ASSESSING THE RISK OF LEPTOSPIROSIS IN RELATION TO FLOODING IN KERALA, INDIA.

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July 2023

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ABSTRACT

Flooding results in many public health challenges, it also serves as a major amplifier of disease risk factors. Recent studies have associated the transmission of leptospirosis with flooding events, however, there is yet limited knowledge of the contributing factors and their extent of influence. This research focuses on leptospirosis as a flood-induced health effect in Kerala. This research employs various spatiotemporal and descriptive methods to analyse incident cases and determine the relation to risk factors in flooded and non-flooded periods. Elements for the risk assessment were obtained from environmental datasets, epidemiological data, and qualitative surveys. The result shows that the incidence of leptospirosis varies over different phases of floods, the most coming during the post-flood phase. Future incidences of leptospirosis can be predicted using flood information. Flooding exacerbates the incidence of leptospirosis by exposing vulnerable populations to the pathogenic environment. Multisectoral synergies between stakeholders are needed to inform and guide local decisions to reduce the risk of infections. Based on the results of this study, actionable recommendations are proposed to support the management of leptospirosis disease before, during and after floods in Kerala.

Keywords: disaster, epidemiology, leptospirosis, assessment, risk factor, flood, climate, modelling.

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1. INTRODUCTION

1.1. Background

The number of environmental disasters has increased around the world in the last two decades (Thimbleby, 2013; UNDRR, 2020) which has also resulted in increased direct or indirect health impacts (Leaning and Guha-Sapir, 2013). The assessment of the health impacts of disasters is referred to as disaster epidemiology. The direct effects of disasters on a population relate to physical and mental health, while indirect effects are associated with damage to the healthcare system and environment (Leppold et al., 2022)

Flooding is the most common disaster globally, and it results in many direct and indirect effects. Multiple studies have associated the incidences of infectious diseases in the aftermath of climate-related disasters (Alcayna et al., 2022). One of the direct health effects of flooding is the rise of infectious diseases. Evidence from literature has suggested that flooding is associated with rodent-borne, water-borne, and vector-borne diseases (Brown and Murray, 2013). One of the common water-borne diseases that have been associated with flooding events is leptospirosis. The increase in the frequency and severity of flooding has led to a higher number of infections in areas endemic to leptospirosis (Chadsuthi et al., 2021).

Leptospirosis is an infectious disease with an immense global burden caused by the bacteria *leptospira*. Earlier studies concluded that it is simply a mere occupational hazard, however, this is not the case anymore (Pappachan et al., 2004). The climatic environment plays a complex role in the interactions between the humans, zoonotic hosts, and pathogens in the environment (Cucchi et al., 2019). Indirect transmissions occur as a result of exposure to a contaminated environment. People can acquire the bacteria during floods when they may come into contact with contaminated water (Lau et al., 2010). The impact of floods on leptospirosis incidence is a relevant and focused disaster epidemiological study which has not been studied extensively thus far.

Understanding the interplay between flood and causal factors for leptospirosis is crucial to reducing future risks to the disease (Chadsuthi et al., 2022). Several studies have analyzed the risk factors of the natural incidence of leptospirosis in different regions of the world (Cruz et al., 2009). These factors relate to the biomedical, ecological, environmental, social, political, and cultural contexts of leptospirosis infections. However, very limited studies have evaluated how those risk factors interact with flood-induced incidences. To improve the management of leptospirosis outbreaks after floods, the incidences and their relationship with risk factors during flood phases need to be analyzed extensively.

1.2. Research Gap

Although it is generally agreed that there is a strong indication that floods increase the risk of an increase in leptospirosis cases, there have been very limited studies to quantify the consequential extent of the influence of flood (Lau et al., 2010; Naing et al., 2019). The relation of flood with leptospirosis incidence needs to be examined extensively. The analysis of the temporal difference between flood exposure and infection can be compared with the time course of leptospirosis infection to further understand its transmission pattern during floods.

The multifaceted nature of leptospirosis factors demands that it should be assessed using an interdisciplinary lens (Souza et al., 2020). Due considerations must be made to its clinical, social, and environmental factors. Most studies on risk assessment of leptospirosis concentrated on the clinical aspects of the disease and animal infections (Mohammadinia et al., 2019). The relatively few studies on the risk of human infections involve environmental factors and occasionally sociodemographic factors but often ignore the clinical information and diagnostics (Wasiński and Dutkiewicz, 2013).

Epidemiological methods are still evolving in high-income countries and even less can be said in Low- and Middle-Income Countries (LMICs). LMICs are not as actively involved in research on disaster epidemiology globally (Liu et al., 2021). Due to the differences in environmental characteristics, global frameworks for risk assessment are not the most efficient for local response (Homberg et al., 2017). Therefore, risk factors must be evaluated to meet public health needs and challenges at a local level.

1.3. Problem Evaluation

A research problem usually becomes a wicked problem if it involves a complex societal issue such as floods and leptospirosis. The degree of complexity can be estimated by focusing on the clarity of the problem and its solution, and the agreement among its associated actors (Alford and Head, 2017) (Figure 1).

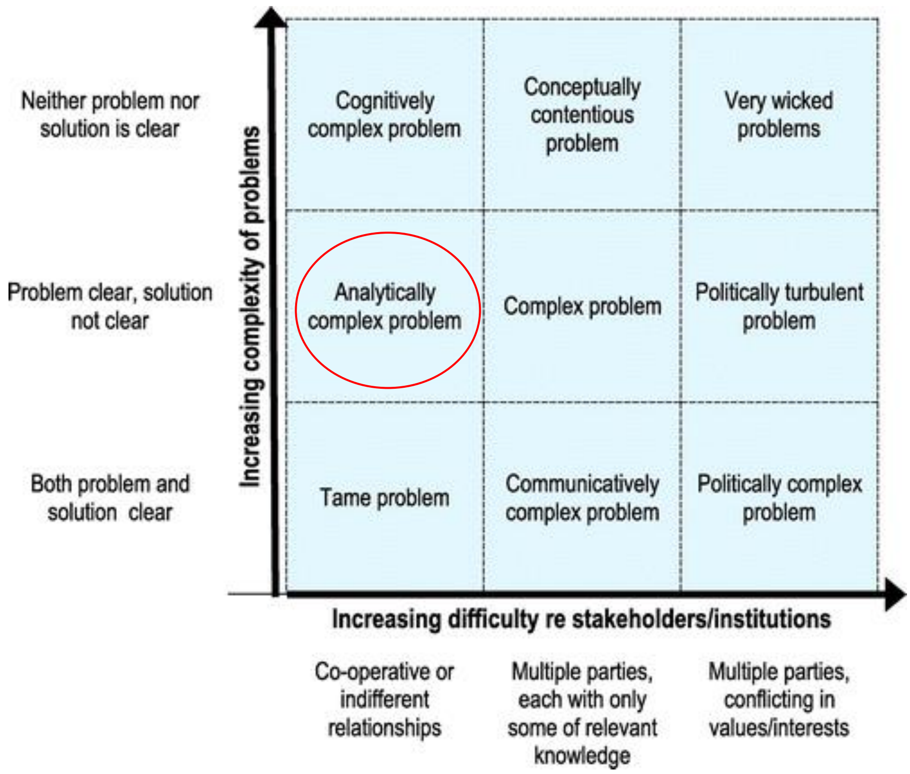

Figure 1 Types of wicked problems (Alford and Head, 2017)

In Kerala, flooding is a prominent disaster - there have been disastrous floods for consecutive years during its monsoon season (Vijaykumar et al., 2021). During the 2018 floods, the Kerala public health authorities acted promptly to distribute antibiotics to counter these illnesses, but much harm had already been done (Carmen, 2018). The obvious effects of floods in Kerala were illnesses, injuries, and deaths. Illnesses include physical illnesses from infections and mental illnesses.

There has been general applause for Kerala's success in managing the health impacts of the major flood despite their subpar level of preparedness (Varughese and Purushothaman, 2021). A unified effort among the Kerala stakeholders reduced the impact of the disaster. Nevertheless, an outstanding but recurrent impact of Leptospirosis suggests that the problem tends towards an unclear solution than conflicts of interest between actors. There is limited knowledge about community-level interventions to manage the risk of leptospirosis in India (Beri et al., 2021). Leptospirosis infection is a complex disease caused by many interconnected risk factors. Although the Directorate of Health Services, Kerala (DHS) acknowledges that there Kerala has a very conducive environment for the transmission of Leptospirosis (KSDMA, 2016), no course of action was documented in the management plan to specifically cater to it.

While there is a large consensus in Kerala on the importance of the safety of human lives, there has not yet been enough knowledge about risk factors to reduce the health risks of leptospirosis after floods. Applying the framework provided in Figure 1, this wicked problem can be described as an analytically complex problem. A better understanding of the health risk of leptospirosis after floods would help the management of disaster response and risk prevention.

1.4. Research Objective and Questions

The overall objective of this research is to assess the factors contributing to leptospirosis infections induced by the 2018 floods among Kerala communities. The results can be used to support response efforts and serve as a basis for monitoring health impacts during and after floods.

The achieve the overall research objective, the following objectives, and respective research questions are highlighted below:

1. To investigate the incidences of leptospirosis in Kerala over space and time and analyze the relation with flood occurrences.
   i. What was the impact of the 2018 and 2019 flooding events in the study area?
   ii. How are flood events associated with the incidences of leptospirosis?
   iii. How do the incidences of leptospirosis differ by flood phase and year?
2. To assess the relevance of the risk factors of leptospirosis in Kerala.
   i. Which geographic areas are associated with leptospirosis incidences in 2018?
   ii. Which risk factors of leptospirosis can be analyzed in Kerala context?
   iii. What demography was affected by leptospirosis infections?
   iv. How do risk factors relate to the incidences of leptospirosis in the study area?
3. To provide recommendations for response efforts towards the mitigation of risks of leptospirosis infection.
   i. What are the risk factors identified by local health experts?
   ii. How should stakeholders be involved in managing epidemic risk?
   iii. How can the findings be used to minimize future risks?

1.5. Structure of the Thesis

This thesis is divided into eight chapters, the next chapters after this introduction and their short descriptions are provided below:

- Chapter 2 is a review of related literature to provide a more extensive background to this research problem. The infectious disease and its risk factors are introduced as established from previous research.
- Chapter 3 introduces the study area and the societal impact of the research problem within the study area. The sampled areas for this research are briefly described.
- Chapter 4 provides an overview of the methods and datasets used in fulfilling the objectives of this research. Ethical considerations and terms used in describing the analysis done were also introduced.
- Chapter 5 addresses the first research objective (RO1) which is the analysis of the incidences of leptospirosis within the study area. The introduction, methods and result of this analysis are described in this chapter.
- Chapter 6 focuses on the second research objective (RO2) which is namely the assessment of risk factors of leptospirosis. The assessment evaluates how flooding affects other factors contributing to the incidence of the disease through multivariate regression modelling. The details about the methods used and the results obtained are explained.
- Chapter 7 builds upon previous chapters to analyse the risk management of the flood-induced epidemic. This fulfils the third research objective (RO3) Based on the results, recommendations are provided to ensure the risk assessment can be translated into actionable plans.
- Chapter 8 summarizes the results from chapters 5 – 7 and provides the interpretation and implication of those results. The limitations of this research and future research possibilities are discussed in detail. Included also is the summary of the conclusive outcomes of this research

2. LITERATURE REVIEW

2.1. Disaster Epidemiology

The UN Office for Disaster Risk Reduction (UNDRR) states that there has been an increase in the number of environmental disasters globally in the last two decades (Thimbleby, 2013; UNDRR, 2020). These disasters have consequently resulted in an increased number of deaths, injuries, diseases, and disabilities in recent years (Leaning and Guha-Sapir, 2013), despite improvements in public health care mainly due to technological advancements.

UNDRR defines a disaster as: "a *serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts*" (UNDRR, n.d.). Hazards can be classified as natural, human-induced or environmental, and disasters are a result of the actual occurrence of a damaging event, resulting in the exposure of vulnerable communities (IFRC, n.d.; WHO, 2019). Most disasters pose threats to public health that need immediate and long-term assessment (Noji, 2000).

The US Center for Disease Control and Prevention (CDC) defines disaster epidemiology as "*the application of epidemiological methods to assess the short- and long-term adverse health impacts of disasters and emergencies and also to estimate the effects of disasters to come*" (CDC, 2019). Disaster epidemiology is relevant in all stages of a disaster –before a disaster to plan or improve health risk reduction, during a disaster to provide precise health information promptly, and finally, after a disaster to reduce casualties and illnesses by recovery measures (Du et al., 2015).

The overall goal of disaster epidemiology is to anticipate and reduce the risk of health effects per disaster event. The approaches that can be applied in different stages of disaster management are summarized in Figure 2. Conducting epidemiological studies before disasters will likely reduce health risks and cater to emerging healthcare needs.

Figure 2. Disaster epidemiology actions and the disaster management cycle. (Malilay et al., 2014)

While disaster epidemiology as a formal field of study is still relatively new, the concept and methods of epidemiology have been applied to disasters for several years (Du et al., 2015). The first application of disaster epidemiology was recorded in 1970 when descriptive studies were used to examine the health status of residents in East Bengal, Bangladesh after a cyclone attack (Malilay and Horney, 2018). Disaster epidemiology is still evolving today, increased knowledge on the impact of the disaster on diseases' emegence makes it even possible to take a step further toward the prediction and mitigation of post-disaster health risks (Malilay et al., 2014).

2.2. Health impacts of floods

Natural disasters, especially climate-related ones, are on the rise globally (López et al., 2018). Floods are the most common type of disaster globally having affected more than 2 billion people in the past two decades (WHO, 2020). The risk of flooding and precipitation events is expected to increase given the effect of global warming on the hydrological cycle (Tabari, 2020).

Flooding can cause adverse health effects but also results in environmental problems that consequently endanger human lives (Azuma et al., 2014) (Figure 3). Impacts on households and healthcare facilities mean that normal living conditions are hindered, and primary healthcare needs cannot be met (Shoaf and Rottman, 2000). In the long term, damage to the food and water system may lead to starvation, malnutrition, and disability among affected victims (Du et al., 2010). Alongside these indirect effects, there are a variety of direct health effects that can occur, - they include injuries and deaths, and in medium term disease transmission (Few et al., 2004). Post-flood cleanup activities can also pose significant health risks (Burton et al. 2016) – the use of bleach for clean-up leads to chlorine exposure and the risk of injury from structural damages. The long-term effects are anxiety and depression (Tunstall et al. 2006).

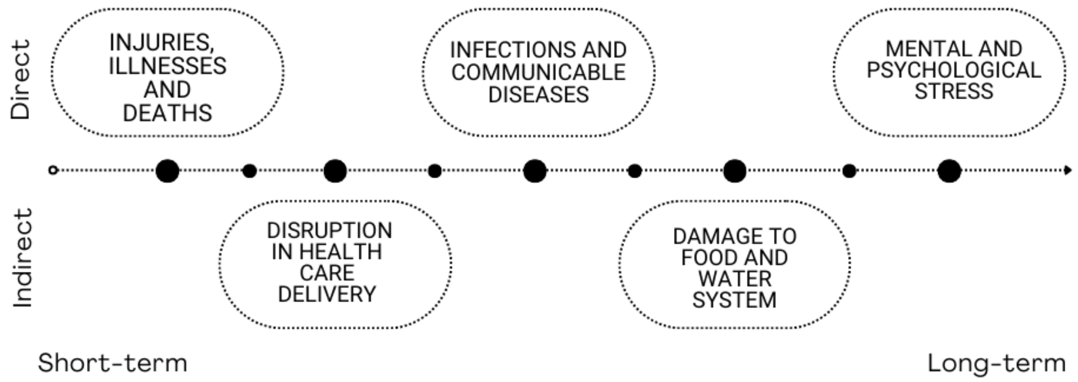

Figure 3 Timeline of the health impacts of flood

Alcayna et al. (2022) explored the connection between climate-related disasters and the outbreak of climate-sensitive infectious diseases (CSID) through a scoping review. Higher evidence and agreement were found to indicate a strong connection between extreme climate events and water-borne diseases than for vector-borne diseases. Vector-borne diseases are infectious diseases that are transmitted by an intermediate animal, while water-borne diseases are spread through exposure to contaminated water or food. Impacts such as destabilization, damage, or destruction to the natural and built environment, displacement of people, and disruption to essential services make heavy rainfall and flooding a major amplifier of disease risk factors. From the analysis of the relationship between infectious disease and flooding, leptospirosis is one of the most common infectious diseases mentioned (Brown and Murray, 2013) (Table 1).

Table 1 Infectious diseases following flooding events.

Country	Year(s) studied	Infectious disease(s)	References
Australia	1998–2001, 2011	Leptospirosis, Ross River virus	(46, 57)
Austria	2010	Leptospirosis	(43)
Bangladesh	1983–2007	Cholera, rotavirus, acute respiratory infection	(23–24, 72–73, 75–76)
Canada	1975–2001	Diarrhea	(22, 26)
China	1979–2000	Schistosomiasis	(58)
Czech Republic	1997, 2002	Leptospirosis, Tahyna virus	(41, 54)
England	2000	Diarrhea	(28)
France	2009	Leptospirosis	(38)
Germany	2005, 2007	Norovirus, leptospirosis	(29, 34)
Guyana	2005	Leptospirosis	(44)
Italy	1993–2010	Hepatitis A, salmonellosis, diarrhea, leptospirosis, leishmaniasis, legionellosis	(18, 36)
India	2001–2006	Leptospirosis	(33, 45)
Indonesia	2001–2003	Paratyphoid fever	(27)
Mexico	2007, 2010	Leptospirosis, dengue fever	(37, 55)
Pakistan	2010	Diarrhea, skin and soft tissue infection, conjunctivitis, respiratory tract infection, suspected malaria	(69)
the Philippines	2009	Leptospirosis	(47)
Sudan	2007	Rift Valley fever	(56)
Taiwan	1994–2009	Leptospirosis, melioidosis, enteroviruses, dengue fever, bacillary dysentery, Japanese encephalitis	(21, 40, 48, 74)
Thailand	2012	Melioidosis	(70)
United States	2001, 2004	Diarrhea, leptospirosis	(25, 32, 35)
Vietnam	2008	Conjunctivitis, dermatitis	(71)

Source: (Brown and Murray, 2013)

2.3. Leptospirosis Infection

Leptospirosis is a global zoonotic disease caused by the Leptospira bacteria. A zoonotic disease is an infectious disease that is transmitted from an infected animal to humans. Human infections of leptospirosis are caused by either direct contact with the urine of an infected animal or more usually, indirect exposure from a contaminated environment such as water and soil (that have been contaminated by the urine of an infected host) (Goarant, 2016). Figure 4 shows the epidemiological triad of the disease. Reservoir hosts are mainly rodents and wild animals who generally show no symptoms of infection. Leptospira's are shed at regular intervals through reservoir host (Cordonin et al., 2020). Eventually, the disease is passed down to humans (the primary or incidental hosts), and other mammals (usually livestock and domestic animals) that further amplifies successive infections.

The incidence of leptospirosis can be explained through its structure of an interrelated space-climate relationship. In developing countries, higher chances of direct and indirect human infections are due to occupational affiliations (Goarant 2016). Workers in abattoirs, livestock farms, and agricultural fields are more exposed to the disease. According to the Royal Society of Tropical Medicine and Hygiene (RSTMH), the probable factors of vulnerability include poor sanitation and hygiene practices, and rodent density in the environment. (RSTMH, 2021). Aside from the complex social context, leptospirosis transmission can be also explored through the effect of climatic factors on human behaviour, the zoonotic host population and the survival of Leptospira in the environment (Cucchi et al., 2019).

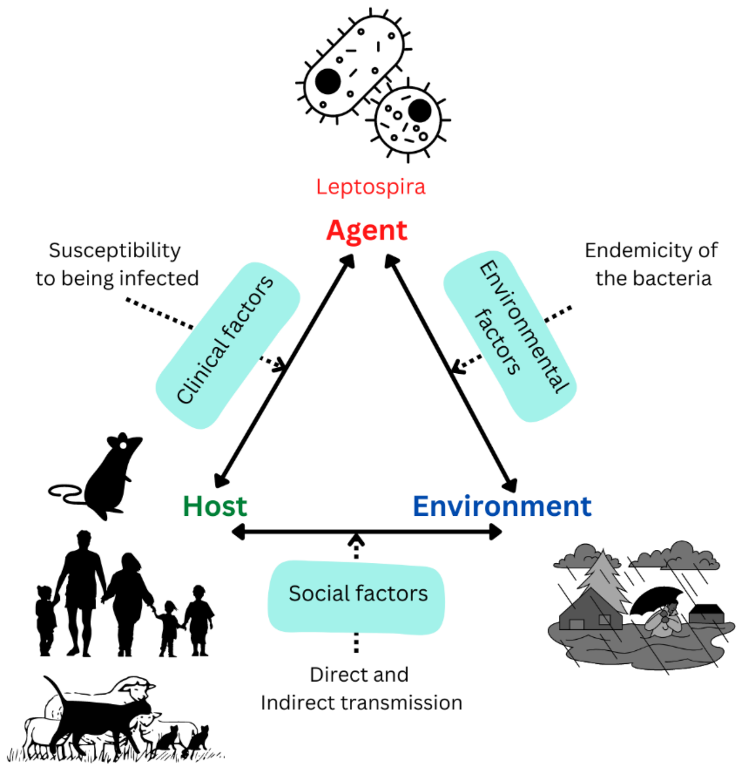

Figure 4 Epidemiological triad of leptospirosis

Though leptospirosis has a global reach, the disease has been shown to have a more serious burden in LMICs than in high-income countries (Costa et al., 2015). The global burden of leptospirosis was estimated to be about 2.90 million Disability Adjusted Life Years (DALYs), with most coming from tropical LMICs (Torgerson et al. 2015) (Figure 5). Due to the close resemblance of symptoms with other acute febrile illnesses, clinical diagnosis is often missed or delayed and thereby leading to severe complications and increased mortality (Lau et al., 2018). Despite the variability of disease incidence and reporting, 59,000 persons are estimated to die every year from leptospirosis (Torgerson et al., 2015). The case fatality of leptospirosis can be as low as 6% or as high as 50% depending on the availability of supportive care (Smith et al., 2019).

