diagnoses and deaths<br>All nonfederal hospitals in one state<br>2007-2011 reference period | - In the two weeks following the storm, the incidence and mortality from myocardial infarctions increased, and the incidence of stroke increased<br>- 22% increase in adjusted attributable rate ratio (95% CI: 1.16, 1.28) for myocardial infarction incidence and for myocardial infarction mortality (ARR: 1.31, 95% CI: 1.22, 1.41) two weeks post-storm<br>- 7% increase in adjusted attributable rate ratio for stroke incidence (95% CI: 1.03, 1.11)<br>- Decrease in adjusted incidence of all cardiovascular events (ARR: 0.92, 95% CI: 0.90, 0.95) but increase in 30-day mortality (ARR: 1.22, 95% CI: 1.15, 1.30) |
| Rath (2007)<br><br>**Quality:** Fair | Storm<br>2005<br>USA | To evaluate difference between children and adolescents with and without chronic conditions immediately following a storm | Facility-based survey: Outpatient pediatric patients<br>Multiple health facilities<br>Participants with and without pre-existing chronic conditions | - Children and adolescents with chronic conditions at increased risk of adverse outcomes following a disaster<br>- Children with chronic conditions more likely to have worsened asthma (16.3 versus 1.9%, p<0.001), miss doctor's visits (49.2% versus 39.8%, p<0.01), run out of medications (33.9 versus 7.9%, p<0.001), or experience one disruption in care (58.4 versus 38.3%, p<0.001) |
| Rabito (2010)<br><br>**Quality:** Good | Storm<br>2005<br>USA | To examine the relationship between mold and dampness exposure and mold sensitization following a storm | Patients presenting for allergen testing<br>1 medical facility<br>Level of exposure to storm-induced dampness and mold | - No significant relationship between mold exposure and allergy sensitization |
| Simeon (1993)<br><br>**Quality:** Fair | Storm<br>1988<br>Jamaica | To investigate effects of a storm on growth and morbidity of at-risk children | Stunted and non-stunted children enrolled in a nutritional program<br>Households in affected areas<br>Stunted and non-stunted groups | - Stunted children gained less weight (p<0.002) and height (p<0.03) than non-stunted children in the two months post-storm<br>- All children spent significantly more time ill post-storm (p<0.001) with nasal discharge and cough than pre-storm |
| Duff (1994)<br><br>**Quality:** Poor | Storm<br>1988<br>Jamaica | To determine if neural tube defects were changed due to a storm | Cases of children $\leq$18 months of age with neutral tube defects; matched controls<br>Maternal exposure to folate in post-storm in affected areas | - Association between low folate intake and neural tube defects after change in food availability post-storm<br>- Daily intake of folate among mothers significantly lower in case group (p<0.0001) than controls |

| Author and quality | Disaster | Study objective | Study population, data sources, and comparison | Main findings |
|---|---|---|---|---|
| Barrios (2000)<br><br>**Quality:** Good | Storm<br>1998<br>Honduras | To report the prevalence of severe and mild-to-moderate malnutrition among children under 5 in 3 affected regions of Honduras | Random sample of children under 5 living at home or evacuated<br>Affected households or evacuation shelters<br>Severely and moderately affected areas; pre-storm nutritional survey data | - Significant increase in stunting and underweight after the storm<br>- Significant differences in mean weight-for-height in severely versus moderately affected areas ($p<0.05$) |
| Howard (2012)<br><br>**Quality:** Good | Storm<br>2005<br>USA | To estimate the impact of a storm on hospitalization rates among dialysis patients | Record review: patients receiving dialysis<br>103 clinics affected by the storm<br>2004-2006 reference periods | - Hospitalization rates among dialysis patients increased in the month following the storm, most significantly for renal-related causes<br>- Rate ratios rose for any hospitalizations (RR: 1.16, 95% CI: 1.05-1.29), renal-related admissions (RR: 2.53, 95% CI: 2.09, 3.06) in the month after the storm<br>- 140 excess renal-related admissions were attributable to storm<br>- Decline in incident cases during period around storm due to outmigration |
| Sihawong (2011)<br><br>**Quality:** Good | Flood<br>2011<br>Thailand | To examine whether the incidences of neck and low-back symptoms were elevated during the floods and to explore flood-related risk factors for neck and low-back symptoms | Participants enrolled in ongoing trial on exercise programs for spine mobility<br>Questionnaires at 6 large offices in a flooded city<br>3 months pre-/post-flooding | - No difference in the incidence of symptoms of neck or low-back pain during or after flooding |
| Ng (2010)<br><br>**Quality:** Good | Flood<br>2007<br>UK | To establish whether the glycemic control of the population of patients with diabetes mellitus was affected by the flooding | All patients in region registered as diabetic<br>Affected and unaffected households<br>12 months pre-/post-flooding; affected and unaffected households | - Glycemic control deteriorated after flooding for those affected who were taking insulin, and was worst at 6-9 months after the flood<br>- No change in mean HbA1C in the unaffected patient group<br>- A significant increase ($p=0.002$) in HbA1C in the affected group from a mean of 7.6% (95% CI: 7.5, 7.7) to a mean of 7.9% (95% CI: 7.7-8.0)<br>- No change in mean HbA1c for insulin takers in the unaffected group<br>- Significant increases in mean HbA1C for both Type 1 patients who took insulin from a mean of 8.1% (95% CI: 7.9, 8.5) to 8.6% (95% CI: 8.2, 8.9) ($p=0.02$) and in Type 2 patients who took insulin from 8.2% (95% CI: 7.9, 8.4) to 8.6% (95% CI: 8.3, 8.8) ($p=0.04$)<br>- Largest and most significant increase from reference Hba1c was 6-9 months post flood, but only in group affected by flooding |
| Kutner (2009)<br><br>**Quality:** Good | Storm<br>2005<br>USA | To investigate whether a storm resulted in excess mortality among dialysis patients | Record review: all patients enrolled in a national dialysis cohort<br>94 dialysis clinics in affected areas<br>2003-2006 reference period | - Storm was not significantly associated with mortality risk |

| Author and quality | Disaster | Study objective | Study population, data sources, and comparison | Main findings |
|---|---|---|---|---|
| Rodrigues-Llanes (2011)<br><br>**Quality:** Good | Flood 2008 India | To explore the strengths of association between flooding and the prevalence of undernutrition while taking other variables that directly affect nutrition into account | Children under five measured for height and weight<br>Randomly selected households in flooded and non-flooded villages<br>Living in flooded and non-flooded villages | - Exposure to floods was associated with long-term malnutrition<br>- Children living in flooded homes more likely stunted (APR: 1.6, 95% CI: 1.05-2.44) and underweight (APR 1.86, 95% CI: 1.04-3.30)<br>- The difference in stunting scores for flooded compared to non-flooded households were only significant for ages 26-36 months (p=0.0006) |
| Cummings (2008)<br><br>**Quality:** Good | Storm 2005 USA | To investigate the relation between respiratory symptoms and exposure to water-damaged homes and the effect of respirator use post-storm | Adults living in affected city area<br>Questionnaires obtained from randomly selected households in 1 affected city area<br>Water-damaged and non-damaged households | - Respiratory symptoms were positively associated with exposure<br>- to water-damaged homes<br>- Significant positive associations between exposure to water-damaged homes and upper respiratory symptoms ($p<0.05$), lower respiratory symptoms (p=0.01) and overall symptoms ($p<0.01$)<br>- |
| Rabito (2008)<br><br>**Quality:** Good | Storm 2005 USA | To examine children's respiratory health and indoor mold levels post-storm | Questionnaires of children aged 7-14 attending a private primary school<br>Children's households<br>Flooded and non-flooded homes; pre-/post-storm | - There was an overall decrease in mold levels and respiratory symptoms over the study period, and lung function and respiratory symptoms were normal 6 months post-storm<br>- By 6 months post-storm, there was a significant decrease in percentage of lower respiratory symptoms at least once per week in respondents compared to before the flood (from 9.7% to 6.9%, p=0.04)<br>- No difference in spirometry values seen 4 and 6 months after storm |
| Hendrickson (1996)<br><br>**Quality:** Good | Storm 1992 USA | To assess whether the storm was associated with increased mortality in the 12-month period following the storm | Record review: registered deaths of island residents<br>Entire affected island<br>5 years pre-/12 months post-storm | - Overall mortality did not increase significantly post event<br>- Deaths from diabetes increased significantly post-event (RR: 2.61, 95% CI: 1.44, 4.74)<br>- Leading causes of death were same in the pre- and post-storm periods |
| McKinney (2011)<br><br>**Quality:** Good | Storm (n=4) 2004 USA | To quantify the number of direct and indirect deaths resulting from four storms | Record review: registered deaths in affected area<br>Multiple affected counties<br>2001-2006 reference period | - Significant increases in overall mortality from selected conditions ($p<0.05$) in the 6 to 8 weeks post-storms<br>- Heart-related deaths significantly elevated for 62 days post-storm<br>- Cancer-related deaths significantly elevated for 24 days post-storm<br>- Diabetes-related deaths significantly elevated for 15 days post-storm |