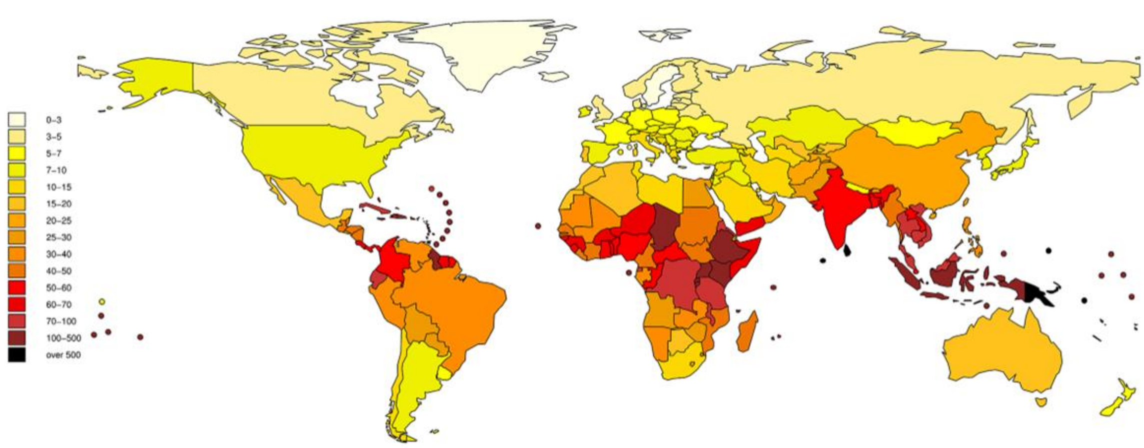

Figure 5 Burden of leptospirosis infection per year (Torgerson et al., 2015).

Although there is not yet an effective vaccine to prevent the infection, the disease can be easily treated when diagnosed early. Despite various initiatives to develop an efficient vaccine against leptospirosis, the results have yielded very limited success (Teixeira et al., 2019). Felix et al. (2020) projected that the achievement of a universal vaccine is only feasible in the next 10-15 years. The incubation period for leptospirosis can range from 2 to 20 days after initial exposure to the bacteria (Sykes et al. 2022). After this period, infection can last for weeks and months depending on the development of antibodies (igM and igG) in the host. This period is followed by the acute phase where symptoms such as fever, headache, and myalgia (Goarant, 2016). There are multiple diagnostic tests applicable for the different phases of the illness (Lau et al., 2018) (Figure 6). Commonly used are PCR tests and the microscopic agglutination test (MAT). US Center for Disease Control and Prevention (CDC) recommends the intake of antibiotics such as doxycycline or penicillin upon suspicion of the presence of the disease (CDC, 2015). In situations where there are already severe complications, hospital treatment is necessary to avoid further damage (Lau et al., 2018).

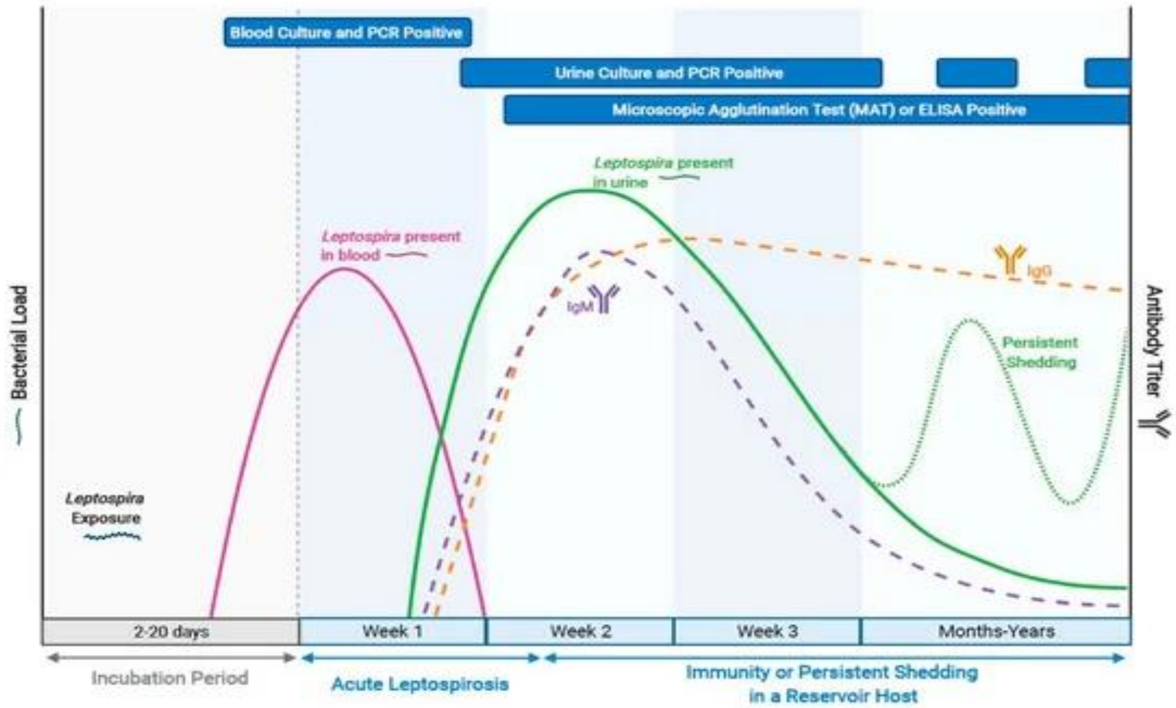

Figure 6 Timeline for leptospirosis infection (Sykes et al., 2022)

2.4. Assessment of Risk Factors

The risk factors associated with a disease can be used for identifying areas potentially at risk (Richard and Oppliger, 2015). The risk of a disease (or an epidemic risk) is the probability of an outbreak occurrence and potential impact (Marin-Ferrer and Vernaccini, 2017). Several articles have estimated the risk of leptospirosis using different factors and methods (Table 2). The risk factors have been broadly classified into three groups: clinical, environmental, and social factors. The methods used for assessing risk factors or estimating risk areas range from laboratory testing and statistical modelling.

There exists a variety of risk factors for leptospirosis (Table 2). In terms of clinical factors, the incidence of leptospirosis is related to the non-vaccination of dogs, the prevalence of pathogenic serovars and other medical diagnostics. Environmental factors associated consist of climatic factors (increase in rainfall, humidity and temperature) and geographic factors (low elevation, high vegetation, proximity to water and farmlands, occurrence of floods). Social factors associated are population demography (different age groups and majorly male gender), population economy (poverty level, dog ownership, occupation), and population density. Other social risk factors are accessibility to health care (Goarant, 2016) and poor sanitation and hygiene of the environment (Mishra, 2022).

Table 2. Risk factors in assessing leptospirosis.

Objective	Study Area (Country)	Risk factors	Methods	Source
Analysis of hotspot of incidences of Leptospirosis in dogs	USA	*Clinical:* Dog vaccination status *Environmental:* Precipitation, Temperature, rodent density *Social*: Socio-economic status, dog ownership	*Laboratory testing* *Spatial Analysis* *Descriptive statistics* *Predictive modeling*: Boosted regression trees (BRTs)	(White et al., 2017)
Spatial-temporal Analysis of Leptospirosis after 2014 floods	Malaysia	*Environmental:* Temperature, humidity, rainfall, and flood levels. *Social*: Age, Gender Garbage clean-up activities.	*Spatial Analysis with GIS.* *Spatial statistics:* Cluster analysis, and spatial correlation *Spatial modelling*: Geographic Weighted Regression (GWR)	(Mohd Radi et al., 2018)
Prediction mapping of human leptospirosis	Iran	*Environmental:* Temperature, precipitation, humidity, elevation, and vegetation.	*Predictive modeling:* Geographically Weighted Regression (GWR), Generalized Linear Model (GLM), Support Vector Machine (SVM), and Artificial Neural Network (ANN)	(Mohammadinia et al., 2019)
Analyzing the trend in human and animal leptospirosis infections	Croatia	*Clinical:* Seroprevalence *Environmental:* Temperature, and precipitation *Social (Human):* Age and Gender	*Medical methods:* Laboratory diagnosis for humans and animals, Identification of serogroups. *Descriptive statistics*	(Habus et al., 2017)
Risk prediction using environmental variables	Netherlands	*Environmental:* land-use variables, water infrastructure, ground soil coverages, population, and farm densities	*Spatial statistics:* Cluster analysis, hotspots analysis, and spatial autocorrelations; Outputs with GIS *Predictive modeling:* Simultaneous Auto Regression (SAR)	(Rood et al., 2017)

Spatial information helps to improve the interrelationship between the environment and public health. Environmental variables can be analyzed spatially using a Geographical Information System (GIS) to understand the risk of leptospirosis (Lau et al., 2012). GIS can play a significant role in not only visualizing the spatial distribution but also investigating the influencing factors and estimating future risks of the disease (Moradi et al., 2021). Utilizing the spatial dimension of risk indices can be used in producing and assessing the accuracy of predictive risk maps (Hierink et al., 2022).

2.5. Management of Health risks

The assessment of risk factors and risk areas should be instrumental to the reduction of further risk of epidemics after floods. To save lives, health risks must be minimized as much as possible (Blanford and Jolly, 2021). Health risk assessment should be translated into decision-making tools for prevention and preparedness for future disaster events. To this end, WHO designed the health emergency and disaster risk management (Health EDRM) framework to provide "*a common language and a comprehensive approach that can be adapted and applied by all actors in health and other sectors who are working to reduce health risks and consequences of emergencies and disasters*." (WHO, 2019).

While disasters cannot be entirely avoided, preparations can be made to reduce their impact on communities. Effectively managing health risks entails building coping and adaptive capacities to reduce the vulnerability of the public (United Nations University, 2011). It also means ensuring improvements in risk communication to reduce exposure through early action measures. Although disaster epidemiology as a field has attracted people all over the world, Liu et al. (2021) found using a bibliometric analysis that studies from LIMCs have had very limited impacts as compared to developed countries. This is mainly due to the limited number of resources that can be devoted to research.

3. STUDY AREA

3.1. Kerala, India

India is frequently affected by natural disasters due to its climate and topographic characteristics. With a population of 33 million people, Kerala state is located on the southwestern coast of India. The weather pattern, high density of population, and geographical location have made Kerala prone to both natural and human-induced disasters (Stephen 2012). According to the Kerala State Disaster Management Authority (KSDMA), the state is commonly plagued by disasters such as floods, landslides, and lightning (KSDMA, 2016). Less frequent disasters are earthquakes, and drought with increasing concerns about the impact of heatwaves as mortality rates have doubled in the last two decades (Ray et al., 2021). All these disasters have impacted the health of residents and increased the population's vulnerability to physical and psychological illnesses. Nearly all districts in Kerala are vulnerable to multiple hazards, however, floods stand out as the most common and may yet become an annual affair in Kerala (Shaji, 2019).

3.2. Floods in Kerala

Declared by the Indian Government as a 'Calamity of Severe nature', a major flood occurred in 2018 largely due to an unexpected amount of rainfall in the monsoon season (Central Water Commission, 2018) (Figure 9). Data from the Indian Metrological Department show that the actual flood rainfall received was 23.34% more than expected between June 1, 2018, and September 30, 2018 (Varughese and Purushothaman, 2021). Although most reports acknowledge the peak of flooding between the 1st to 19th of August 2018, the Govt. of Kerala (2018) reported that the low-lying areas of Alappuzha were already flooded in late July (Figure 8). The assessment by UNDP (2018) revealed that 1,259 out of 1,664 villages were affected by floods and landslides, forcing 1.4 million people to be displaced and took 433 lives. Diseases such as fever, dengue, cholera, leptospirosis, and diarrhoea were reported during the flood period (Mishra 2022). In addition, flood survivors also experienced depression, anxiety, and stress after the event (Rahana et al. 2021).

Figure 7 Flooded houses in Kerala (Image by Reuters, (2018))

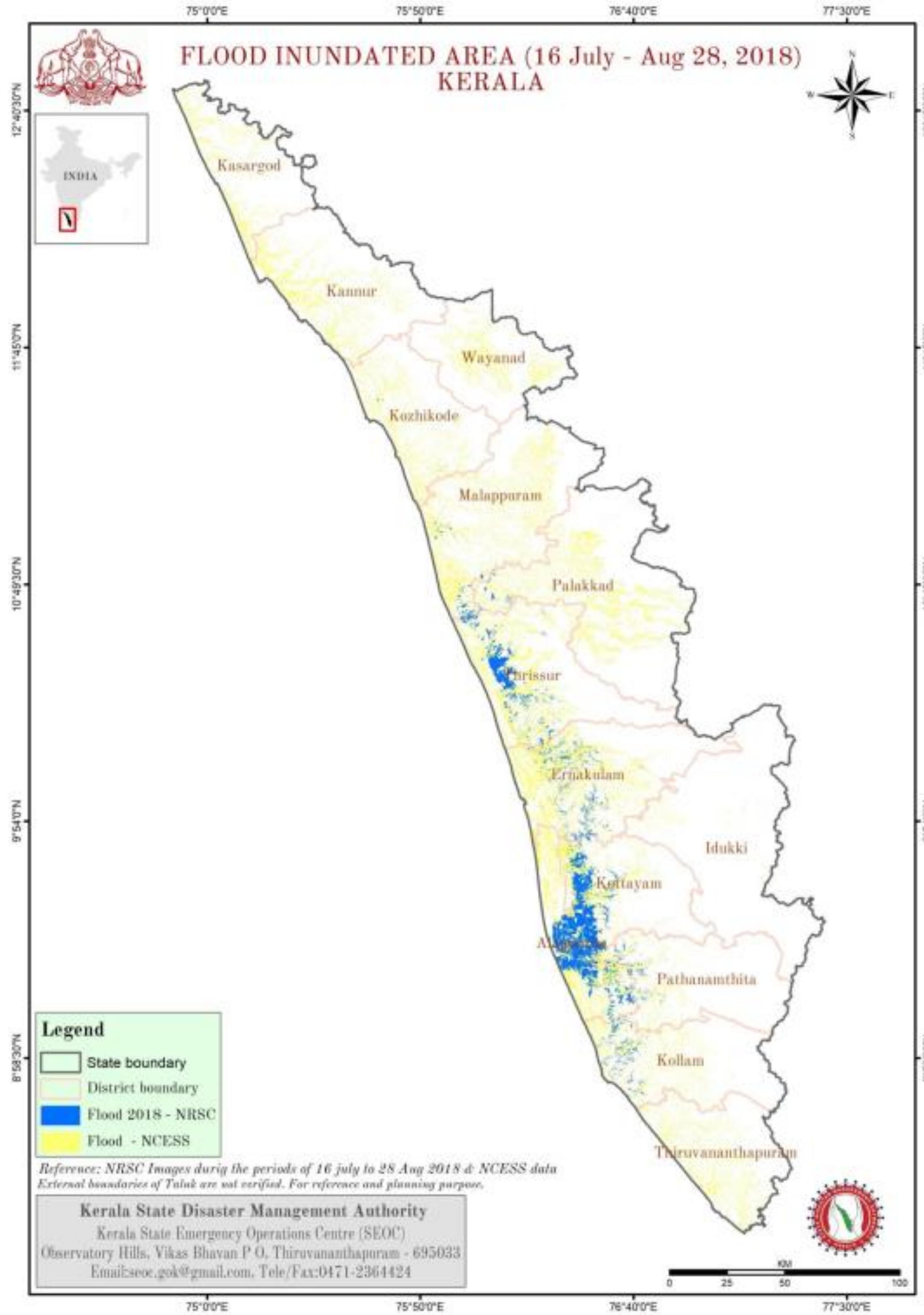

Figure 8 Flood-affected areas in Kerala (Govt. of Kerala, 2018).

Despite the intensity of the flood event, the communities in Kerala managed to rescue the situation from excessive damage. Although it is more than likely that the health effects were underreported due to a lack of sufficient resources, an impending crisis was averted (Varughese and Purushothaman, 2021). Further, plans were made to monitor the psychological effects of the flood (Kiran et al., 2020). A coordinated and concerted effort by the civil authorities, non-governmental organizations, and citizens helped in the response and management (Walia et al., 2022). The societal resilience shown by Kerala moderated the impact from floods, but more efforts should have been put into disaster preparedness.

Although the flood of 2018 was the most extreme flood in Kerala in almost a century, other flood events occurred in the consecutive years. The 2019 flood is considered a minor one in terms of the number of deaths, nevertheless, the pattern of floods is more evidently caused by the climate change currently experienced globally (Vijaykumar et al., 2021). The flood is an outcome of a series of heavy rains in August as a result of a mesoscale mini cloudburst (Vijaykumar et al., 2021) (Figure 9). Alappuzha was also one of the districts that were severely affected during this flood period (Mehrishi et al., 2022). There have been regular floods in the monsoon period since 2019, but none has been as severe as the flood experienced in 2018 (Srija et al., 2021).

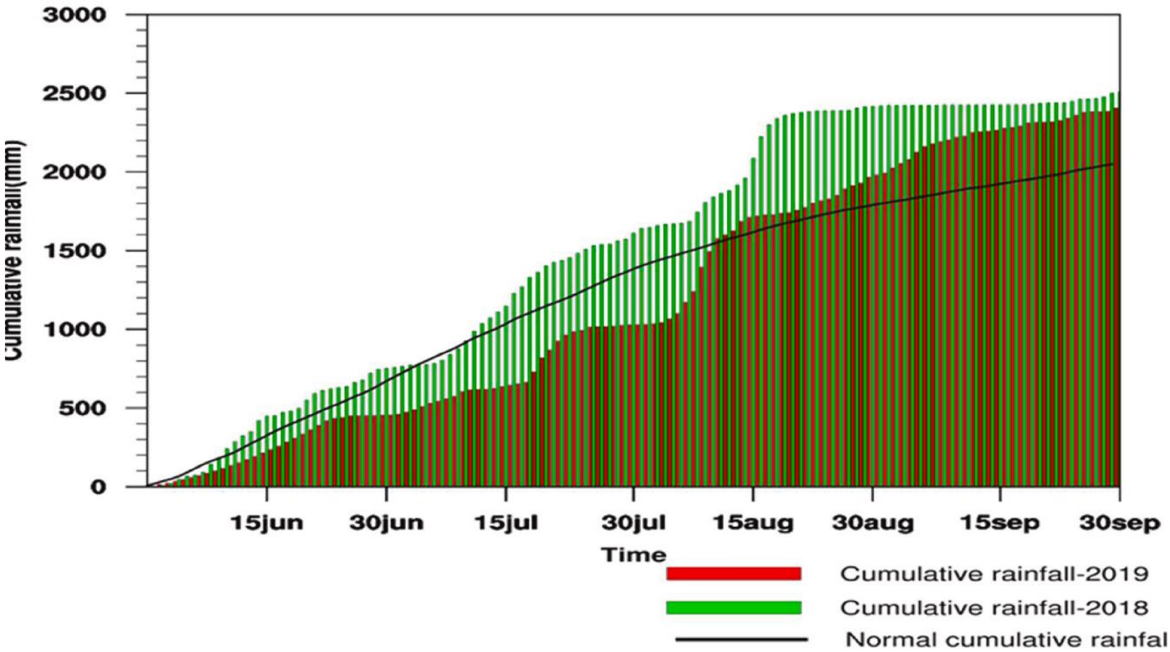

Figure 9 Cumulative rainfall in Kerala during 2018 (Green) and 2019 (red) monsoon seasons. (Source: (Vijaykumar et al., 2021)

3.3. Health Effects and Outbreak of Leptospirosis

The incidence of leptospirosis in Kerala was first reported three decades ago, nonetheless, the floods of 2018 reintroduced the presence of the neglected infection (James et al., 2018; Kuriakose et al., 1990). Amongst other diseases reported during Kerala 2018 floods, both leptospirosis and acute diarrhoea increased significantly in comparison with floods in previous years nevertheless, there was no outbreak of acute diarrhea (Amitabha et al., 2019; Varughese and Purushothaman, 2021). Amitabha et al. (2019) suggested that a supply of safe water may have prevented an outbreak of diarrhea diseases. However, given the ecology and risk factors of Leptospirosis, the provision of safe water is simply not enough to prevent the disease.

Data from the Kerala Directorate of Health Services (DHS) revealed that Kerala reached an all-time high record of 2,076 cases and 99 deaths from Leptospirosis in 2018 (DHS, 2019) with more than half of the cases recorded during August and September, right after the floods (Figure 10). During 2018, the highest number of cases were reported in the southern districts of Kerala (Figure 11). For this reason, the two most heavily affected districts were selected (Alappuzha and Pathanamthitta) to better understand the risk of leptospirosis in relation to flooding.