## APPENDIX 3: STUDY III TOPIC GUIDE FOR FOCUS GROUP DISCUSSIONS AND SEMI-STRUCTURED INTERVIEWS

**Flood experiences**

*Give example of recent flood in the area and confirm event (when, where, length of flood)*. What happened during this flood?

> *Explore*: Effect on village and health, other recent floods

**Care seeking and management of health needs**

How do women take care of their pregnancy during a flood? What do women do when they give birth during a flood?

> *Explore:* Health center, private providers, spiritual healers, traditional medicine, traditional birth attendants, role of family, baby's father, boats and transport, delivering at home, community-based programs from health center during floods

How do floods change the prenatal care women can get? How do floods change the delivery care women can get?

> *Explore:* Reasons for changes, change in quality of care, supplies, medicines, and providers, cost, access and availability

Is the way women manage their pregnancy during floods different if you compare…? What about for deliveries?

> a) Women who are richer with women who are poorer, b) First child or multiple children, c) Grew up in this district or from another district, d) Complicated or uncomplicated pregnancy, e) Early in the pregnancy versus last month of the pregnancy

**Anticipating and coping with uncertainty**

When a woman is pregnant, how does she prepare for the rainy season?

> *Explore:* Beginning compared to end of pregnancy, transport and boats, money, spiritual or traditional medicine practices

What does a woman do if there is a problem with her pregnancy during a flood? What does she do if there is a problem during the birth and there is a flood?

> *Explore:* Care seeking by type of provider and reasons why, decision to seek care, referrals to hospital

**External factors influencing the health system**

What makes it easier for women to manage their pregnancy or birth during floods? What makes it harder?

Can you describe a time when a woman was not able to get prenatal care during a flood? What happened?

What about a time when a woman was not able to get delivery care? What happened then?

**Interaction with the community**

What are some reasons that women visit _____ providers for prenatal care during floods? What are some reasons that women visit ____ when she delivers a baby during a flood?

> *Explore:* Public providers, private providers, traditional birth attendants, drug shops, traditional medicine providers, other

How do you think the pregnant women feel about the prenatal care that they can get during floods? How do you think pregnant women feel about the delivery care they can get during floods?

> *Explore:* Trust in provider, attention, convenience, and quality of services, feeling of ownership

**Gathering and using knowledge**

How do women decide what kind of prenatal care they will get during floods? How do they decide what kind of delivery care they will get?

> *Explore:* Sources of information, social media and how they communicate with others, ability to make decisions

Who do women talk to about prenatal care during floods? Who do they talk to about delivery care during floods?

> *Explore:* Interaction with providers, traditional birth attendants, spiritual healers, traditional medicine, family and community

What is an example of something that all women in this village should know about managing their pregnancy during floods? …for delivering a baby?

## APPENDIX 4: STUDY IV TOPIC GUIDE FOR SEMI-STRUCTURED INTERVIEWS

**Flood experiences**

*Give example of recent flood in the area and confirm event (when, where, length of flood)*. Can you tell me about the last flood that happened near your [facility/catchment area]?