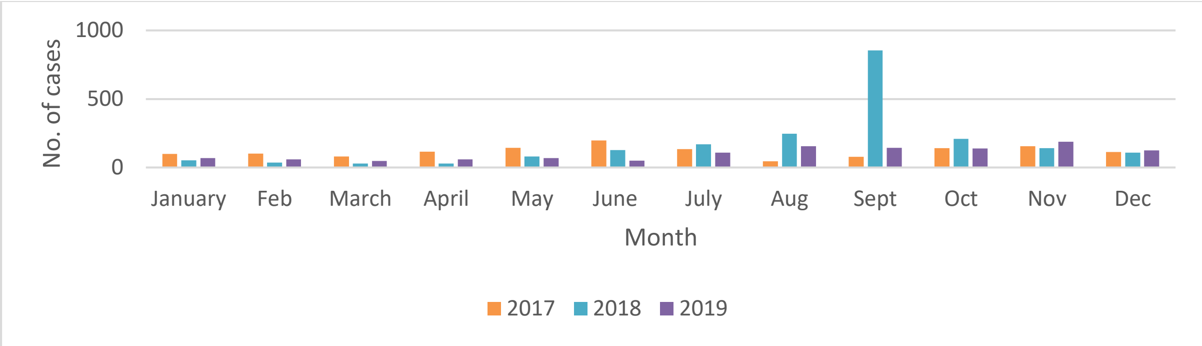

Figure 10 Leptospirosis incidence per month between 2017-2019 in Kerala (Created using dataset from DHS (2019))

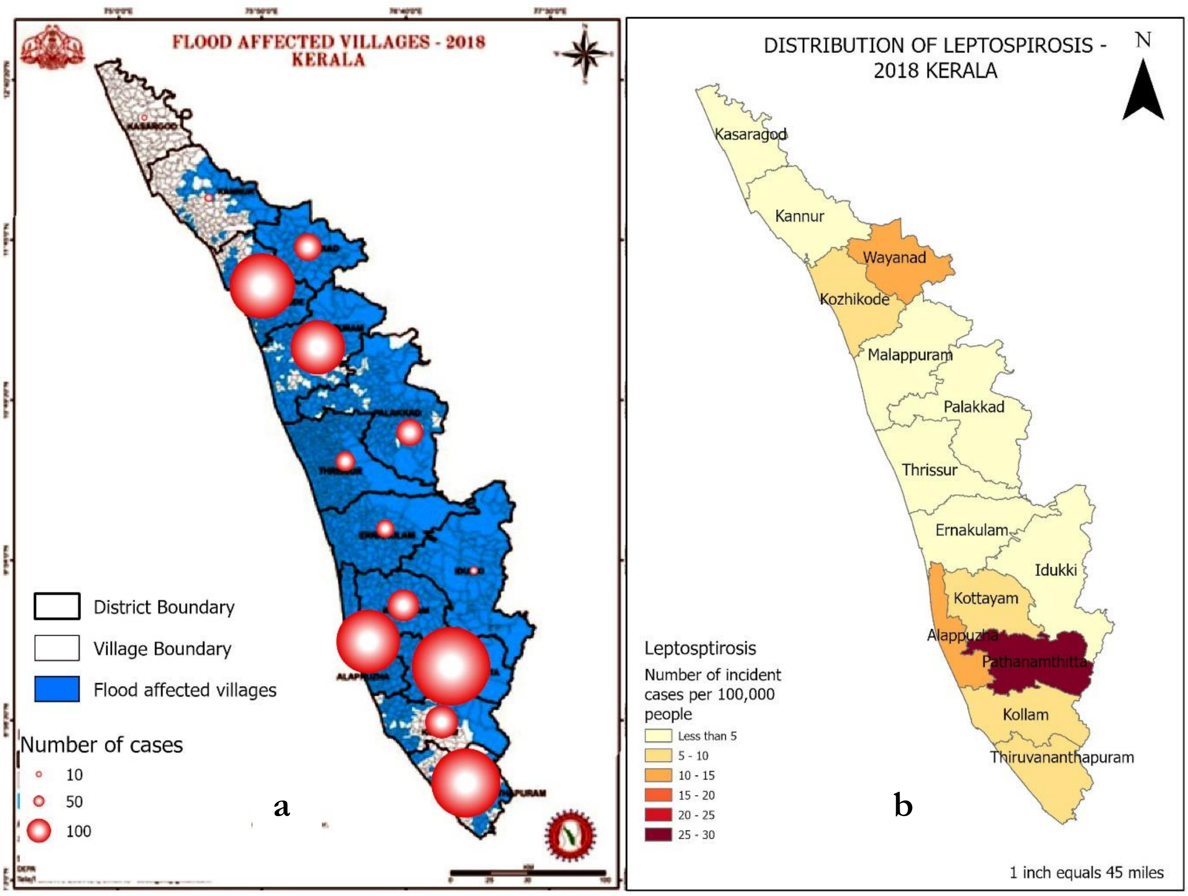

Figure 11 Areas affected by (a) flood and (b) leptospirosis (Created using datasets from DHS (2019) and the Government of Kerala (2018))

3.4. Study area – Alappuzha and Pathanamthitta Districts

The study area considered is the districts Alappuzha and Pathanamthitta. They consist of 135 panchayats (125 Gram panchayats and 10 municipalities) with a population of 3,325,201 people (Table 3, Figure 12). Gram panchayats are the panchayats governed by village councils in rural areas, while the municipalities are panchayats that are located in the urban areas of each district.

Table 3 Characteristics of Alappuzha and Pathanamthitta

District	No. of municipalities	No. of Gram Panchayats	Female population per 2011 census	Male population per 2011 census	Total Population
Alappuzha	6	72	1,114,647	1,013,142	2,127,789
Pathanamthitta	4	53	635,696	561,716	1,197,412
Total	10	125	1,750,343	1,574,858	3,325,201

(Source: https://censusindia.gov.in/census.website/data/census-tables)

Alappuzha is the smallest district in Kerala. With a size of 1,414 sq. km, it constitutes 3.64% of the total state area, and Pathanamthitta covers 2,653 sq. km. The District Planning Offices (DPO) state Alappuzha has a higher population per sq. km (1079) than Pathamthita (453) (DPO, n.d.) Alappuzha has a coastline along the Arabian Sea, while Pathanamthitta is a highly vegetated area. Alappuzha lies between the Vembanad Lake and the Arabian Sea while Pathanamthitta has a reserve forest that account for 50% of the district area (DPO, n.d.). Alappuzha is a low-lying area with some parts below the sea level. Pathanamthitta has a huge elevation variation across the the district with high mountianous regions in the west and lowlands towards the border of Alappuzha and Pathanamthitta respectively. Average temperatures are 27°C and 25°C in Alappuzha and Pathanamthitta. In both districts, the rainy season is the annual southwest monsoon period (June to September).

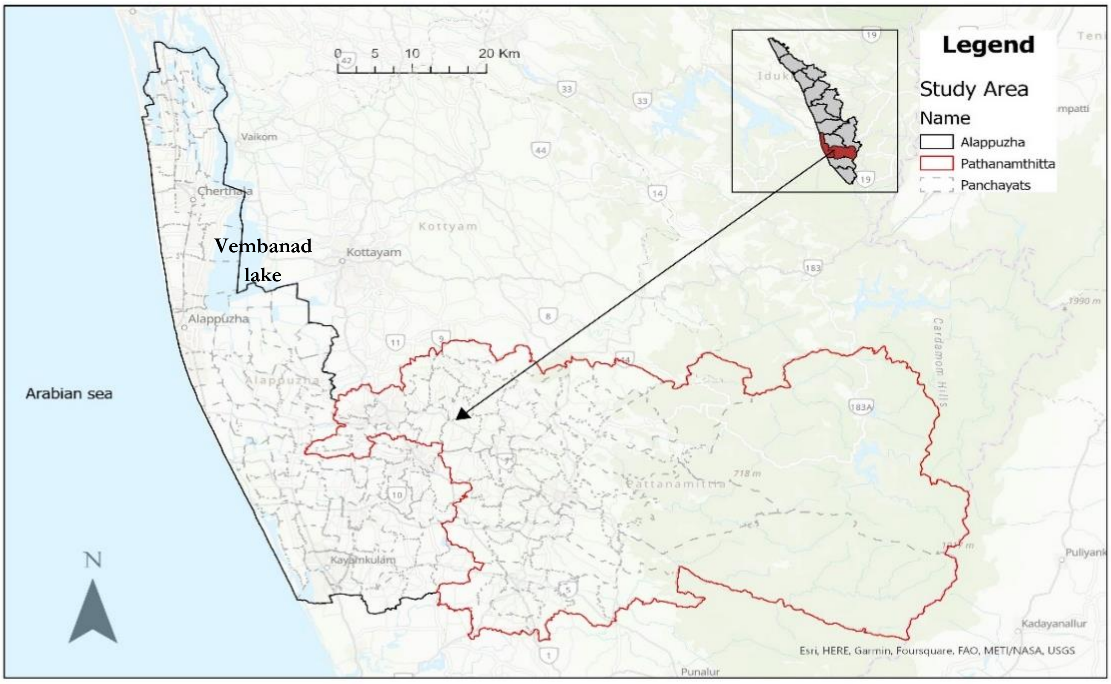

Figure 12 Showing the study area and the panchayats

4. METHODOLOGY OVERVIEW

A variety of methods were used to achieve the given objectives. This chapter provides an overview of the methods, datasets and terminologies used in this study. The research questions that each method aims to fulfil, and outcomes are provided. The common terms used in the results of the analysis in further chapters are also defined. The methodological considerations made concerning research ethics are also explained.

4.1. Overview of Methods

The methods used in this study are summarized in Table 4. The research questions that each method aims to fulfil, and outcomes are provided. Each method would be described in sufficient detail in the respective sections in chapters 5-7.

Table 4 Overview of methods

Objective	Research Questions	Methods	Outcomes
RO1: Incidence Analysis.	What was the impact of the 2018 and 2019 flooding events?	Analysis of flood characteristics for both years. Impact analysis of flood among the population in the study area **(5.3.1)**	Identification of the flood trend and distribution. Insight into exposed areas and population to flood. **(5.4.1)**
	How are the flood events associated with the incidences of leptospirosis?	Trend analysis of Leptospirosis using Epidemiological curve. Visualization of incident rates (IR) and Cluster Analysis (Global Moran's I, ANN, and Hotspot Analysis) **(5.3.2)**	Insight into the trend of incidences during the phases of the flood. Identification of the pattern and spatial characteristics of the incidences during the phases and years. **(5.4.2)**
	How do the incidences of leptospirosis differ by flood phase and year?	ANOVA analyses to test for differences between phases and years. Regression analyses for flood extents and incidences for 2018 and 2019. **(5.3.3)**	Difference between the two situations. The importance of flood duration in the transmission of diseases. **(5.4.3)**
RO2: Assessment of risk factors	Which geographic areas are associated with leptospirosis incidence in 2018?	Assessment of leptospirosis incidence comparison to urban/rural settings and land use **(6.3.1)**	Insight into which panchayat type and land use class were more affected by leptospirosis in 2018 **(6.4.1)**
	Which risk factors of leptospirosis can be obtained in Kerala?	Data gathering and preparation for risk factors. **(6.3.2)**	An understanding of the available risk factors that can be quantified as indicators for leptospirosis **(6.4.2)**

	What demography that was affected by leptospirosis cases?	Sociodemographic factor analysis using descriptive and frequency statistics **(6.3.3)**	Insight into the age and gender groups vulnerable to leptospirosis and how they are impacted by flood dynamics **(6.4.3)**
	How do risk factors relate to the incidences of Leptospirosis in the study area?	Temporal analysis of dynamic factors and leptospirosis. Multivariable regression analyses in spatial and temporal scales during the phases of flood **(6.3.4)**	Visualization of how the dynamic factors relate to the leptospirosis incidence weekly. Understanding the risk factors that are relevant in the different phases of floods in space and time **(6.4.4).**
RO3: Risk management	What are the potential risk factors identified by local health experts?	Surveys were conducted on the situation using health experts and volunteer workers as respondents **(7.3.1)**	New findings about the local risk factors within Kerala communities **(7.4.1)**
	How should stakeholders be involved in managing epidemic risk?	Review of the response of stakeholders to 2018 post flood epidemic. Analysis of stakeholders' roles and involvement **(7.3.2).**	An insight into the management of 2018 situation by involved stakeholders, suggestions for improvements **(7.4.2)**.
	How can the findings be used to minimize future risks?	Translation of the risk assessment in Kerala into action points **(7.3.3)**	Recommendations on areas and vulnerable groups to prioritize for local interventions. Action points for stakeholders **(7.4.3)**

4.2. Datasets used.

A variety of data was used as summarized in table 5, all datasets were received, analysed, managed and presented in accordance with guidelines for ethical research.

Table 5 Summary of data used.

Objective(s)	Datasets	Description of variable(s)	Type (Resolution)	Date	Source
RO1 **RO2** **RO3**	Record of Leptospirosis cases	Records of incident cases in 2017, 2018 & 2019	Vector file (Point)	2019	KSDMA
RO1 **RO2** **RO3**	Administrative boundaries	Boundaries of Kerala districts, panchayats and population	Vector file (Polygon)	2022	KSDMA

RO1 **RO2**	Flood extent for Kerala	The extent of the flood of 2018 & 2019	Raster file (10m)	2023	(Glas, 2023)
RO1	Flood depth	Depth of the floods in the study area (2018 and 2019)	Raster file (150m)	2023	(Glas, 2023)
RO1 **RO2**	Flood discharge	Daily water levels from river discharges at stations in the study area (2018 & 2019)	Excel file	2023	KSDMA
RO1 **RO2**	Population density	Population density	Raster file (1km)	2021	Meta
RO2	Climatic variables	Daily Precipitation and temperature	Excel file	2023	ERA5
RO2	Local Climatic variables	Daily Precipitation and temperature	Excel file	2022	KSDMA
RO2	Precipitation	Total precipitation for the study area	Raster file (5.6km)	2023	CHIRPS
RO2	Temperature	Average temperature for the study area	Raster file (1km)	2023	MODIS
RO2	Vegetation	Normalized Difference Vegetation Index (NDVI) value	Raster file (500m)	2023	MODIS
RO2	Elevation	Digital elevation of areas in Kerala	Raster file (30m)	2015	Copernicus DEM
RO2	Water bodies	Extent of existing water bodies	Raster file (30m)	2015	Copernicus DEM
RO2	Land use	Land use areas: Vegetation, Residential and Farmlands.	Vector file (Polygon)	2023	Open Street Map (OSM)
RO2	Poverty	Relative wealth index	Vector file (Point data)	2023	Meta
RO2	Shapefile of healthcare facilities	The locations of treatment facilities	Vector file (Point)	2023	Healthsites
RO3	Questionnaire	Qualitative survey	N/A	2023	Health workers
RO3	Expert interview		N/A		Medical doctor

4.3. Terminologies used.

Due to the interdisciplinary nature of this study, some common terms that are frequently used highlighted below. The operational definitions are also added to aid its comprehensiveness:

- Number of cases: it simply means the count of individuals that have been confirmed by clinical diagnosis of having leptospirosis disease.
- Incidence: the number of cases that occur within a given period
- Incidence rate: is the ratio of incidence to the population involved. It is obtained by dividing the total number of cases by the total population affected. It is often expressed as per 100,000 population.
- Outbreak: This refers to an incidence that exceeds the expected or usual incidence among a given population.
- Panchayat: It is the unit of division used in this study, it is an assembly of communities with a geographically defined boundary and population count.
- Clusters of incidences: Clusters refer to the aggregation of geographically panchayats with a similar incidence. A group of panchayats with high incidence (high-high) are referred to as the hotspots of the disease. A group of panchayats with low incidence (low-low) are referred to as the cold spots of the disease. A group of panchayats mixed with both high and low incidences (low-high or high-low) are referred to as outliers.
- Flood: It is the amount of water covering an area that is usually dry or less wet
- Flood extent: this is the amount of area covered by flood.
- Flood discharge: it is the volume of water received flowing through a watercourse or river during the time of a flood.
- Flood depth: Also referred to as flood level, it refers to the height of flood at a certain location during a flood.
- Phases of flood: The disaster phases are defined as preflood, (during) flood and postflood phases. Where the preflood phase represents the time before the flood, the flood phase is when the flooding occurred, and postflood phase means the time the flood no longer was present.

4.4. Ethical considerations.

The conduct of this study accounted for as many nuances as possible to ensure its ethical integrity. This research made use of a substantial amount of personal data of inhabitants of the Kerala district, therefore proper considerations was made to ensure data privacy and protection. The surveys conducted were fully examined against ethical risks. For the questionnaire, no personal information such as age and location were collected. Informed consent was communicated properly to ensure that respondents who volunteer were fully aware of the purpose of the survey. A high level of professionalism was on display during the expert interview, and transcript were shared given the full consent of the interviewee. The completed surveys as part of the research were approved after a thorough ethical review by GEO Ethics Committee, University of Twente.

5. ANALYSES OF THE INCIDENCES OF LEPTOSPIROSIS

This chapter provides the methods and results related to the first objective of this research. The incidences of leptospirosis occurred in different places at different times. Leptospirosis data were obtained for three years: 2017 (non-flood year) and two years with flooding, 2018 (heavy flooding) and 2019 (moderate flooding). To obtain the first indication of the relationship between flooding and leptospirosis, the distribution of the cases with respect to the flooding events were assessed spatially and temporally. A comparison was made between and within the incidences of each year to ascertain the relationship between flooding and leptospirosis incidence.

5.1. Introduction

Leptospirosis is a common zoonotic disease that can be transmitted to humans through contaminated flood water. Several studies have connected the incidence of leptospirosis with flooding by comparing the temporal and spatial association of the epidemic and disaster events. (Chadsuthi et al., 2021; Mohd Radi et al., 2018; Warnasekara et al., 2021) This chapter fulfils the first research objective which is to investigate the incidences of leptospirosis in Kerala over space and time and analyse the relation with flood occurrences. The research questions are:

i. What was the impact of the 2018 and 2019 flooding events in the study area?
ii. How are flood events associated with the incidences of leptospirosis?
iii. How do the incidences of leptospirosis differ by flood phase and year?

To examine how incidences of leptospirosis changed over time and in relation to the flood of 2018, three phases of flood were defined. No reported flood event occurred in 2017, and the 2018 floods occurred within the months of June and August. Therefore, the chosen start and end dates for the flood period were defined based on the published flood map shown in Figure 8. The 2019 flood in Kerala occurred between August 8 and 31, 2019 (Govt. of Kerala, 2019).

For all years considered, the preflood phase is defined as three months before the flood, and postflood phase as three months after the flood. Three months were chosen because it provides sufficient time for incubation and transmission between hosts, this classification was also previously used by Mohd Radi et al. (2018). The three flood phases considered in this study and the associated dates are shown in Table 6.

Table 6. Classification of flood phases used for 2017 – 2019.

Year	Preflood (3 months before)	Flood period (During)	Postflood (3 months after)
2017	No flood	No flood	No flood
2018	April 15 – July 15	July 16 - August 28	August 29 – November 29
2019	May 7 – August 7	August 8 – 31	September 1 – December 1

5.2. Data

As summarized in Table 7, a variety of data were used to conduct the analysis in this chapter. The preparation needed for each section are described below:

For **5.3.1**, the dataset used are:

- Flood discharge data was obtained from daily river discharges measured at two stations in the study area: Station Q_Erapphuza (located in the Alappuzha district), and Station Q_Kurudamannil (located in Pathanamthitta district). A total of 21 out of 199 missing values in the river discharge data were estimated using a temporal trend method for 2018 to model the peak flood period. This method involves the estimation of missing values using time-series values for consecutive days (ESRI, n.d.). The summary of the estimation and timesteps is provided in **Appendix A.1.1.**
- Precipitation: Local rainfall data was only available for Alappuzha, therefore the rainfall data from a global source (ERA) was used to obtain values for Pathanamthitta. To check for accuracy, the datasets were compared for similarity. The correlation between data from local and global sources for Alappuzha was 0.67. The rainfall data was deemed acceptable to model local variation given its moderate correlation according to definitions by Schober and Schwarte (2018).
- Flood depth map was obtained from simulation by Glas (2023) using the fast flood model. The input variables used for the model are gridded rainfall (72hr return period) and elevation.
- Similarly, raster maps created by Glas (2023) from Sentinel-1 Radar imagery were used to demarcate the extent of flooding in Kerala during the flood phase for both years (2018 and 2019).
- Population density represents the population in the study area for the year 2021. Each raster tile is equivalent to the number of people within a resolution of 1km.

For **5.3.2**, additional datasets are:

- Administrative boundaries were obtained to demarcate the area of each Panchayat. The shapefiles, which included the total population for each panchayat, were obtained in 2022.
- For leptospirosis cases (also referred to as incidences or cases), incidence data was obtained for three years (2017- 2019). Data were captured daily and aggregated by the Panchayats. The incidence data was summarized into epidemiological weeks (epi weeks), where epi week 1 starts on the first Sunday and ends on Saturday of each year (PAHO, 1999).

Table 7. Data used in this chapter.

Datasets	Description	Type (Resolution)	Date	Source
Leptospirosis cases	Daily records of positive leptospirosis in 2017, 2018 & 2019 at panchayat level	Vector file (Point)	2019	KSDMA
Administrative boundaries	Boundaries of Kerala districts and panchayats in study area. The total population for each panchayat is included	Vector file (Polygon)	2022	KSDMA
Flood extent	The extent of the flood of 2018 & 2019	Raster file (10m)	2023	(Glas, 2023)
Flood depth	Depth of the floods in the study area (2018 and 2019)	Raster file (150m)	2023	(Glas, 2023)
Flood discharge	Daily water levels from river discharges obtained for 2018 & 2019	Excel file	2023	KSDMA
Precipitation	Local daily rainfall for Alappuzha for 2018	Excel file	2022	KSDMA
	Daily rainfall from global climatic data for study area from 2017 to 2019	Excel	2022	ERA5
Population density	Distribution of human population in the study area.	Raster file (1km)	2021	Meta

5.3. Methods

All spatial analysis were performed in ArcGIS Pro version 3.1.1, while R was used for statistical analysis (the scripts are provided in **Appendix A.3.1**)

5.3.1. Assessment of the impact of 2018 and 2019 Floods

The size, extent and impact of the flood were assessed for each year. Descriptive statistics were used to evaluate the amount of precipitation received, and flood discharges for each year. The area exposed to the different flood depth is computed from the pixels of the flood depth map, the depths are classified into 6 categories (No flood, <5m, <1m, <2m, <4m, and <6m). For years with flooding (2018 and 2019), the percentage of panchayats and population exposed during each flooding event was determined by overlaying the flood extent maps with the administrative boundaries and population density map.

5.3.2. Analysis of leptospirosis incidence in relation to flood events

Descriptive statistics were used to summarize the incidences of leptospirosis over the three years, these incidences of leptospirosis were also examined through boxplots in relation to flood discharges. An epidemiological curve was constructed to compare the flood discharge and the number of incidences. The incidences during flooded years were compared against 2017 (non-flood year) to understand the differences and similarities temporally through epidemiological curves and maps.

The trend of the cases was analysed over the flood phases and years through spatial and non-spatial analyses. The incident rates of leptospirosis per 100,000 people among the panchayats were calculated by dividing the number of leptospirosis cases by the population of each panchayat. Global Moran's I was used to determine whether spatial clustering of leptospirosis incidence occurred using the inverse distance method to conceptualize its spatial relationship. Average Nearest Neighbor (ANN) analysis, relevant in neighbourhood identification (Thompson et al., 2022), was also used to compute the average distance among panchayats of infected persons. Cluster and Outlier Analysis was completed using the Anselin Local Moran's I statistic (Anselin, 1995) to identify significant hot spots (high-high clusters), cold spots (low-low clusters), and spatial outliers (high-low and low-high clusters) among the panchayats.

5.3.3. Statistical comparison of the incidences of leptospirosis

Analysis of variance (ANOVA) one-way test was conducted to determine if there are significant differences over the three years of incidence. Previously used by Kim (2014) ANOVA two-way test was conducted on the incidences within the three phases of floods and between the flooded years (2018 & 2019) to determine if there is a significant difference between them. The regression between flood extent and cases in 2018 was compared with the same regression model for 2019 to understand if there are differences between them. The F-value is obtained by dividing the mean squares (MS) computed from the sum of squares (SS) and degree of freedom (df). If the p-value of an ANOVA is less than .05, then the null hypothesis (there is no variation or that there is an interaction within the groups) is rejected.

The spatially varying coefficient (SVC) regression model (Equation 1) was used to compare the relationship between each pair (flood extent and the number of incidences) for the flooded years (2018 & 2019).

$$y(s) = \beta_0(s) + \beta_1 x_1(s) \qquad \text{Equation 1}$$

- Where y is the total number of leptospirosis cases,
- s refers to the locations of each panchayat.
- β_0, β_1 are the regression coefficients,
- x_1 refers to the flood extent.

5.4. Results

5.4.1. Assessment of the impact of 2018 and 2019 Floods

The precipitation and flood discharge in the study area are shown in Table 8 and Figure 13. Although similar amount of precipitation was received in Alappuzha, the amount of precipitation received in Pathanamthitta was highest (3144mm) in 2018 (Table 8). The maximum flood discharge and flood depth in 2018 are higher than that of 2019 in both districts (Table 8). Although there was a high amount of discharge in June 2018, it was not sustained long enough in comparison to the July – August 2018. Even though, there were higher discharge values in Pathanamthitta, the flood discharge in Alappuzha experienced weaker fluctuations. The flood peak occurred on the 18th of August 2018 (week 33) with a discharge of 949.9m³/s. Similarly, the 2019 floods peaked on the 8th of August 2019 (week 32) at 1360.3m³/s. There was a single peak period for the flood discharge in 2019 as compared to two peak periods in 2018 (Figure 13).

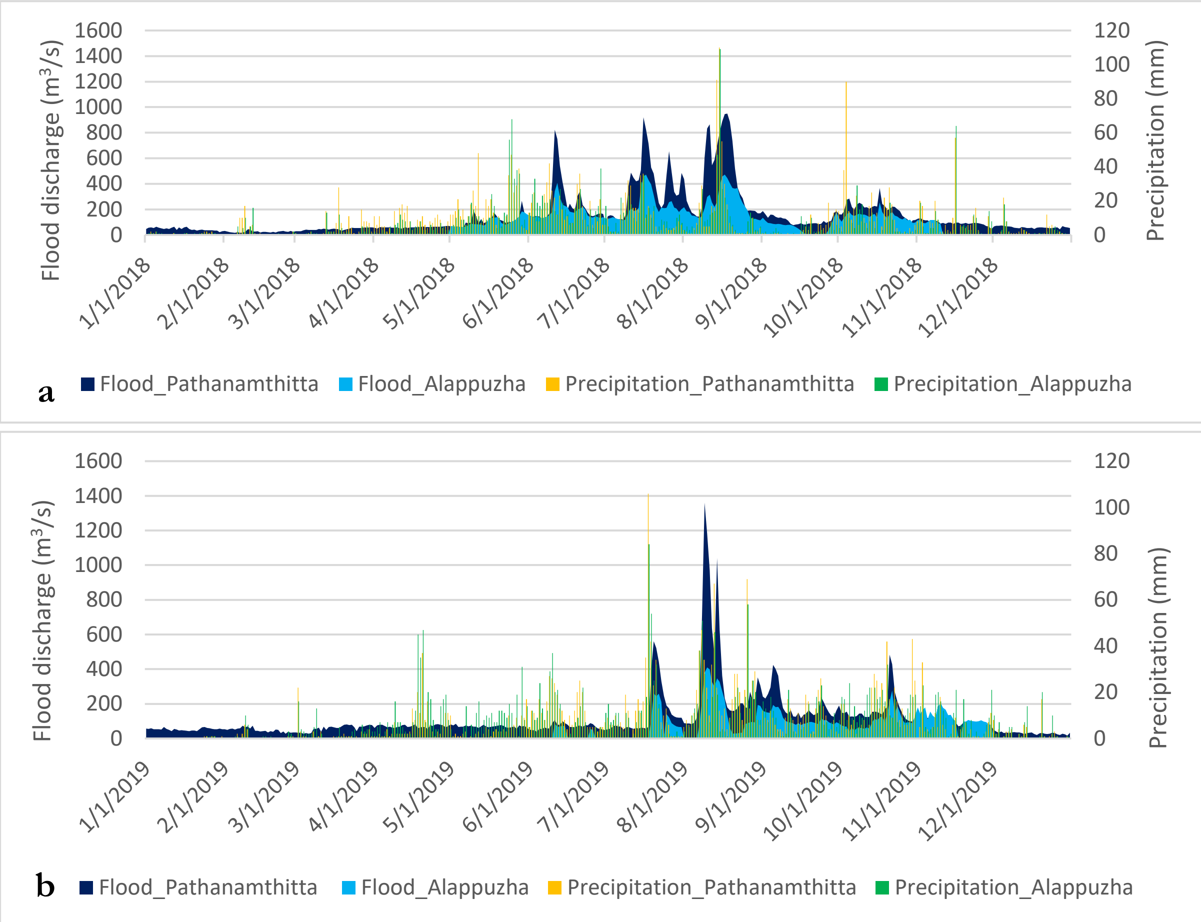

Figure 13 The trend of flood discharge and precipitation in flooded years (a) 2018 (b) 2019

Table 8. Total precipitation and maximum flood discharge observed between 2017 – 2019.

	Category	2017	2018	2019
Alappuzha	Total Precipitation (mm)	2650	2602	2602
	Maximum flood discharge (m³/s)		472.2	409.9
	Maximum flood depth (m)	-	2.9	2.6
Pathanamthitta	Total Precipitation (mm)	3086	3144	2788
	Maximum flood discharge (m³/s)		949.9	1360.3
	Maximum flood depth (m)	-	5.7	5.5

The maximum flood depths were higher in Pathanamthitta (5.7m in 2018; 5.5m in 2019) than Alappuzha (2.9m in 2018; 2.6m in 2019) (Table 8). A closer look is provided in Table 9. Most of the areas in both districts were not affected by floods (82.3% in 2018; 82.7% in 2019). Among the flooded areas, the most common flood depth experienced was less than 0.5m in both years (9.5% in 2018; 9.8% in 2019).

Table 9 Flood discharges and areas exposed in study area (2018 and 2019)

Category	**Areas in sq.km exposed in 2018**			**Areas in sq.km exposed in 2019**		
Flood depth (m)	Alappuzha Area (%)	Pathanamthitta Area (%)	Total Area (%)	Alappuzha Area (%)	Pathanamthitta Area (%)	Total Area (%)
No flood	891.0 (70.4)	2338.0 (87.9)	3228.9 (82.3)	897.3 (70.9)	2346.8 (88.3)	3244.1 (82.7)
< 0.5	169.9 (13.4)	202.5 (7.6)	372.5 (9.5)	175.7 (13.9)	207.4 (7.8)	383.2 (9.8)
0.5 – 1	68.8 (5.4)	57.3 (2.2)	126.1 (3.2)	86.3 (6.8)	55.1 (2.1)	141.4 (3.6)
1 – 2	125.4 (9.9)	38.1 (1.4)	163.5 (4.2)	98.4 (7.8)	35.6 (1.3)	134.0 (3.4)
2 – 4	10.0 (0.8	21.1 (0.8)	31.1 (0.8)	7.3 (0.6)	12.8 (0.5)	20.1 (0.5)
4 – 6	-	1.5 (0.1)	1.5 (0.04)	-	0.8 (0.03)	0.8 (0.02)

The flood event occurred in Alappuzha and Pathanamthitta, however former was more affected. The panchayats in the central areas of Alappuzha were the most affected by floods (Figure 14). Venbanad Lake is the largest water body close to the flooded areas. The flooding appears to have been aggravated by the main rivers in Alappuzha.

The population exposed to the flood was higher in Alappuzha (N=53,145, 2018 and N=59,135, 2019) than in Pathanamthitta (N=5,990 in 2018 and N=3,804 in 2019) (Table 9). 60% of the total number of panchayats were equally exposed to floods in 2018 and 2019, however, the population exposed in 2019 (1.0%) was lower than that of 2018 (1.9%) (Table 10).

Table 10 Count of panchayats and population exposed to floods in 2018 and 2019.

Year	**2018**			**2019**		
Categories	Alappuzha (%)	Pathanamthitta (%)	Total (%)	Alappuzha (%)	Pathanamthitta (%)	Total (%)
Panchayats (N = 135)	43 (31.9)	38 (28.1)	81 (60)	42 (31.3)	39 (28.9)	81 (60)
Population (N = 3,193,446)	53,145 (1.7)	5,990 (0.2)	59,135 (1.9)	29,060 (0.9)	3,804 (0.1)	32,864 (1.0)

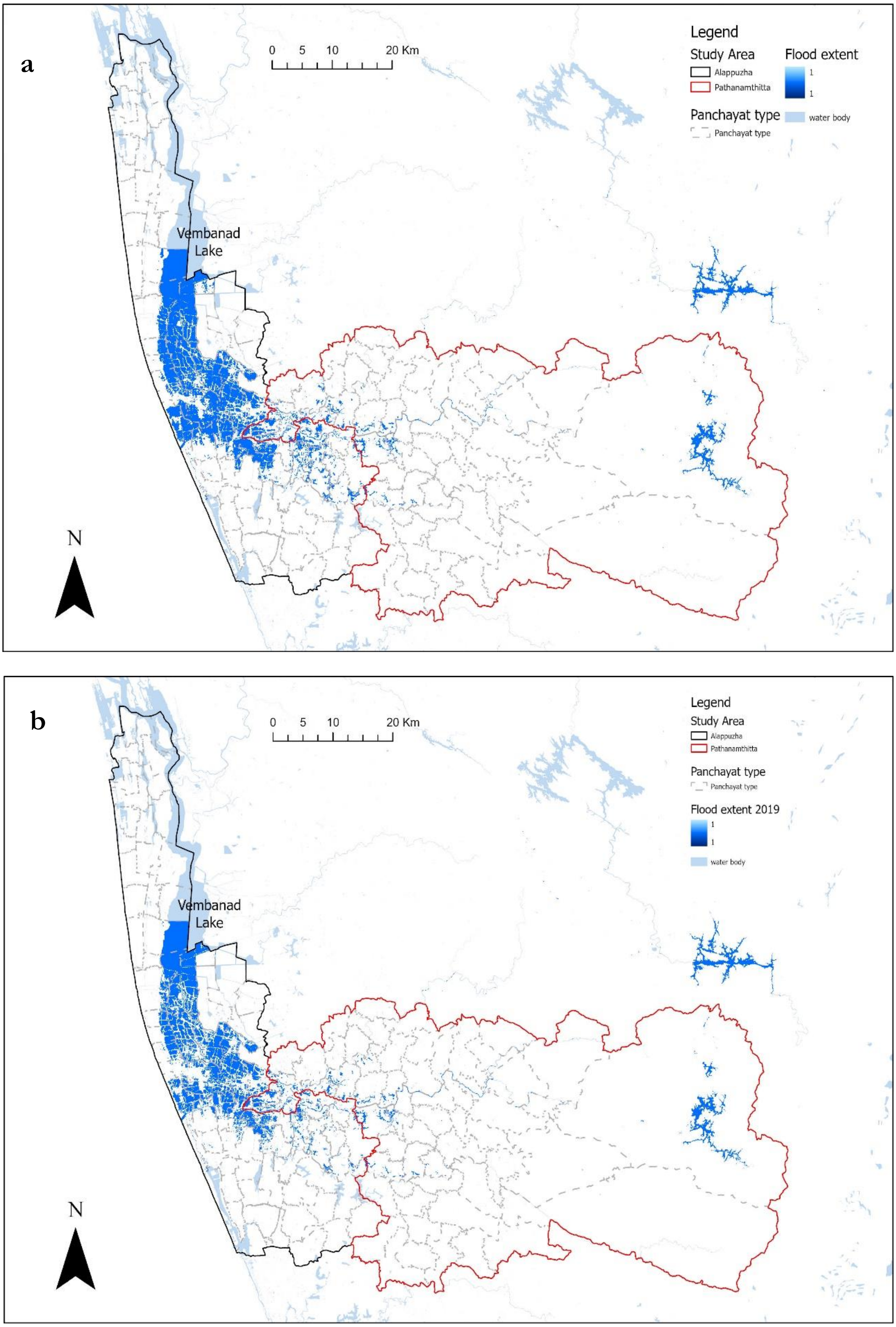

Figure 14 Flood extent maps in the study area (a) 2018 (b) 2019

5.4.2. Analysis of leptospirosis incidence in relation to flood events

The incidence of leptospirosis in the study area varied over the three years considered (Figure 15). The maximum number of cases in 2018 in both districts (N = 64 in Alapphuzha; N=77 in Pathanamthitta) was at least four times higher than other years (N=15 in 2017 and 11 in 2019, Alappuzha; N=9 in 2017 and N=7 in 2019, Pathanamthitta) (Figure 15).

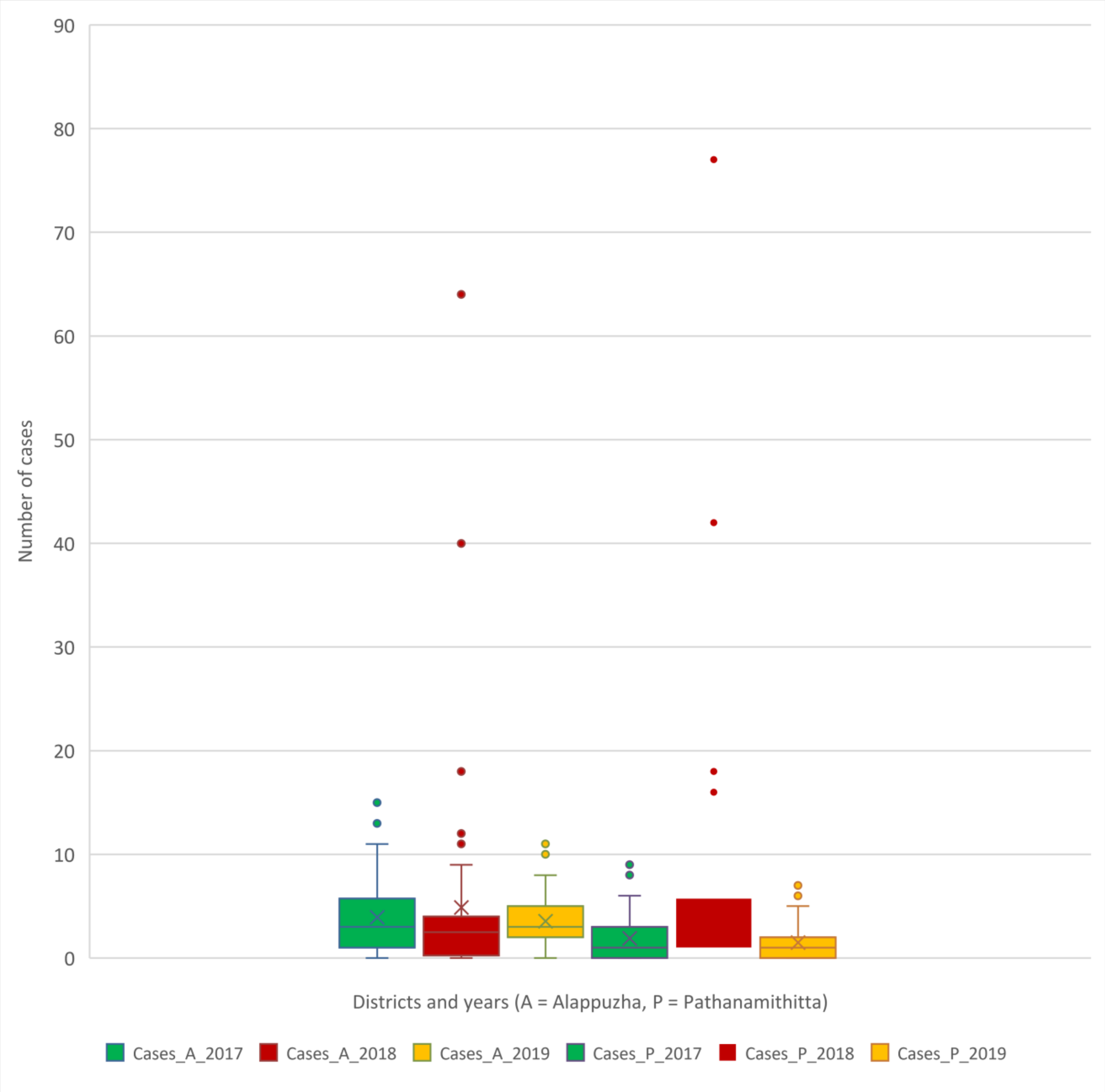

Figure 15. Total number of incidences of leptospirosis between 2017 – 2019. (A boxplot where green boxes = cases in 2017; red boxes = cases in 2018; yellow boxes = cases in 2019. A = Alappuzha, P = Pathanamthitta)

The incidences were observed in multiple panchayats in 2018, while the incidences of leptospirosis were common in the central areas of Alappuzha in 2017 and 2019 (Figure 16). The highest concentration of cases can be seen in 2017 incidence map in Alappuzha municipality, Alappuzha district (N =75). The maps showing the incidence rates and clusters can be found in **Apendix A.1.2.** The results show that higher incidences occurred in Alappuzha communities in 2017 and 2019, but in 2018 the central parts of Pathanamthitta become strongly affected also.