> *Explore*: Effect on villages and health

Can you describe your experiences of working during a flood?

> *Explore:* Changes/differences in care compared to no floods

**Provision and maintenance of services**

When there is a flood, what happens to prenatal care services at your [facility/catchment area]? What happens to delivery care services?

> *Explore:* Demand and access to care, staff changes, supplies, medicines, user fees, budget, management from upper levels

Can you describe a time when a woman was not able to get prenatal care at a [facility] during a flood? What happened? What about a time when a woman was not able to get delivery care at a [facility]? What happened then?

**Anticipating and coping with uncertainty**

How do you prepare prenatal services for the rainy season? How do you prepare delivery services?

Can you share specific examples of things that you do at the [facility/health department] to make sure that pregnant women are able to continue getting care during floods?

**External factors influencing the health system**

What are some reasons that your [facility/health department] might not be able to provide prenatal care during floods? What about for delivery care?

> *Explore:* Support and work with other departments/sectors/NGOs/committees, transport and access to facilities, supply chain, available funds, staff personal lives and priorities, changes in health, emergencies

What do you think influences pregnant women to come to your facility for prenatal care during floods? What about for delivery care?

**Interaction with the community**

How does the [facility/health department] work with pregnant women in the village during floods?

> *Explore:* Reasons for visiting other providers or home delivery, outreach in villages, input and accountability with community

In your opinion, how do you think the pregnant women feel about the prenatal care that they can get at [facilities] during floods? What about delivery care?

> *Explore:* Trust and quality, social media, feeling of ownership

**Gathering and using knowledge**

What kind of decisions do you have to make about services for prenatal care during floods? For delivery care?

> *Explore:* Referring patients to hospital, emergency obstetric cases, sources of information, communication with other departments/facilities/committees, flexibility and ability to make decisions

From your experience working during floods, what have you learned about providing prenatal care during floods? What have you learned about providing delivery care?

Can you give me an example of something you would like to know when there is a flood that would help make prenatal care better during floods? And for delivery care?

## APPENDIX 5: STUDY II TABLE OF INCIDENCE RATE RATIOS

Incidence rate ratios and 95% confidence intervals for diarrhea, acute respiratory infections, vector-borne diseases, skin infections, noncommunicable diseases and injuries by district, corresponding to a ten square kilometer increase in flood water, controlled for season and year. Rate ratios and confidence intervals written in bold text are statistically significant.

| **Diarrhea** | | | | |
|---|---|---|---|---|
| | Lag 0 | Lag 1 | Lag 2 | Lag 3 |
| *Prey Veng* | | | | |
| Kamchay Mear | 0.82 (0.49–1.35) | 0.90 (0.51–1.57) | 0.73 (0.52–1.01) | 0.95 (0.52–1.72) |
| Kampong Trabek | 0.93 (0.84–1.03) | **0.88 (0.82–0.94)** | **0.87 (0.80–0.95)** | **1.17 (1.05–1.29)** |
| Mesang | 0.99 (0.78–1.25) | 0.95 (0.69–1.30) | **0.81 (0.67–0.99)** | 1.04 (0.81–1.33) |
| Peam Ror | 1.03 (0.99–1.07) | **0.94 (0.90–0.99)** | 1.00 (0.96–1.05) | **1.06 (1.02–1.11)** |
| Peareaing | 0.99 (0.95–1.04) | 0.98 (0.95–1.02) | 0.98 (0.95–1.02) | 1.04 (0.99–1.08) |
| Preah Sdach | **1.05 (1.00–1.09)** | 0.99 (0.94–1.04) | 0.98 (0.92–1.05) | 1.04 (0.98–1.10) |
| Svay Antor | 1.04 (0.95–1.13) | 0.96 (0.86–1.06) | 0.86 (0.73–1.03) | **1.14 (1.02–1.27)** |
| *Kampot* | | | | |
| Angkor Chey | 0.03 (0.00–31.52) | 0.83 (0.00–104.51) | 0.00 (0.00–3.29) | 4.01 (0.03–535.26) |
| Chhouk | **0.00 (0.00–0.67)** | 2.2e+9 (0.00–1.6e+24) | 0.00 (0.00–2.8e+7) | 214.10 (0.00–5.6e+15) |
| Kampong Trach | **1.68 (1.40–2.00)** | **0.76 (0.65–0.90)** | **0.74 (0.56–0.97)** | 1.16 (0.87–1.54) |
| Kampot | 1.62 (0.22–11.66) | 0.43 (0.08–2.21) | 9.62 (0.80–115.87) | 1.30 (0.40–4.25) |
| | Lag 0 imputed | Lag 1 imputed | Lag 2 imputed | Lag 3 imputed |
| *Prey Veng* | | | | |
| Kamchay Mear | | | | |
| Kampong Trabek | | | | |
| Mesang | | | | |
| Peam Ror | | | | |
| Peareaing | 0.99 (0.95–1.03) | 0.97 (0.94–1.01) | 0.99 (0.95–1.03) | 1.04 (0.99–1.08) |
| Preah Sdach | | | | |
| Svay Antor | 1.00 (0.94–1.07) | **0.92 (0.85–0.99)** | 0.95 (0.87–1.03) | **1.09 (1.01–1.16)** |
| *Kampot* | | | | |
| Angkor Chey | 2.14 (0.27–16.80) | 2.75 (0.55–13.74) | 0.22 (0.01–5.05) | **22.54 (4.49–113.21)** |
| Chhouk | 0.00 (0.00–19.05) | 297.45 (0.00–3.7e+12) | 0.03 (0.00–3.5e+9) | 163179.1 (0.00–5.3e+15) |
| Kampong Trach | **1.55 (1.33–1.80)** | **0.79 (0.71–0.89)** | 0.85 (0.72–1.00) | 1.23 (1.00–1.50) |
| Kampot | 0.49 (0.11–2.04) | 0.96 (0.31–2.97) | 1.48 (0.50–4.42) | 1.32 (0.46–3.79) |

| Acute respiratory infections | | | | |
|---|---|---|---|---|
| | Lag 0 | Lag 1 | Lag 2 | Lag 3 |
| *Prey Veng* | | | | |
| Kamchay Mear | 0.61 (0.34–1.09) | 0.74 (0.48–1.14) | 0.98 (0.69–1.40) | 1.21 (0.92–1.59) |
| Kampong Trabek | 1.01 (0.90–1.12) | 1.02 (0.93–1.13) | 0.97 (0.87–1.07) | 1.08 (0.98–1.20) |
| Mesang | 0.97 (0.80–1.19) | 1.03 (0.79–1.34) | 0.88 (0.75–1.02) | 1.08 (0.91–1.28) |
| Peam Ror | 1.02 (0.98–1.06) | **0.94 (0.90–0.99)** | **1.05 (1.01–1.10)** | 1.03 (0.99–1.07) |
| Peareaing | **1.05 (1.02–1.08)** | 1.01 (0.99–1.03) | 0.99 (0.96–1.02) | **1.03 (1.00–1.05)** |
| Preah Sdach | 1.04 (0.99–1.08) | 0.99 (0.95–1.04) | 1.01 (0.95–1.07) | 1.02 (0.96–1.08) |
| Svay Antor | 1.07 (0.98–1.07) | 0.96 (0.87–1.07) | 0.94 (0.82–1.08) | **1.11 (1.02–1.22)** |
| *Kampot* | | | | |
| Angkor Chey | 2.98 (0.32–28.15) | **8.02 (2.18–29.46)** | 0.49 (0.00–248.27) | 1.72 (0.02–168.71) |
| Chhouk | 11167.12 (0.00–1.8e+12) | 48187.75 (0.00–2.2e+13) | 0.00 (0.00–1069161) | 0.00 (0.00–290249.7) |
| Kampong Trach | **1.44 (1.28–1.62)** | 0.92 (0.83–1.01) | 0.89 (0.76–1.03) | **1.20 (1.05–1.38)** |
| Kampot | 0.84 (0.30–2.33) | 0.85 (0.30–2.39) | 1.10 (0.37–3.32) | **0.40 (0.16–0.96)** |
| | Lag 0 imputed | Lag 1 imputed | Lag 2 imputed | Lag 3 imputed |
| *Prey Veng* | | | | |
| Kamchay Mear | | | | |
| Kampong Trabek | | | | |
| Mesang | | | | |
| Peam Ror | | | | |
| Peareaing | **1.04 (1.01–1.07)** | 1.00 (0.99–1.02) | 0.99 (0.97–1.02) | **1.03 (1.01–1.05)** |
| Preah Sdach | | | | |
| Svay Antor | 1.04 (0.98–1.12) | 0.94 (0.86–1.02) | 1.00 (0.93–1.08) | **1.08 (1.01–1.16)** |
| *Kampot* | | | | |
| Angkor Chey | | | | |
| Chhouk | | | | |
| Kampong Trach | | | | |
| Kampot | | | | |