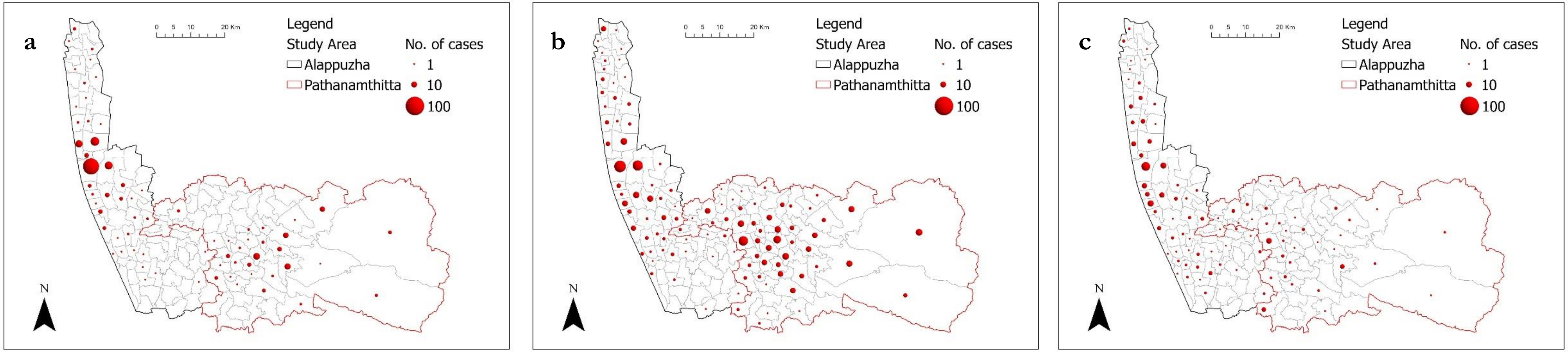

Figure 16 Distribution of the total number of cases among panchayats across all three years (a) 2017 (b) 2018 (c) 2019

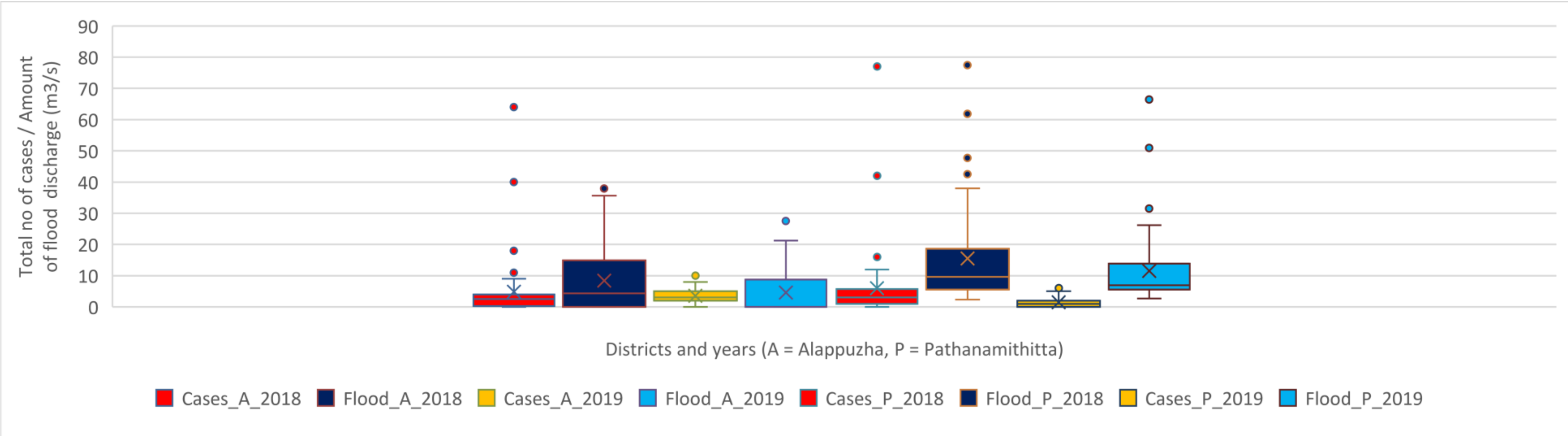

Figure 17 Total number of cases and amount of flood discharge in study area for 2018 and 2019. (A box plot where red boxes = cases in 2018 and yellow boxes = cases in 2019; dark blue = flood discharge in 2018 and light blue = flood discharge in 2019; A = Alappuzha, P = Pathanamthitta)

The result of the Moran's I show that the incidences in all three years are significantly clustered (positive z-score values and p-value statistically significant) (Table 11). The panchayats with incidences in 2018 have the lowest mean distance (4120.24) and the panchayat with incidences in 2017 are the farthest apart (4437.75). The cases in 2018 have a higher spatial coverage than other years.

Table 11 Moran's I and ANN for the three years (2017 – 2019)

	Moran's I			**ANN**			
Year	Moran's I	z-score	Pattern	Observed Mean Distance	Expected Mean Distance	Nearest Neighbor Ratio	z-score
2017	0.14	9.17**	Clustered	4437.75	4559.32	0.97	-0.42
2018	0.18	7.71**	Clustered	4120.24	3831.06	1.08	1.48
2019	0.27	11.62**	Clustered	4178.35	4146.35	1.01	0.14

**($p<0.01$)

Despite the high flood discharges in 2018 and 2019, only the incidences in 2018 showed a high increase (Table 12, Figure 17). The incidences in different flood phases are therefore considered closely in further analyses.

Table 12 Summary of leptospirosis cases and average flood discharge between 2017 – 2019 by epi weeks (N = 52).

	Leptospirosis Cases						**Flood discharge (m^3/s)**					
District	Alappuzha			Pathanamthitta			Alappuzha			Pathanamthitta		
Category	2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019
Mean	3.9	4.9	3.6	1.9	6.0	1.5	-	84.4	46.0	-	154.9	115.1
Standard Deviation	3.6	10.4	2.7	2.5	12.1	1.7	-	102.4	66.9	-	160.9	117.1
Minimum	0	0	0	0	0	0	-	0.0	0.0	-	236.0	26.7
Maximum	15	64	11	9	77	7	-	379.4	275.5	-	774.3	664
Sum	204	253	185	98	312	77	-	4389.2	2393.1	-	8056.3	5984

Figures 18 and 19 display the differences between the trend of leptospirosis cases during the three flood phases of flooded years (2018 and 2019) and non-flooded year (2017) in the study area. A sharp increase in the number of cases can be seen immediately after the flood phase in both districts in 2018. The high number of cases was recorded on Epi week 36, precisely on the 4th of September 2018, which is 17 days after the flood peak (18th of August 2018). On the other hand, the number of cases in 2019 in both districts was very similar to the non-flooded year, as no peak in increase can be observed.

The distribution of cases during the postflood phase of 2018 is more evident than that of 2019 in both districts even though the incidences in all phases are distributed in similar locations (central parts of Alappuzha and Pathanamthitta). (Figures 20 and 21). The number of cases during the flood phase was lower in comparison with other phases. The result of Moran's I and cluster analysis is provided in **Appendix A.1.2.**

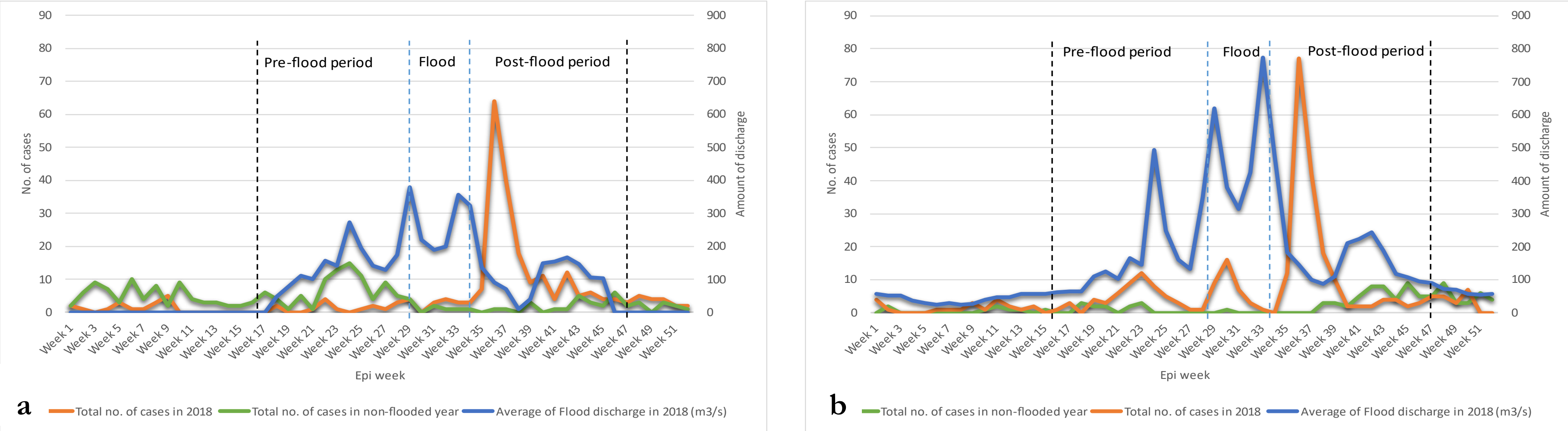

Figure 18 Trend of leptospirosis in flood phases in 2018 in the study area. (a) Alappuzha (b) Pathanamthitta

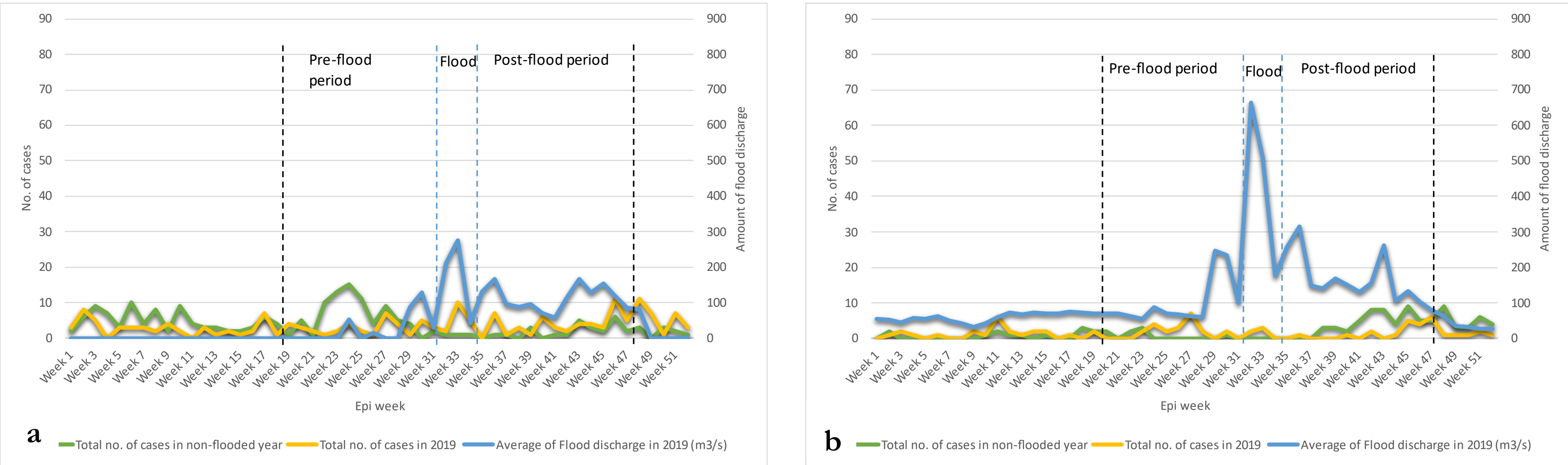

Figure 19 Trend of leptospirosis in flood phases in 2019 in the study area. (a) Alappuzha (b) Pathanamthitta

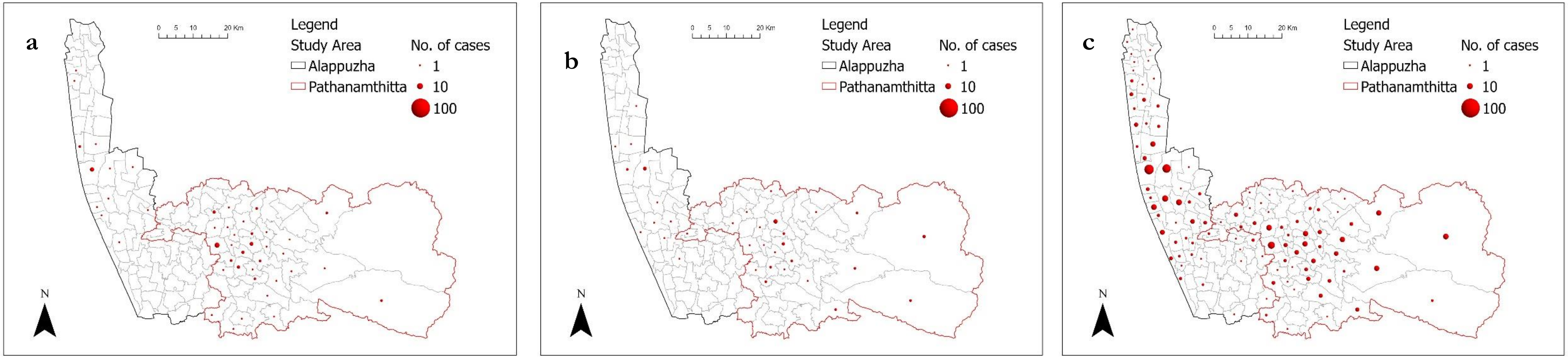

Figure 20 Distribution of leptospirosis cases among panchayats across flood phases in 2018 (a) before flood (b) during flood (c) after flood

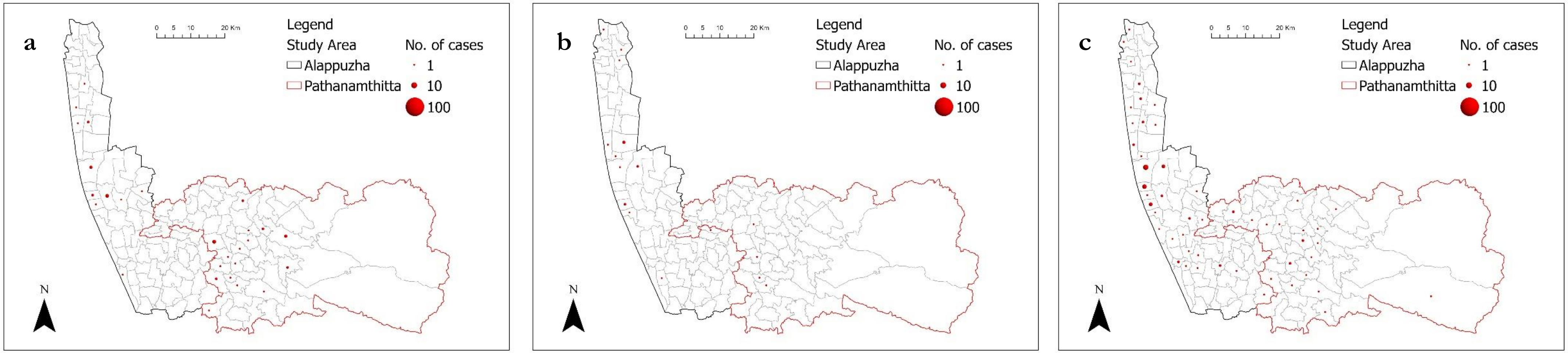

Figure 21 Distribution of leptospirosis cases among panchayats across flood phases in 2019 (a) before flood (b) during flood (c) after flood

Table 13 shows the summary of flood discharge and leptospirosis cases in the study area. As expected, the average amount of flood discharge was highest during the flood phase in 2018 (277.9m³/s in Alappuzha; 498.3m³/s in Pathanamthitta) and 2019 (138.0m³/s in Alappuzha; 341.7 in Pathanamthitta). The flood discharges were consistently higher in 2018 than 2019 in all phases, except during the postflood phase of 2019 (109.2m³/s in Alappuzha; 150.2m³/s in Pathanamthitta) In both districts, the highest number of cases occurred during the postflood phase of 2018 (N= 192, Alappuzha; N=187, Pathanamthitta) but not in 2019 (N= 59, Alappuzha; N=21, Pathanamthitta) (Table 13). The number of cases during the flood phase was lower in comparison with other phases.

Table 13 Flood discharge and leptospirosis cases across flood phases

Phase	**Category**	**2018**		**2019**	
		Alappuzha	Pathanamthitta	Alappuzha	Pathanamthitta
Preflood	Maximum flood discharge (m^3/s)	118.9	171.2	21.7	94.4
	Total leptospirosis cases	17	56	18	25
Flood	Maximum flood discharge (m^3/s)	277.9	498.3	138.0	341.7
	Total leptospirosis cases	15	36	16	4
Postflood	Maximum flood discharge (m^3/s)	90.5	146.1	109.2	150.2
	Total leptospirosis cases	192	187	59	21

The clusters and outliers of the incidences of leptospirosis in 2018 and 2019 can be found in Appendix A.1.2. The result of overlaying the flood extent and the clusters of letpospirosis in shown in Figures 20 and 21. It can be seen that the flood events in 2018 and 2019 Are related to the hotspots (high-high cluster) of the incidence during the postflood phase.

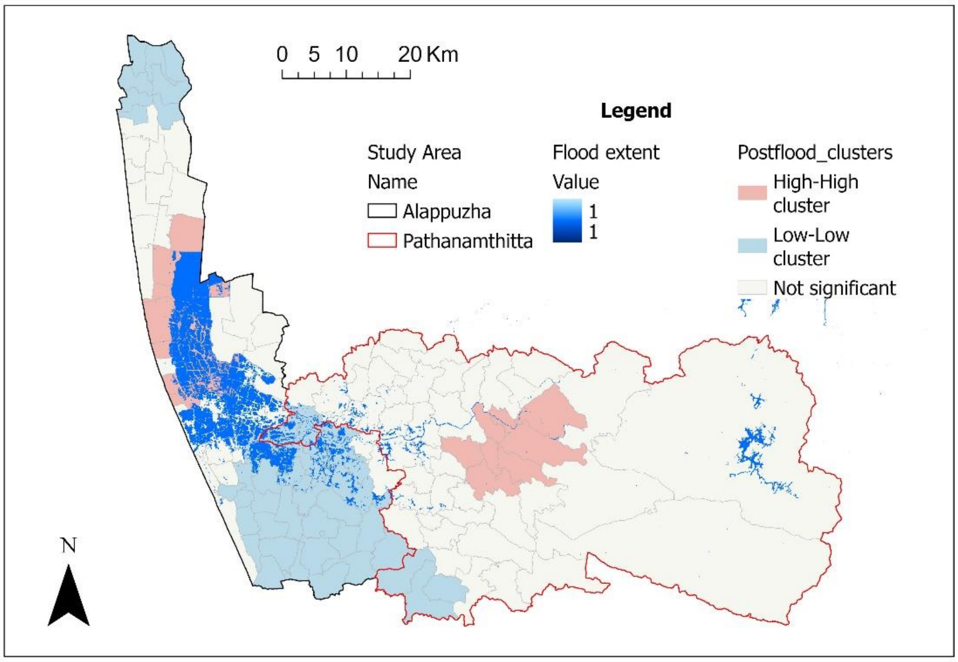

Figure 22 Flood extent and the cluster of postflood incidence in 2018

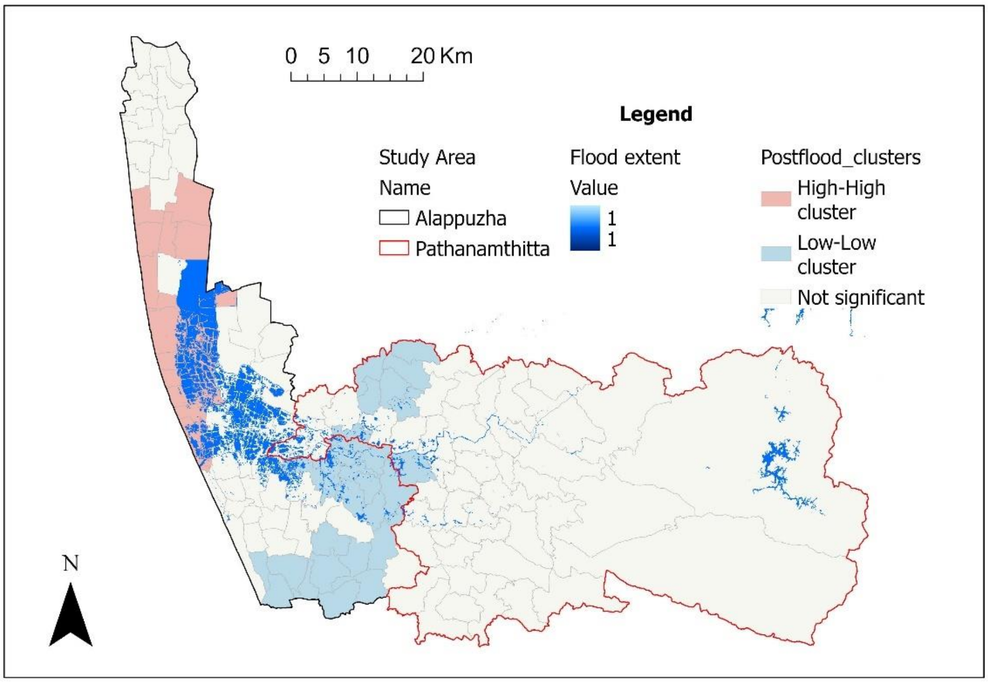

Figure 23 Flood extent and the cluster of postflood incidence in 2019

Using the population exposed during floods in Table 10 and the postflood incidences, the incidence rates because of the the flood are shown (Table 14, Figure 24). The highest flood-induced incidence rate per 100,000 was observed in Pathanamthitta in 2018 (3121.9). The overall incident rate in both districts in 2018 (640.9) is higher than that of 2019 (243.4). The increase in postflood is more directly related to flood exposure in Alappuzha than in Pathanamthitta (Figure 24)

Table 14 Incidence rates as a result of flooding in 2018 and 2019.