| Vector-borne diseases | | | | |
|---|---|---|---|---|
| | Lag 0 | Lag 1 | Lag 2 | Lag 3 |
| *Prey Veng* | | | | |
| Kamchay Mear | 0.36 (0.02–5.81) | 0.24 (0.01–8.78) | 0.47 (0.03–7.91) | 1.68 (0.04–70.87) |
| Kampong Trabek | 1.28 (0.75–2.16) | 0.96 (0.53–1.74) | 0.60 (0.25–1.43) | 0.63 (0.25–1.56) |
| Mesang | 1.56 (0.29–8.27) | 2.31 (0.25–21.07) | 2.72 (0.39–19.01) | 1.46 (0.23–9.43) |
| Peam Ror | 1.25 (0.92–1.70) | 0.99 (0.67–1.48) | 0.64 (0.29–1.41) | 1.30 (0.60–2.81) |
| Peareaing | **0.77 (0.60–0.99)** | **0.75 (0.58–0.97)** | 1.02 (0.71–1.47) | 1.03 (0.77–1.37) |
| Preah Sdach | 0.99 (0.74–1.33) | 0.96 (0.67–1.38) | 1.05 (0.76–1.45) | 1.00 (0.74–1.37) |
| Svay Antor | **2.07 (1.39–3.10)** | 0.75 (0.46–1.21) | 0.79 (0.46–1.34) | 0.96 (0.60–1.55) |
| *Kampot* | | | | |
| Angkor Chey | 0.00 (0.00–94.71) | 0.00 (0.00–3.65) | **0.00 (0.00–0.37)** | 0.00 (0.00–2.24) |
| Chhouk | **7.8e+23 (3.0e+8–2.0e+39)** | 12.87 (0.00–9.1e+15) | **6.9e+40 (2.3e+15–2.0e+66)** | **0.00 (0.00–0.00)** |
| Kampong Trach | 0.83 (0.28–2.47) | **0.27 (0.09–0.85)** | 2.26 (0.95–5.42) | 0.92 (0.45–1.86) |
| Kampot | 0.35 (0.09–1.41) | 0.98 (0.17–5.71) | 0.23 (0.04–1.20) | 0.74 (0.18–3.01) |
| | Lag 0 imputed | Lag 1 imputed | Lag 2 imputed | Lag 3 imputed |
| *Prey Veng* | | | | |
| Kamchay Mear | | | | |
| Kampong Trabek | | | | |
| Mesang | | | | |
| Peam Ror | | | | |
| Peareaing | | | | |
| Preah Sdach | | | | |
| Svay Antor | | | | |
| *Kampot* | | | | |
| Angkor Chey | 0.01 (0.00–142.57) | 0.02 (0.00–2.37) | 0.00 (0.00–1.25) | 0.00 (0.00–1.62) |
| Chhouk | 2.0e+9 (0.12–3.5e+18) | 582.59 (0.00–1.2e+14) | 0.02 (0.00–1.0e+12) | 0.00 (0.00–50.79) |
| Kampong Trach | **0.48 (0.26–0.88)** | **0.30 (0.14–0.61)** | **2.35 (1.28–4.34)** | 0.91 (0.56–1.47) |
| Kampot | 0.29 (0.07–1.29) | 0.90 (0.15–5.35) | **0.18 (0.04–0.96)** | 1.20 (0.40–3.65) |

| Skin infections | | | | |
|---|---|---|---|---|
| | Lag 0 | Lag 1 | Lag 2 | Lag 3 |
| *Prey Veng* | | | | |
| Kamchay Mear | 0.81 (0.53–1.23) | 0.91 (0.54–1.55) | 0.85 (0.55–1.30) | 0.81 (0.51–1.29) |
| Kampong Trabek | 0.98 (0.89–1.07) | 0.99 (0.90–1.09) | 0.97 (0.86–1.08) | 1.04 (0.90–1.19) |
| Mesang | 1.17 (0.94–1.46) | 0.92 (0.75–1.13) | 0.98 (0.80–1.19) | 1.11 (0.85–1.45) |
| Peam Ror | 1.14 (0.96–1.35) | 0.87 (0.73–1.04) | 0.98 (0.90–1.06) | **1.10 (1.01–1.20)** |
| Peareaing | **1.06 (1.02–1.10)** | 0.98 (0.95–1.02) | 0.98 (0.94–1.01) | **1.05 (1.02–1.09)** |
| Preah Sdach | **1.09 (1.02–1.16)** | 0.94 (0.88–1.01) | 1.02 (0.95–1.09) | 1.05 (0.99–1.12) |
| Svay Antor | **1.14 (1.02–1.28)** | **0.81 (0.69–0.94)** | 0.91 (0.76–1.08) | **1.35 (1.18–1.54)** |
| *Kampot* | | | | |
| Angkor Chey | 1.33 (0.22–7.99) | 0.81 (0.04–15.46) | 0.04 (0.00–16.41) | 0.14 (0.00–58.17) |
| Chhouk | 1.14 (0.00–1.7e+9) | 1926.42 (0.00–2.3e+13) | 9.4e+10 (0.00–6.9e+23) | 0.00 (0.00–6.9e+8) |
| Kampong Trach | **3.86 (2.40–6.21)** | 1.04 (0.91–1.19) | 0.44 (0.17–1.14) | 0.94 (0.45–1.96) |
| Kampot | 0.48 (0.16–1.41) | 0.94 (0.38–2.30) | 1.75 (0.50–6.15) | 0.79 (0.31–1.99) |
| | Lag 0 imputed | Lag 1 imputed | Lag 2 imputed | Lag 3 imputed |
| *Prey Veng* | | | | |
| Kamchay Mear | | | | |
| Kampong Trabek | | | | |
| Mesang | | | | |
| Peam Ror | | | | |
| Peareaing | | | | |
| Preah Sdach | | | | |
| Svay Antor | | | | |
| *Kampot* | | | | |
| Angkor Chey | 0.01 (0.00–142.57) | 0.02 (0.00–2.37) | 0.00 (0.00–1.25) | 0.00 (0.00–1.62) |
| Chhouk | 2.0e+9 (0.12–3.5e+18) | 582.59 (0.00–1.2e+14) | 0.02 (0.00–1.0e+12) | 0.00 (0.00–50.79) |
| Kampong Trach | **0.48 (0.26–0.88)** | **0.30 (0.14–0.61)** | **2.35 (1.28–4.34)** | 0.91 (0.56–1.47) |
| Kampot | 0.29 (0.07–1.29) | 0.90 (0.15–5.35) | **0.18 (0.04–0.96)** | 1.20 (0.40–3.65) |