Year	**2018**			**2019**		
Categories	Alappuzha	Pathanamthitta	Total	Alappuzha	Pathanamthitta	Total
Postflood incidence	192	187	379	59	21	80
Population exposed to flood	53,145	5,990	59,135	29,060	3,804	32,864
Incidence Rate per 100,000	361.3	3121.9	640.9	203.0	552.1	243.4

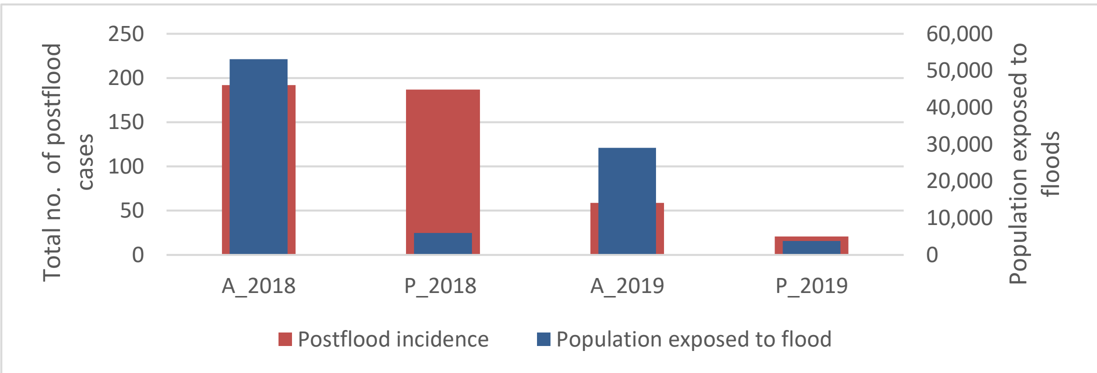

Figure 24 Postflood incidence and areas exposed to floods (A= Alappuzha, P=Pathanamthitta).

The result of the Global Moran's I and ANN analyses for 2018 and 2019 are shown in Tables 15 and 16 respectively. Although the incidences in all phases of flood appear to be significantly clustered, the average distances between the incidences differ. The highest Moran's I values (0.21 in 2018; 0.18 in 2019) were recorded in the postflood phase of with the highest z-score (8.69 in 2018; 7.97 in 2019). This point out that the incidences were most clustered after the floods. The incidences have the highest mean distance during the flood phase (6645.59m in 2018; 6412.26m in 2019), and the lowest mean distance during the postflood phase in both 2018 and 2019 (3873.12m in 2018; 4828.85m in 2019). The nearest neighbour ratio in the flood phase of 2018 (1.35) is the only statistically significant ratio. The mean distance of leptospirosis cases during postflood in 2018 is about 1000m lower than that of 2019.

Table 15 Global Moran's I and ANN for 2018 flood phases

	Moran's I			**ANN**			
Phases	Moran's I	z-score	Pattern	Observed Mean Distance	Expected Mean Distance	Nearest Neighbor Ratio	z-score
Preflood	0.16	6.78**	Clustered	4930.44	4966.68	0.99	-0.09
Flood	0.17	6.91**	Clustered	6645.59	4917.82	1.35	3.92**
Postflood	0.21	8.69**	Clustered	4172.46	3873.12	1.08	1.49

**(p<0.01)

Table 16 Global Moran's I and ANN for 2019 flood phases

	Moran's I			**ANN**			
Phase	Moran's I	z-score	Pattern	Observed Mean Distance	Expected Mean Distance	Nearest Neighbor Ratio	z-score
Preflood	0.06	2.84**	Clustered	5551.72	5535.72	1.04	0.40
Flood	0.12	5.21**	Clustered	5949.06	6412.26	0.93	-0.55
Postflood	0.18	7.97**	Clustered	4684.65	4828.85	0.97	-0.41

**(p<0.01)

5.4.3. Statistical comparison of the incidences of leptospirosis

The result of the ANOVA tests shows that there is a significant difference between the incidences across years in Pathanamthitta (p<0.01) but not in Alappuzha (Table 17). In both districts, there is a significant difference in the mean of leptospirosis cases over the three flooded phases (p<0.01). Also, there is no significant interaction between the 2018 and 2019 flood phases (Table 18), which means the incidences in 2018 did not influence the emergence of 2019 incidence. They can be therefore regarded as independent events.

Table 17 Result of ANOVA test for incidences of all three years (2017 – 2019)

Source of Variation	**SS**	**df**	**MS**	**F**	**SS**	**df**	**MS**	**F**
	Alappuzha				Pathanamthitta			
Between Groups (Years)	23.7	2	23.7	0.6	644.7	2.0	322.3	6.2**
Within Group (District)	42.7	153	42.7		7891.3	153.0	51.6	
Total	23.7	155			8535.9	155.0		

**(p<0.01)

Table 18 Result for ANOVA test for incidences in three flood phases (2018 - 2019)

Source of Variation	SS	df	MS	F	SS	df	MS	F
	Alappuzha				Pathanamthitta			
Sample (Years)	4.3	1	4.3	0.0	58.2	1	58.2	9.3**
Columns (Flood phases)	1932.5	1	1932.5	9.3**	62.5	1	62.5	10.0**
Interaction	10.2	1	10.2	0.0	12.0	1	12.0	1.9
Within Group (District)	9943.1	48	207.1		300.2	48	6.3	

**($p<0.01$)

The result of SVC regression analyses is presented in Table 19. Based on the probability of their Z values, the flood extent of 2018 is a significant predictor for postflood incidences of 2018 at a 95% confidence level. The flood extent of 2019 does not show statistical significance to postflood incidences in 2019 spatially. Given the insignificance of the 2019 flood in inducing leptospirosis infections, only the 2018 flood event is considered in further analysis.

Table 19 Spatial regression analysis for flood extents

	Estimate	Std. Error	Z value	Estimate	Std. Error	Z value
	2018 Analysis (R^2 = 0.978)			2019 Analysis (R^2 = 0.825)		
(Intercept)	2.5943	0.9510	2.728**	0.4334	0.1080	4.015***
Flood	1.1488	0.5319	2.160*	0.1475	0.2772	0.532

***($p<0.001$), **($p<0.01$), *($p<0.05$)

5.5. Conclusions

This chapter has evaluated the incidences of leptospirosis in relation to flooding events by comparing flood phases and years. The conclusions associated with each research question are:

i. The flood events in 2018 and 2019 had major impacts in the study area, the former having more severe impacts in terms of areas affected, population and panchayats exposed.

ii. The postflood incidence of leptospirosis can be associated with the flood event that occurred the same year in space and time. The total incidences in both 2018 and 2019 increased in the postflood phase, the increase in 2018 being more evident.

iii. The incidences of leptospirosis differ significantly over the three flood phases, regardless of the year. Unlike the 2019 flood, the flood of 2018 is a significant spatial indicator for postflood incidences.

6. ASSESSMENT OF THE RISK FACTORS OF LEPTOSPIROSIS

In this chapter, the focus is on the second research objective which is to assess the risk factors of the Kerala communities to an outbreak of Leptospirosis after floods. Known risk factors from the literature review are quantified using available data sources. The demographic characteristics of infected individuals are analysed in the two Kerala districts. Socio-environmental factors are then examined to gain insight into how they vary in space and time in relation to leptospirosis incidences. Finally, surveys were conducted with health workers in Kerala to identify clinical risk factors.

6.1. Introduction

Leptospirosis occurs as a result of complex interrelationships between human, zoonotic hosts and pathogens in the environment (Cucchi et al., 2019). The incidence of leptospirosis is governed by several factors as summarized by the epidemiologic triad for leptospirosis (Figure 4). A number of risk factors have been found to be associated with leptospirosis from literature (Section 2.4) and can be grouped into clinical, social, and environmental factors (Table 20).

Table 20 Risk factors from literature

Group	Factors
Clinical	Non-vaccination of dogs; Prevalence of serovars; Medical diagnostics
Environmental	Climatic variables (increase in rainfall, humidity, temperature); Geographic variables (low elevation, high vegetation, proximity to water and farmlands, occurrence of floods)
Social	Population demography (different age groups and majorly male gender); Population economy (poverty level, dog or pet ownership, occupation); Healthcare accessibility; Environmental sanitation and hygiene

The purpose of this study is to assess the risk of leptospirosis in Kerala., this chapter fulfils the second objective which is to assess the relevance of the risk factors of leptospirosis in Kerala. The analysis in Chapter 5 already shows that the 2018 flooding event is a significant indicator for the postflood incidences in 2018. This chapter, therefore, focuses on the incidences of 2018 and assesses the factors that contribute to its occurrence in the study area. The research objectives considered are:

i. Which geographic areas are associated with leptospirosis incidences in 2018?
ii. Which risk factors of leptospirosis can be obtained in Kerala?
iii. What demography was affected by leptospirosis infections?
iv. How do risk factors relate to the incidences of leptospirosis in the study area?

6.2. Data

A variety of data was used in this chapter to accomplish its objective, they are summarized in Table 21. The processes of preparing them are described in the sections that follow.

Table 21 Data used in Chapter 6.

Datasets	Description	Type (Resolution)	Date	Source
Leptospirosis cases	Daily records of leptospirosis in 2018 at panchayat level. The age and gender of patients were included.	Vector file (Point)	2019	KSDMA
Administrative boundaries	Boundaries of Kerala districts, panchayats and population.	Vector file (Polygon)	2022	KSDMA
Flood extent for Kerala	The extent of the flood of 2018.	Raster file (10m)	2023	(Glas, 2023)
Flood discharge	Daily water levels from river discharges for 2018	Excel file	2023	KSDMA
Precipitation	Total rainfall for the study area	Raster file (5.6km)	2023	CHIRPS
	2018 Daily rainfall data for Alappuzha	Excel file	2022	KSDMA
	Daily rainfall data from global climatic data for study area for 2018	Excel	2022	ERA5
Temperature	Average temperature for the study area	Raster file (1km)	2023	MODIS
	Daily average temperature for Alappuzha for 2018	Excel file	2022	KSDMA
	Daily temperature from global climatic data for study area for 2018	Excel	2022	ERA5
Vegetation	Daily Normalized Difference Vegetation Index (NDVI) value	Raster files (500m)	2023	MODIS
Elevation	Digital elevation of areas in Kerala	Raster file (30m)	2015	Copernicus DEM
Water bodies	Extent of existing water bodies	Raster file (30m)	2015	Copernicus DEM
Land use	Land use areas: Vegetation, Residential and Farmlands.	Vector file (Polygon)	2023	Open Street Map (OSM)
Poverty	Relative wealth index of the population	Vector file (Point data)	2023	Meta
Healthcare facilities (HCF)	The locations of treatment facilities	Vector file (Point)	2023	Healthsites

To achieve **6.3.1**,

- Leptospirosis cases (also referred to as incidences or cases), daily incidence data for 2018 was aggregated at panchayat level. Administrative boundaries were obtained to demarcate the area of each panchayat (gram panchayats and municipalities). The leptospirosis cases were joined with the administrative boundaries to examine the distribution of incidence among the panchayats. (560 out of 565 cases were correctly joined)
- Landuse data was obtained from Open Street Map (OSM).and classified into 5 categories relevant to leptospirosis incidence (farmland, farmyard, forest, residential areas and water bodies) based on their existing attributes of the dataset. A total of 2,571 polygons were considered.

To analyse demographic characteristics (**6.3.3**) Leptospirosis data contained age and gender information. To make this study comparable with other studies, the classification of age groups used are: 0-14, 15-29, 30-44, 45-59, 60-74, and ages above 75 as previously used by Mohd Radi et al. (2018).

For the assessment of socio-economic factors (**6.3.4**), data was prepared for each risk factor. The risk factors were subjected to spatial regression to understand their relationship with leptospirosis incidences. The risk factors considered in this section are shown in Table 22.

Table 22 Description of risk factors considered.

Indicators	Description	Category	Relation
Poverty	Insufficiency of money to meet basic needs such as food, clothing, and shelter	Static	(+)
HCF Density	The number of healthcare facilities within an area	Static	(+)
Elevation	The altitude of the area	Static	(-)
Precipitation	Amount of rainfall received	Dynamic	(+)
Temperature	Amount of temperature received	Dynamic	(+)
Vegetation	Amount of areas covered by forests and agricultural lands	Static	(+)
Population Density	Population per unit land area	Static[1]	(+)
Water bodies	Amount of area covered by water bodies (such as rivers, lakes, ditches, streams)	Static	(+)
Flood	Amount of an area covered by water that is normally dry	Dynamic	(+)

Data preparation for temporal analysis: The three dynamic risk factors were involved in this section.

- Flood discharge data as described in **5.2.**
- Climate data (Precipitation and Temperature) were obtained from ERA daily aggregates. ERA5 daily provides daily aggregated values for climate reanalysis parameters by combining model data with global satellite observations (Bell et al., 2021). Like precipitation, temperature was also validated against local data with 0.70 correlation before use.
- Leptospirosis cases were summarized into epidemiological weeks (epi weeks), where epi week 1 starts on the first Sunday and ends on Saturday of each year (PAHO, 1999).

Data preparation for spatial regression:

Spatial regression was done to compare the risk score for each factor per panchayat against the incidence of leptospirosis during preflood and postflood phases. The definition of the phases of flood is the same as defined in Table 6. To summarize the index score for each panchayat, datasets needed to have a uniform geographic coverage over the study area. Most of the obtained datasets were available in raster files except for population density, poverty and the density of healthcare facilities (HCF) (Table 23).

While summarized value for each indicator remained the same for preflood and postflood periods, the value for dynamic factors and vegetation was different in both phases. As required, the flood was only included in the regression analysis for postflood incidence.

[1] The population changes during flood were not captured in the data used.

Table 23 Summarization of risk indicators for spatial regression

Indicators	Data type	Transformation technique	Raster format	Range (min, max)	Rescaled (min, max)
Poverty	Vector file	IDW	Continuous	-0.7,1.3	10,0
HCF Density	Vector file	KDE	Continuous	1,9420	0,10
Elevation (m)	Raster file	-	Continuous	0,1923	10,0
Precipitation (mm) [preflood; postflood]	Raster file	-	Continuous	9,24; 8,13	0,10
Temperature (K) [preflood; postflood]	Raster file	-	Continuous	290,337; 294,320	0,10
Vegetation [preflood; postflood]	Raster file	-	Continuous	-0.04,0.83; 0.18,0.93	0,10
Population Density (persons per sq.km)	List	-	-	22.8,4887.6	0,10
Water bodies	Raster file	-	Binary	0,1	0,10
Flood	Raster file	-	Binary	0,1	0,10

- Flood (or flood extent) refers to the raster map created by Glas (2023) through historical modelling were used to demarcate the extent of flooding in Kerala during the flood phase for 2018.
- Amount of water bodies refers to areas classified as water based on the categories (Ocean, Lake or River). The obtained binary map indicates areas that show the presence (1) or absence (0) of water bodies.
- The gridded point data for poverty were interpolated to cover the extent of the study area using inverse distance weighting (IDW). IDW is a common method that is very straightforward yet effective approach for interpolation (Li, 2021)
- Both datasets for elevation and poverty were inverted before further analysis: Evidence shows that whereas with lower elevations are at higher risk of infection (Silva et al., 2020). The data for poverty was provided as a wealth index score, therefore inverted to ensure poorer areas are at a higher risk. Poorer areas are more vulnerable to the occurrence of leptospirosis in LMICs (Zhao et al., 2016).
- The location of healthcare facilities (HCF) was summarized to obtain the healthcare density for the study area. The method used in the Kernel Density Estimation (KDE) approach was previously used by Blanford et al. (2012). This raster map was calculated using a kernel function to create a magnitude-per-unit area. The default search radius as defined by Silverman (1986) was obtained from the spatial configuration of the input data.
- Population density was obtained by dividing the total population of each panchayat by their areas in square kilometres. This helps to ensure that the areas with the highest population per panchayat are regarded as high-risk areas.

Finally, a risk score for each indicator was obtained by averaging the indicator values per panchayat. To enable the comparison of risk factors by their regression coefficients, all risk indicators were rescaled to

[0,10]. A linear function was used for the rescaling where 0 equates to the minimum value and 10 equates to the maximum value. Using a linear method for rescaling ensures that the variation in the original data is preserved.

6.3. Methods

Several analyses were conducted using different methods to provide answers to the first set of research questions, they are described in the sections that follow. All spatial analyses were performed in ArcGIS Pro version 3.1.1, while SPSS version 28 and R was used for statistical analysis (R scripts used are provided in **Appendix A.3.2**)

6.3.1. Contextualizing the 2018 leptospirosis incidence in the study area

The leptospirosis cases were joined with the administrative boundaries to examine the distribution of incidence among the panchayats. A comparison was made between incidences in urban areas (municipalities) and rural areas (gram panchayats). Furthermore, leptospirosis incidences were overlaid on the land use of the study area to visualize the possible connections between the incidence and the physical environment.

6.3.2. Relevant risk factors in Kerala

The selection of risk factors for this study area was dependent on data availability and suitability. An extensive data search was completed to quantify other risk factors identified in Table 18. Openly available data sources were preferred, as it improves the applicability of epidemic risk assessments (Hierink et al., 2022). The data gathered was evaluated to ensure the information needs of each factor were met.

6.3.3. Demographic characteristics of Leptospirosis cases

A quantitative analysis is done to examine the sociodemographic characteristics of individuals that were infected with leptospirosis in Alappuzha and Pathanamthitta. The variables considered are age and sex categories. The classification of age groups used are: 0-14, 15-29, 30-44, 45-59, 60-74, and ages above 75 as previously used by Mohd Radi et al. (2018). Finally, the variables were also considered and examined over the three phases of the flood in both districts.

6.3.4. Assessment of environmental and socioeconomic risk factors

To assess the risk factors for leptospirosis after floods, factors were evaluated with leptospirosis incidence. Temporal analyses were carried out through the visualization from trends. The outcomes of data prepared in Table 23 for each risk indicator are presented in **Appendix A.2.1**. The risk indicators were subjected to regression analysis in relation to the preflood and postflood incidence of leptospirosis. All factors were assessed spatially through the spatially varying coefficient (SVC) regression. SVC offers a rich framework to confirm the relevance of model parameters (Finley, 2011). The SVC model was used to model the spatial regression between risk factors and incidences during preflood and postflood phases (Equation 2)

$$y(s) = \beta_0(s) + \beta_1 x_1(s) + \beta_2 x_2(s) + \cdots + \beta_k x_k(s) \qquad \text{Equation 2}$$

- Where y is the total number of cases,
- s refers to the locations of each panchayat.
- $\beta_0, \beta_1, \beta_2 \ldots \beta_k \ldots$ are the regression coefficients,
- $x_1, x_2 \ldots x_k$ are the predictor variables (all risk indicators in Table 23)

6.4. Results

6.4.1. Contextualizing the 2018 leptospirosis incidence in the study area

Panchayats within Pathanamthitta were more affected before and during the floods, however, during the postflood phase, the cases became more evenly dispersed (Figure 25). In Alappuzha, the Alappuzha municipality is the centre of the hotspots during the three flood phases, similarly, the Pathanamthitta municipality experienced leptospirosis incidence in all three phases. Table 24 provides the breakdown of the situation. The number of cases in gram panchayats (N = 486) is consistently more than that of municipalities (N=98), and more panchayats (78.4%) reported leptospirosis cases than municipalities (70%). This same trend occurred over the flood phases.

Table 24 Distribution of cases over the type of panchayat in 2018

Panchayat type	No. of panchayats affected (%)	No. of cases (%) (N=560)
For the whole year		
Municipalities (N = 10)	7 (70)	74 (13.2)
Gram Panchayat (N = 125)	98 (78.4)	486 (86.8)

By flood phase

Panchayat type	No. of panchayats affected (%)			No. of cases (%)		
	Preflood	Flood	Postflood	Preflood (N = 71)	Flood (N = 54)	Postflood (N = 378)
Municipalities (N = 10)	2 (20)	2 (20)	7 (70)	7 (9.9)	4 (7.4)	50 (13.2)
Gram Panchayat (N = 125)	42 (33.6)	32 (25.6)	95 (76)	64 (90.1)	50 (92.6)	328 (86.8)

Figure 26 shows the location of cases with respect to the land use of the study area. In both districts, the incidence of leptospirosis only became pronounced around areas with small farmyards, not large forests before and during floods. In the post-flood phase, panchayats with highly vegetated areas appear to have more cases than before the floods.

6.4.2. Relevant risk factors in Kerala

Upon data availability and suitability checks, the risk factors considered in Kerala are shown in Table 25. The obtainable risk factors are related to environmental factors (N=7), and social factors (N=5). Limited clinical factors could be obtained, therefore qualitative surveys with health experts were employed as information sources.