| Noncommunicable diseases | | | | |
|---|---|---|---|---|
| | Lag 0 | Lag 1 | Lag 2 | Lag 3 |
| *Prey Veng* | | | | |
| Kamchay Mear | 0.00 (0.00–13.62) | 5.97 (0.00–111891.5) | 13.61 (0.02–11675.79) | 0.00 (0.00–143726.6) |
| Kampong Trabek | 0.69 (0.05–9.10) | 0.45 (0.00–23.06) | 2.65 (0.53–13.17) | 0.32 (0.05–2.13) |
| Mesang | **0.11 (0.01–0.98)** | 2.08 (0.12–36.93) | 0.66 (0.06–6.97) | 0.30 (0.04–2.04) |
| Peam Ror | 0.74 (0.38–1.46) | 1.10 (0.59–2.04) | 1.36 (0.57–3.28) | 0.80 (0.46–1.37) |
| Peareaing | 1.02 (0.83–1.26) | 1.13 (0.87–1.48) | 1.00 (0.76–1.32) | **1.57 (1.21–2.03)** |
| Preah Sdach | 1.89 (0.30–11.87) | 0.06 (0.00–51410.43) | 0.00 (0.00–307.59) | 4.0e+12 (0.00–1.9e+34) |
| Svay Antor | 1.05 (0.66–1.67) | 0.62 (0.33–1.18) | 0.90 (0.50–1.62) | 1.40 (0.97–2.03) |
| *Kampot* | | | | |
| Angkor Chey | 0.00 (0.00–1869.58) | 0.73 (0.00–1165.72) | 15469.45 (0.04–5.5e+10) | 7.07 (0.00–45910.69) |
| Chhouk | **0.00 (0.00–0.00)** | **5.0e+122 (2.1e+96–1.1e+150)** | 1.0e+60 (0.00–2.5e+125) | **0.00 (0.00–0.00)** |
| Kampong Trach | **3.5e+50 (1.0e+50–1.2e+51)** | **0.00 (0.00–0.00)** | **2.0e+94 (2.7e+92–1.6e+94)** | **0.00 (0.00–0.00)** |
| Kampot | 0.16 (0.00–24.31) | 14.04 (0.02–9471.05) | 0.00 (0.00–46.35) | 572.7 (0.28–1171946) |
| | Lag 0 imputed | Lag 1 imputed | Lag 2 imputed | Lag 3 imputed |
| *Prey Veng* | | | | |
| Kamchay Mear | | | | |
| Kampong Trabek | | | | |
| Mesang | | | | |
| Peam Ror | | | | |
| Peareaing | 1.02 (0.92–1.13) | 1.03 (0.86–1.22) | 1.05 (0.93–1.18) | 0.94 (0.82–1.08) |
| Preah Sdach | | | | |
| Svay Antor | | | | |
| *Kampot* | | | | |
| Angkor Chey | | | | |
| Chhouk | 0.00 (0.00–9.3e+44) | **1.9e+35 (1.0e+10–3.6e+78)** | 4.0e+16 (0.00–2.7e+79) | 0.00 (0.00–3.9e+13) |
| Kampong Trach | | | | |
| Kampot | 0.12 (0.01–1.80) | 0.27 (0.01–5.48) | 3.65 (0.04–326.34) | 0.86 (0.03–21.89) |

| Injuries | |
|---|---|
| **Lag 0** | |
| *Prey Veng* | |
| Kamchay Mear | 0.48 (0.09–2.46) |
| Kampong Trabek | 0.88 (0.70–1.10) |
| Mesang | 1.44 (0.85–2.46) |
| Peam Ror | **0.94 (0.90–0.98)** |
| Peareaing | 0.98 (0.95–1.02) |
| Preah Sdach | 1.01 (0.97–1.05) |
| Svay Antor | 1.09 (0.96–1.24) |
| *Kampot* | |
| Angkor Chey | **9.06 (2.18–37.62)** |
| Chhouk | 0.00 (0.00–2.29) |
| Kampong Trach | **1.17 (1.09–1.62)** |
| Kampot | 0.91 (0.51–1.61) |
| **Lag 0 imputed** | |
| *Prey Veng* | |
| Kamchay Mear | |
| Kampong Trabek | |
| Mesang | |
| Peam Ror | |
| Peareaing | |
| Preah Sdach | |
| Svay Antor | |
| *Kampot* | |
| Angkor Chey | |
| Chhouk | |
| Kampong Trach | **1.17 (1.03–1.34)** |
| Kampot | |