Table 25 Obtainable risk indicators for Kerala

Sections in this study	Clinical	Social	Environmental
(6.4.3)	-	Age, Gender	-
(6.4.4)	-	HCF density, Poverty, Population density	Elevation, Vegetation, Amount of Water bodies, Flood, Precipitation, Temperature
(7.4.1)	Local risk factors from health experts.	-	-

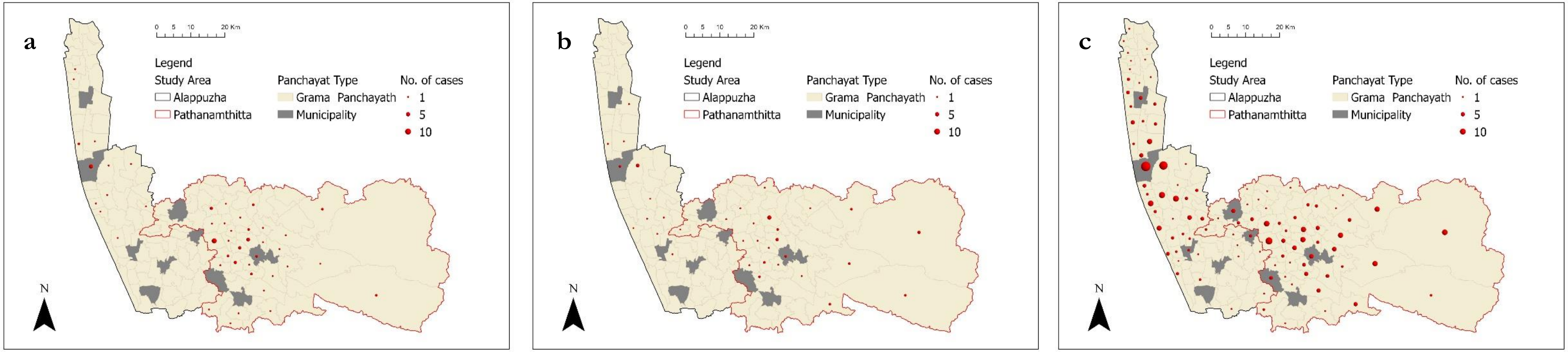

Figure 25 Distribution of cases among panchayats across flood phases in 2018 (a) before flood (b) during flood (c) after flood

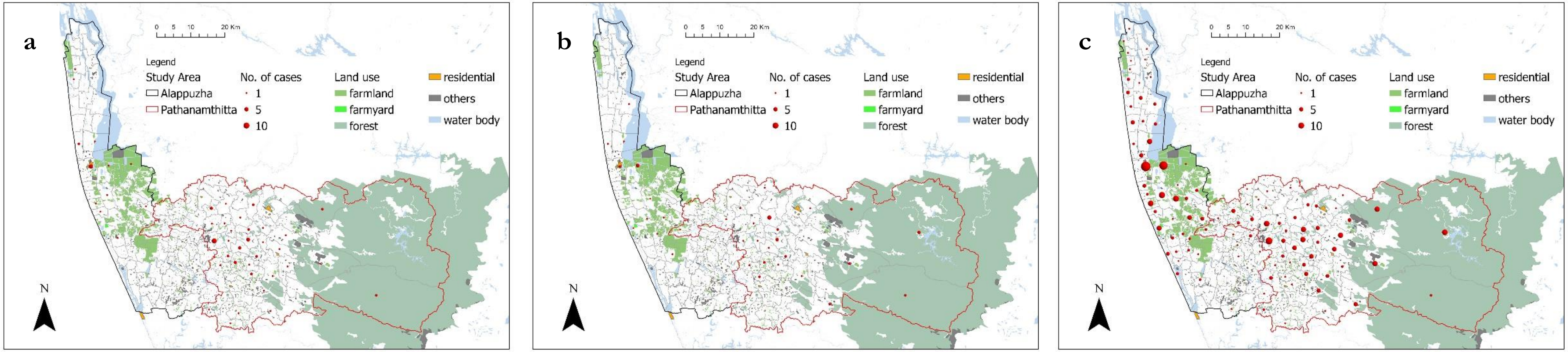

Figure 26 Distribution of cases and land use classes across flood phases in 2018 (a) before flood (b) during flood (c) after flood

6.4.3. Demographic characteristics of leptospirosis cases

Leptospirosis was found to be more common among men (64.7%) than women (35.2%) in the study area (Table 26). Similarly, the total number of cases of males (62%, Alappuzha; 67.4%, Pathanamthitta) almost doubled compared with females (38%, Alappuzha; 32.6%, Pathanamthitta) in the study area during the post-flood phase. (Table 26).

Table 26 Total number of leptospirosis cases by gender and age in the study area in 2018

Category	Number of cases in Alappuzha (%) (N = 253)	Number of cases in Pathanamthitta (%) (N=312)	Total Number of cases (%) (N=565)
Gender			
Female	99 (39.1)	100 (32.1)	199 (35.2)
Male	154 (60.9)	212 (67.9)	366 (64.7)
Age			
Mean (±SD)	44.85 (17.72)	39.14 (20.16)	
Median	47	39	
0-14	17 (6.7)	40 (12.8)	57 (10.1)
15-29	33 (13)	72 (23.1)	105 (18.6)
30-44	61 (24.1)	68 (21.8)	129 (22.8)
45-59	86 (34)	76 (24.4)	162 (28.7)
60-74	48 (19)	44 (14.1)	92 (16.3)
>=75	8 (3.2)	12 (3.8)	20 (3.5)

The most vulnerable group was found to be age group 45 – 59 in both districts. The average age of infected persons in Alappuzha was 44.85 years and 39 years in Pathanamthitta (Table 26, Figure 27). The highest number of cases occurred during the post-flood phase (N=72, Alappuzha; N=51, Pathanamthitta Table 27). While the age group (45-59) were the most susceptible to leptospirosis, lower age groups were found to be more vulnerable in both district during floods (30-44 in Alappuzha and 15-29 in Pathanamthitta (Table 27)

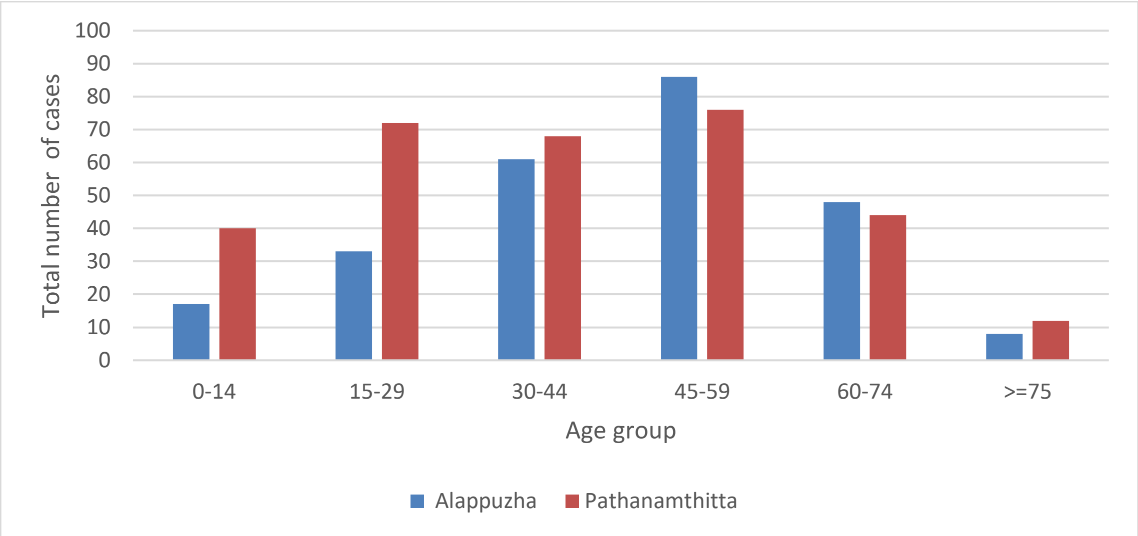

Figure 27 Total number of cases by age group in 2018

Table 27 Number of leptospirosis cases by gender and age in Alappuzha and Pathanamthitta for each of the flood phases in 2018.

Factors	Pre (%) (N = 17)	During (%) (N = 15)	Post (%) (N = 192)	Pre (%) (N = 56)	During (%) (N = 36)	Post (%) (N = 187)
	Alappuzha			**Pathanamthitta**		
Gender						
Female	11 (64.7)	5 (33.3)	73 (38)	15 (26.7)	14 (38.9)	61 (32.6)
Male	6 (35.3)	10 (66.7)	119 (62)	41 (73.2)	22 (61.1)	126 (67.4)
Age						
0-14	1 (5.9)	1 (6.7)	12 (6.3)	9 (16.1)	5 (13.9)	21 (11.2)
15-29	3 (17.6)	2 (13.3)	25 (13)	9 (16.1)	11 (30.6)	46 (24.6)
30-44	4 (23.5)	5 (33.3)	42 (21.9)	13 (23.2)	7 (19.4)	41 (21.9)
45-59	5 (29.4)	3 (20)	72 (37.5)	15 (26.8)	6 (16.7)	51 (27.3)
60-74	2 (11.8)	4 (26.7)	35 (18.2)	9 (16.1)	7 (19.4)	19 (10.2)
>=75	2 (11.8)	0 (0)	6 (3.1)	1 (1.8)	0 (0)	9 (4.8)

Table 28 reveals the incidence rate for each gender in 2018. The incidence rates per 100,000 of the male gender (15.2 in Alappuzha, 37.7 in Pathanamthitta) is consistently higher than that of the female gender (8.9 in Alappuzha, 15.7 in Pathanamthitta) in both districts despite a lower population than females. The overall incidence rate for both genders is higher in Pathanamthitta (26.1) than in Alappuzha (11.9).

Table 28 Incidence rate by gender type in 2018.

Year	**Alappuzha**			**Pathanamthitta**		
Categories	Female	Male	Total	Female	Male	Total
Number of cases (N)	99	154	253	100	212	312
Population	1,114,647	1,013,142	2,127,789	635,696	561,716	1,197,412
Incidence rate per 100,000	8.9	15.2	11. 9	15.7	37.7	26.1

6.4.4. Assessment of environmental and socioeconomic risk factors

Table 29 provides the summary of the regression analysis and Figure 28 displays the association between risk factors and leptospirosis. Poorer and highly vegetated areas are more susceptible to leptospirosis in the postflood phase (β = 0.45, poverty; β=0.24, vegetation) than the preflood phase (β = 0.11, poverty; β=0.05, vegetation, Table 29). Similarly, the amount of water bodies in each panchayat becomes positively associated during postflood phase (β = 0.26, preflood; β=0.02, postflood, Table 29) The density of health care shows negligible association with post-flood incidences (β = 0.01, preflood; β=0.03, postflood, Table 29)

Interestingly, elevation is negatively associated with the post-flood incidence of leptospirosis, though being weakly associated before the occurrence of floods (β = 0.09, preflood; β=-0.35, postflood, Table 29). Dynamic factors are positively associated with leptospirosis incidence after floods. Flood is a most dominant factor associated with the increase of post-flood leptospirosis incidence (β=0.88, postflood, Table 29). Precipitation is negatively associated with leptospirosis infection before floods and positively associated after floods (β = -0.15, preflood; β=0.23, postflood, Table 29). Areas with increased temperature are not strongly associated with places with high incidence during the pre-flood and post-flood phases (β = 0.09, preflood; β=0.07, postflood, Table 29)

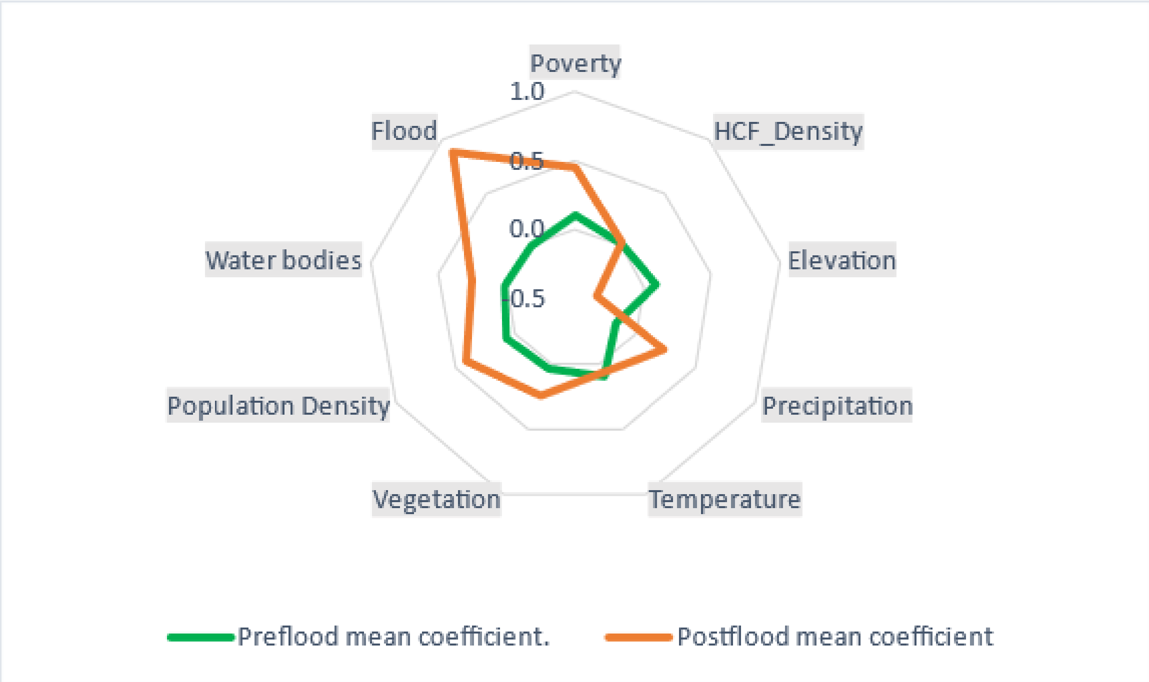

Figure 28 Association of risk factors to preflood and postflood incidences

Table 29 Spatial regression analysis for risk factors

Factors	**Preflood mean coefficient.** **(R^2=0.99)**	**Postflood mean coefficient.** **(R^2 = 0.99)**	**Negative Association** **(β < -0.1)**	**Negligible association** **(|β| < 0.1)**	**Positive Association** **(β > 0.1)**
(Intercept)	-0.66	-0.83	-	-	-
Poverty	0.11	0.45			Preflood; Postflood
HCF_Density	0.01	0.03		Preflood; Postflood	
Elevation	0.09	-0.35	Postflood	Preflood	
Precipitation	-0.15	0.23	Preflood		Postflood
Temperature	0.09	0.07		Postflood; Preflood	
Vegetation	0.05	0.24		Preflood;	Postflood
Population Density	0.07	0.41		Preflood;	Postflood
Water bodies	0.02	0.26		Preflood	Postflood
Flood	-	0.88			Postflood

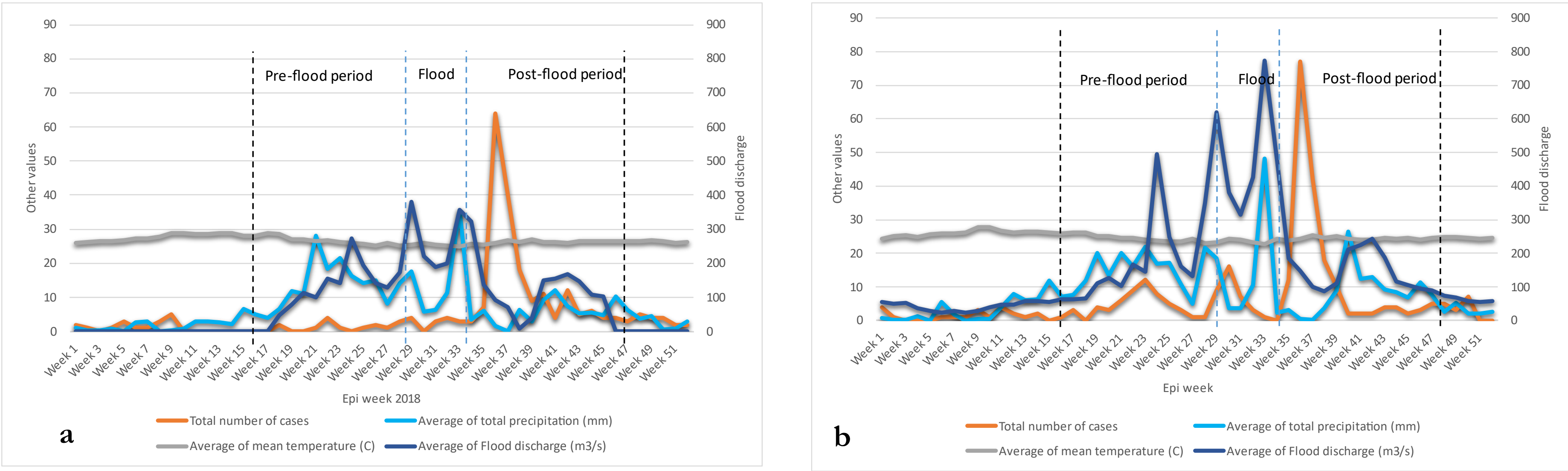

Figure 29 Trend analysis for dynamic factors and leptospirosis incidence in 2018 (a) Alappuzha (b) Pathanamthitta

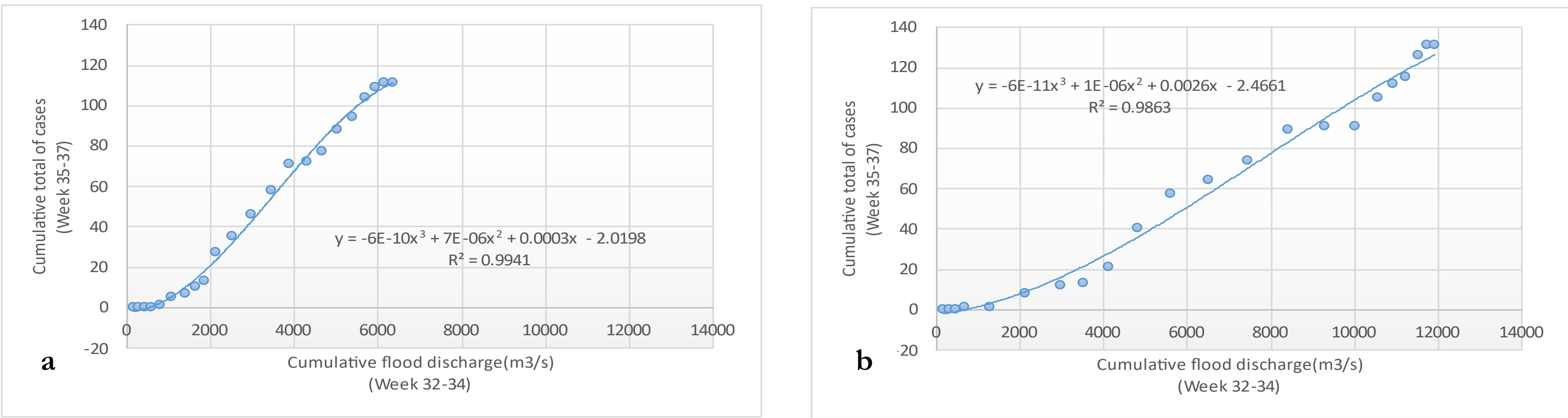

Figure 30 Cumulative flood discharge and leptospirosis cases in 2018 (a) Alappuzha (b) Pathanamthitta

From the trend in Figure 29, the relationship among precipitation, temperature, flood discharge as well as the number of incidences. The peak in the total number of leptospirosis cases occurred on 4th of September 2023 which is 17 days after the peak of peak level of flood on 18th of August 2023 (Figure 29). In both districts, the amount of flood discharge peaked twice during the flood phase but appears that the increase in flood discharge is leads to an increase in the number of cases a period. The flood discharges in both districts exceeded 300m^3/s and outlasted for over two peaks to cause a significant increase in the number of incident cases. The temperature was stable in all three phases ranging between 20°C and 30°C in both districts (Figure 29).

With consideration to the peak period, there is a strong association between the daily increase in flood discharge and the daily reported number of cases using a time lag (Figure 30). Third-order polynomial trendlines were fitted to visualize the trend in both districts. Using a lag period of three epi weeks, the trend shows that a sustained accumulation of flood will lead to an increase in the number of cases eventually. In both districts, the number of cases increased when 70cm of flood discharge was accrued and showed a similar upward trend However, the cases started to subside in Alappuzha earlier than Pathanamthitta as a result of a reduction in flood discharges (Figure 30).

6.5. Conclusions

In relation to the research objectives presented in the introduction, the key concluding points are:

i. The number of cases in rural areas is relatively higher than that of urban areas throughout the flood phases. Incidences tend to occur in small farmyards and croplands before floods, instead of highly forested areas.

ii. The risk factors that are obtainable and considered in this study are mostly environmental and social factors. Information from local health experts is used to suffice for the clinical aspects.

iii. In this study area, male adults are the most vulnerable risk group to leptospirosis. Younger adults are susceptible to infections during flooding. The incident rate in Pathanamthitta is higher than in Alappuzha.

iv. Flooding is the most dominant factor for postflood incidence. Most environmental and social factors show a stronger association to postflood incidence than preflood incidences. Notable factors are population density, poverty, and the amount of water bodies per panchayat.

7. RISK MANAGEMENT OF LEPTOSPIROSIS IN KERALA

This chapter provides the methods and results related to the third objective of this research. The outcomes of the risk assessment completed in this research are translated into measures that can be used to guide decisions and planning for the prevention of infections after potential flood event. The response to the epidemic by Kerala authorities in 2018 is reviewed and areas for improvement will be identified. Recommendations are made with a focus on minimizing the risk of leptospirosis after floods while giving to the activities of the multiple actors involved.

7.1. Introduction

The understanding of risk factors of leptospirosis enables the development of prevention and intervention strategies to reduce the burden of infections among the affected people (Goarant, 2016). A number of prevention strategies have been developed to address water-related hazards based on Bradley (1974) classification (Blanford et al., 2021; Holzworth and Gute, 2015). Diseases that are caused by host-related characteristics therefore would demand a variety of approaches to break the chain of transmission (Blanford et al., 2021). Leptospirosis is a complex disease that is strongly dependent on the interaction of all three elements (host, pathogen and environment) of the epidemiological triad (Figure 4). Reducing the risk of transmission of leptospirosis requires interventions that address environmental and social risk factors (Mwachui et al., 2015), as well as the clinical factors (Miguel et al., 2020).

This chapter fulfills the third objective which is to provide possible recommendations for response efforts towards the mitigation of risks of leptospirosis infection. It aims to provide answers to the research questions:

i. What are the risk factors identified by local health experts?
ii. How should stakeholders be involved in managing epidemic risk?
iii. How can the findings be used to minimize future risks?

7.2. Data

The data used for in this chapter is described in Table 30.

Table 30. Data used in Chapter 7

Datasets	Description of variable(s)	Type (Resolution)	Date	Source
Administrative boundaries	Boundaries of Kerala districts, panchayats and population	Vector file (Polygon)	2022	KSDMA
Questionnaire	Qualitative survey	N/A	2023	Health workers
Expert interview		N/A		Medical doctor

To assess the local risk factors of leptospirosis (7.3.1) and management of epidemic risk in Kerala (7.3.2), the questionnaires and employed interviews were relied upon as data sources. The questionnaire and transcript of the interview are provided in Appendix A.4 and A.5 respectively.

- A semi-structured questionnaire was created on Microsoft Forms with a variety of open-ended and close-ended questions. The questionnaire was distributed to medical experts and health workers to identify the risk factors within the Kerala communities It was shared with groups of health workers via social media. The questionnaire was available for 19 days.

- An interview was held with a medical doctor in the Government medical college in Malappuram, Kerala. The interview was conducted at the 3 days before the questionnaire was closed for submission. The interview was recorded and transcribed in English.

Finally, the proposed recommendations (7.3.3) are provided based on the various findings in this research and supplemented by evidence from literature.

7.3. Methods

7.3.1. Identification of local risk factors in Kerala

Surveys (through questionnaires and an interview) were conducted with questions that addresses the local factors contributing to the risk of leptospirosis in Kerala. The information from questionnaires and expert interviews with health workers was analysed to assess clinical factors. Both surveys were examined and approved by the ethical review committee

7.3.2. Risk management of leptospirosis after floods

A stakeholder assessment is also carried out to understand the actors involved in the mitigation of the epidemic risk after the floods in 2018. Data sources for this assessment are from a combination of literature reviews and qualitative surveys.

7.3.3. Actionable recommendations from risk assessment

Finally, the results of the risk assessment in the study are used to inform recommendations that can be used in the different phases of the flood. Recommendations are made for action points by concerned actors towards the prevention, response, and recovery from leptospirosis. To reduce the risk of infections, the three dimensions of the epidemiological triad are considered. The results from the analyzed risk factors in Table

The set of recommendations is therefore classified into actions relevant to three classifications of risk factors (clinical, social, and environmental) and the three phases of a disaster event (pre, during and post) (Figure 2). Considerations are also made to stakeholder involvement based on information from 7.3.2

7.4. Results

A total of 29 health officers responded to the questionnaire, they are from different districts in Kerala (Figure 31). Only 2 respondents work in the selected study area, the rest of the respondents work in different positions at various institutions. The majority of the respondents work either as public health practitioners (11) or medical doctors (11) (Table 31). There was only one administrative officer among the respondents, most others work in medical colleges (7), and the different public health centres (Table 31).

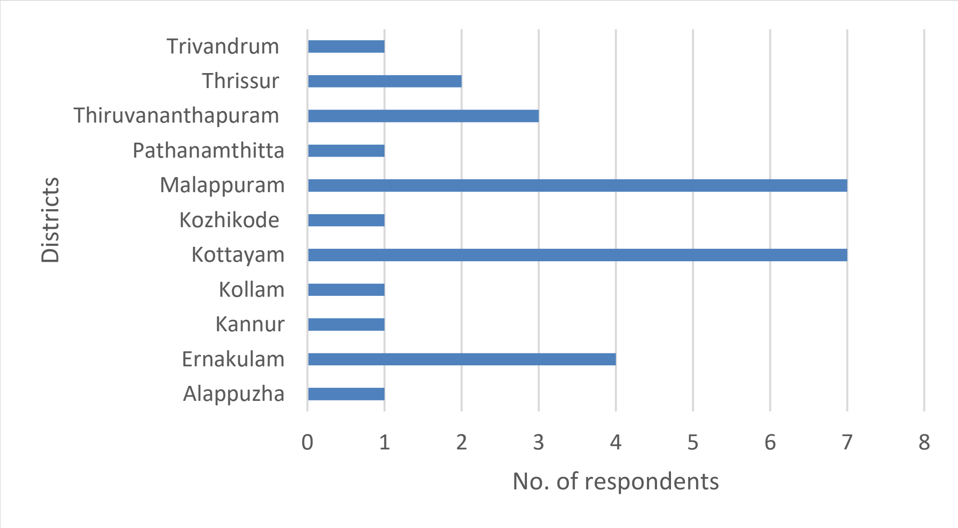

Figure 31 Questionnaire respondents by districts in Kerala.

Table 31 Health position and institution of the respondents.

Category	Medical doctor	Academician	Junior Health Inspector	Public health officer	Total
District Medical Office	-	-	-	1	1
Community Health Centre	1	-	2	7	10
Family Health Centre	2	-	3	1	6
General Hospital	1	-	-	-	1
Medical College	5	1		1	7
Primary health centre	2		1	-	3
Women & Children Hospital	-	-	-	1	1
Total	11	1	6	11	29

7.4.1. Identification of local risk factors

Communicable or infectious diseases were the most notable impact of the 2018 floods according to our respondents (35%) (Figure 32). Leptospirosis also became more commonly known during and after floods (Yes = 79%) than before it (Yes = 68%). Despite underreporting, more flood deaths were caused by leptospirosis than drowning (Anish, Appendix A.5)

Figure 33 shows the responses provided about underreporting of leptospirosis incidence. The results show there is some consensus that the incidences are underreported in Kerala (Yes= 39%, Maybe=42%, No=19%). This was consequently agreed upon by the interviewee. Although lack of testing capacity (27%) and the possibility of self-treatment (28%) are important, the major challenge being mentioned is the difficulty in diagnosing infected patients (45%).

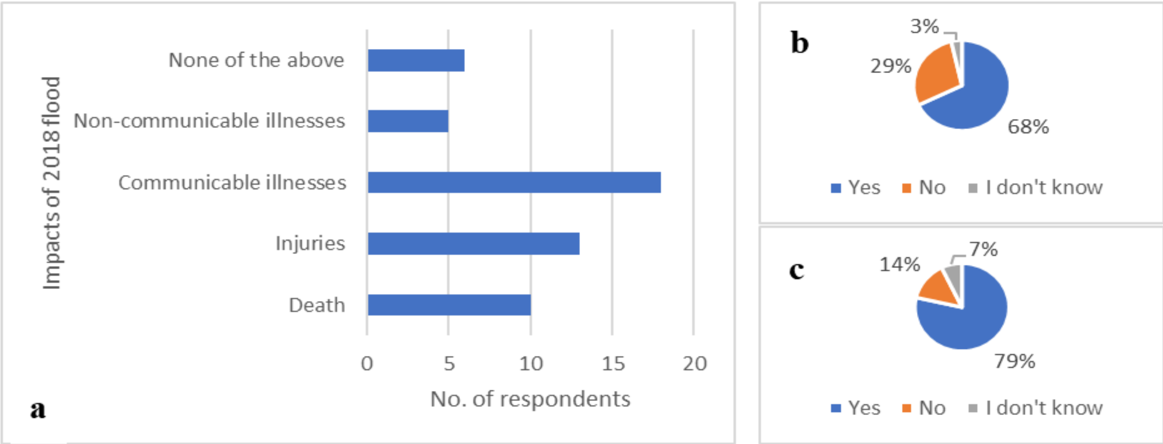

Figure 32 Leptospirosis and health impact of floods (a) health impact of the floods (b) leptospirosis incidence before floods (c) leptospirosis incidence during and after floods

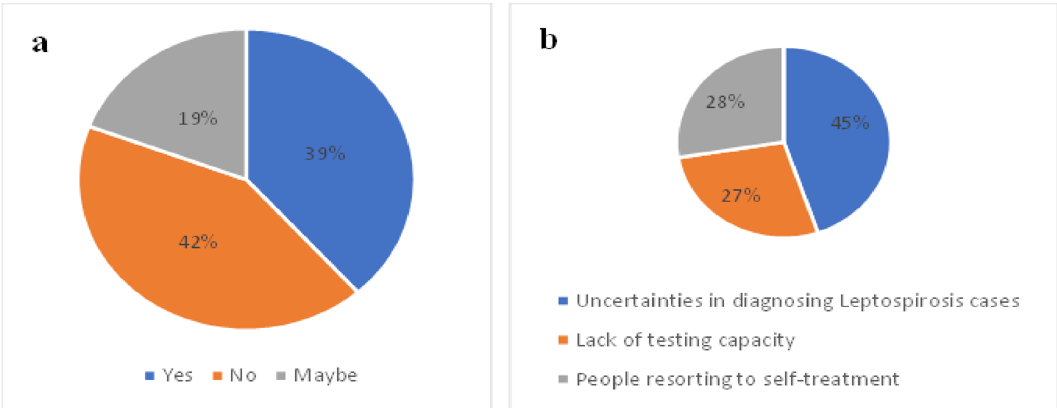

Figure 33. Underreporting of leptospirosis (a) perception by health workers (b) reasons for underreporting.

One of the respondents explained why this is one of the major challenges of clinicians:

"It is very difficult to differentiate between other common fevers and leptospirosis initially. Common viral fevers also present with joint pain and muscle pain. So initiation of doxycycline on the first day of fever may not be practical in an OP where 50% patients come with viral fever symptoms. But leptospirosis worsens in 3 to 4 days and even death happens in the initial 5 days in many cases. This is a challenge for clinicians. To identify the cases on the first visit itself"

Anish (Appendix A.5) explained that it is a combination of all factors. Patients may think the infection is only a mild fever and not report to the health facility. The clinician may not suspect leptospirosis when a patient reports illness, and sometimes the facility may not be well equipped to perform the diagnostic test. He also mentioned that the application of doxycycline (prophylactic treatment) is more efficient before exposure to contaminated water than after infection. Nevertheless, it is not optimal for preventing leptospirosis because of possible abuse in usage and potential individual side effects.

Finally, the relevance of certain social and environmental risk factors was examined from a local perspective (Figure 34). Most respondents (63%) think that the occupation type of people is the most important social cause of leptospirosis. On the other hand, sanitation of the environment is considered important by more than half of the respondents (51%). Heavy rainfall and flooding as a risk factor is given less consideration (19%) as compared to proximity to water bodies (30%).

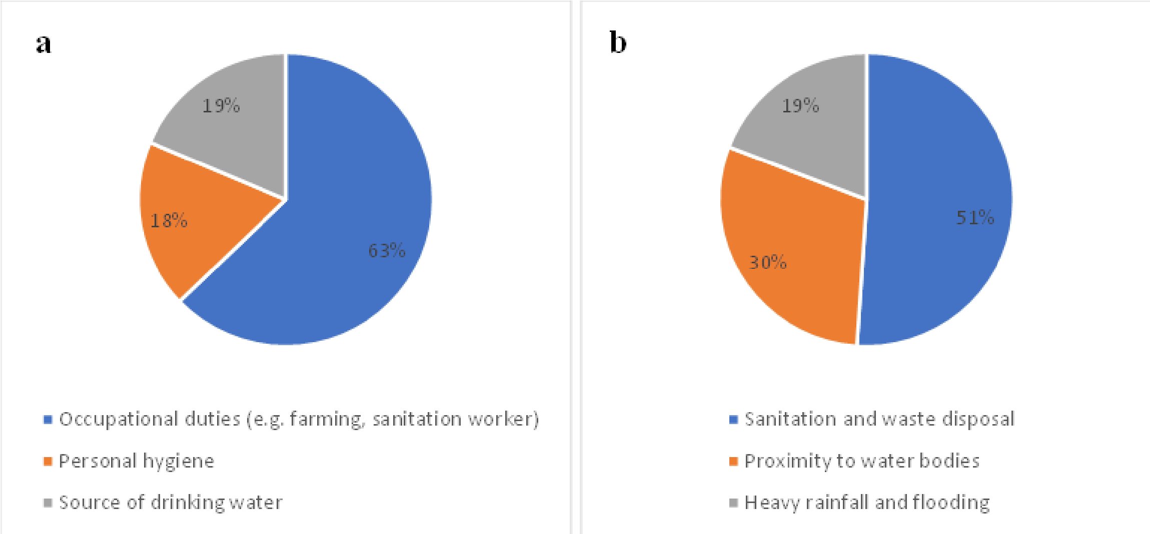

Figure 34. Other factors from a local perspective (a) social factors (b) environmental factors

7.4.2. Risk management of leptospirosis in Kerala

To identify health action points, inputs from the survey are used to understand what has been carried out and what is yet to be done. The responses from Table 32 show that there is a high awareness and understanding of Leptospirosis infection in Kerala (Yes= 64.3%, Question 1, Yes=53.6%, Question 1, Table 30). Anish (Appendix A.5) also agrees that enough awareness has been created on the possibility of leptospirosis infections after floods. Although most respondents (64.3%) believe that a framework has been developed to guide the management of leptospirosis after floods (Table 32), Anish (Appendix A.5) strongly disagrees. He describes the Kerala system as one that is better at "*firefighting than planning strategically*". Provision of safety wears to emergency workers (N=20), immediate and periodic testing of affected people (N=14), and effective communication of risk (N=11) were recognized as important activities that are not yet in place in Kerala (Figure 35).

Table 32 Response to questions on health actions (N = 29)

Questions	Yes (%)	Maybe (%)	No (%)	I don't know (%)
Does the general public understand Leptospirosis?	18 (64.3)	9 (32.1)	1 (3.6)	0 (0)
Are people aware that floods could increase the risk of Leptospirosis?	15 (53.6)	9 (32.1)	3 (10.7)	1 (3.6)
Is there a developed framework to specifically address Leptospirosis infections after floods in Kerala?	18 (64.3)	6 (21.4)	1 (3.6)	3 (10.7)

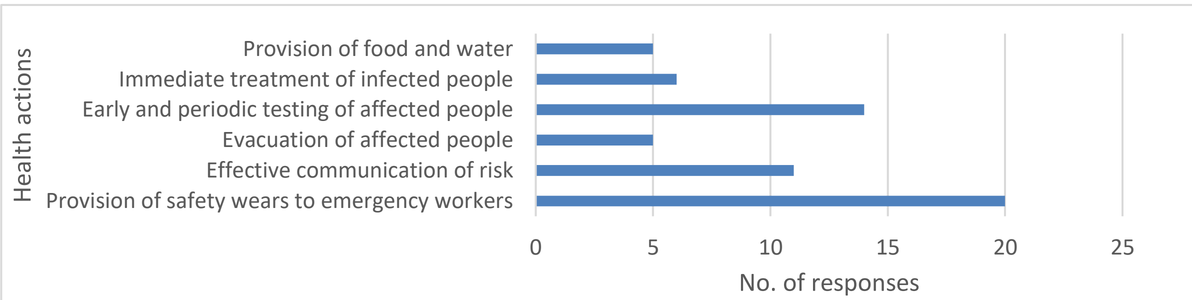

Figure 35 Relevant health actions not yet in place in Kerala

The response to the leptospirosis and other health impacts of flood in Kerala involved a lot of multilevel stakeholders. Stakeholder includes national and governmental agencies, non-governmental agencies, and members of the civil society. Table 33 highlights the stakeholders involved in the management of the 2018 flood and its resulting health impacts. The list is limited to activities that relate to leptospirosis risk and therefore not the entire spectrum of flood impacts.

In response to the question about the stakeholders that should be involved in the management of the risk of leptospirosis, high number of respondents mentioned agriculture (Figure 36). Professionals in the field of animal husbandry, veterinary and agricultural organization, and food safety are closely related responses. Anish (Appendix A.5) agrees with this suggestion and believes that incorporating actors from animal husbandry and the larger agricultural community will improve the tackling of this infectious disease.

Table 33 Stakeholders' involvement in response to the health impact of the 2018 flood

S/N	Stakeholders	Description	Role	Source
1	Central government authorities	National government, Kerala state government, and Local self-governments (LSGs)	-Declared the situation as an emergency -Provision of administrative support and funds	(Varughese and Purushothaman, 2021)
2	KSDMA	Kerala State Disaster Management Authority	-Was responsible for evacuation, rescue and relief operations for affected people.	(Varughese and Purushothaman, 2021)
3	Health officials	Public and private health workers and volunteers	-Provision of medical assistance to affected persons in hospitals and relief camps -Created awareness about methods of improving drinking water	(Devasia TK, 2018; UNDP, 2018; Varughese and Purushothaman, 2021)
4	NGOs	Organizations into humanitarian initiatives	-Identified damaged homes and potential hotspots for epidemics	(Paliath, 2018)
5	Affected Communities	The civil society, General public.	-Used social media and mobile devices to mobilize relief efforts.	(Thiagarajan, 2018; Varma, 2018)
6	National agencies	National Disaster Response Force, the Army, Air Force, and the Navy	-Contributed to rescue operations through with specialized tool and personnel	(Varughese and Purushothaman, 2021)
7	International agencies	UN Agencies,	-Collaboration with local authorities to compile impact assessment and needs assessment report	(UNDP, 2018)

Figure 36 Recommended stakeholders for leptospirosis risk mitigation

7.4.3. Actionable recommendations from risk assessment

Based on the result of this risk assessment, several recommendations are provided to reduce the burden of leptospirosis in Kerala. Not all flood events lead to an influx in leptospirosis incidence (5.4.3), but the risk of leptospirosis should be managed through continuous activities. The recommendations for each disaster phase are summarized in Table 34 and Figure 37.

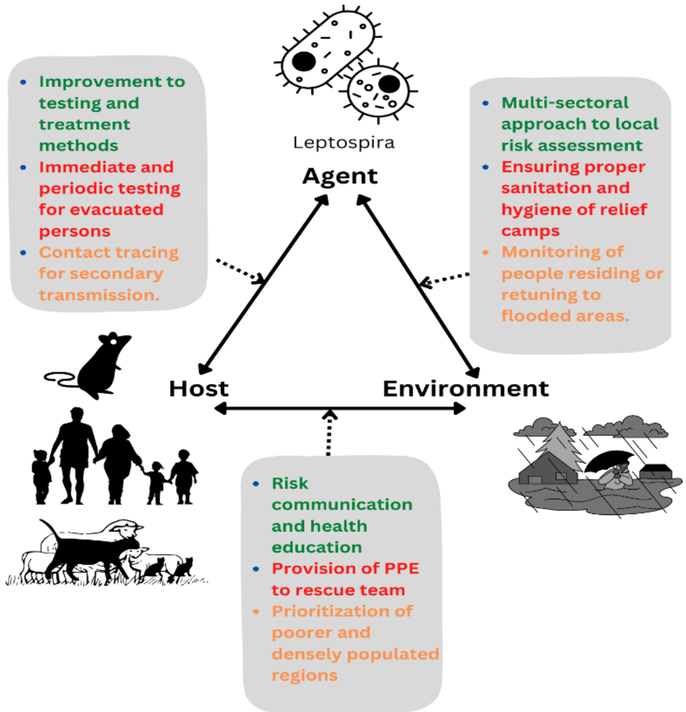

Figure 37. Proposed recommendations for leptospirosis management during flood phases (green = preflood, red =during flood, orange = postflood)

Need for multisectoral-based risk assessments.

Efforts should be devoted towards the identification and mitigation of epidemic risk as a result of flooding. This study suggests that leptospirosis is endemic in the central parts of Pathanamthitta in the preflood phase (Figures 20 and 21). Further risk analyses should be carried out to determine the underlying causes of infection in these areas. Assessment should be carried out on the endemicity of pathogens in the environment by sampling large volumes of street water. The environmental conditions that are responsible for the presence of the bacteria should be determined. Furthermore, the population residing in these areas should be analysed to understand socio-demographical characteristics that make them more vulnerable to infections from Leptospira.

To achieve to an effective risk assessment locally, a concerted effort from multilevel and multisectoral stakeholders is crucial to identifying vulnerable population. Local knowledge on risk areas can be harvested from farmers and agricultural workers who are exposed to livestock. Veterinarians could provide information on common locations of infected pets. There is a high number of stray dogs in Kerala (Anish, Appendix **A.5**). The presence and vaccination status of dogs should be investigated to determine which areas are conducive for Leptospira transmission. The development of risk maps for non-flood and flooded periods would be end product of the assessment so that localized actions can be taken.

Risk communication and education

Effective communication was named among the important actions that should be taken (Figure 35). Developed risk maps should be communicated to the public at each phase of a flood. The improvement in awareness about the areas at risk of the infection will assist people within such areas to be conscious of the disease and avoid being infected. Risk communication improves the resilience of the community to the disease.

This study identified that male adults are more vulnerable to leptospirosis after floods (Tables 24 and 25) and may be linked to their occupation (Figure 34). Risk groups (waste management and agricultural workers, fishermen, flood rescue, swimmers etc) should be educated about the threat of the infectious disease through different communication methods is necessary for epidemic preparedness.

Improvement to treatment and diagnostics

Prophylactic treatments are recommended specifically for people within identified risk group categories to reduce the risk of leptospirosis infection and deaths (section **7.4.1**). Development and acquisition of sufficient testing kits should be prioritized before another potential flood event. Another salient recommendation is to ensure early and periodic testing for people that were evacuated from their locations during flood phase.

The temporal pattern of flood can be used to inform and guide decisions to reduce the risk of postflood infections. This study showed the incidence of leptospirosis occurred 17 days after the peak of the flood event (Figure 29). Health actions must be taken within two weeks of flood occurrence to prevent delayed treatment and avert an outbreak. The increase in the level of floods can be used to estimate the expected number of leptospirosis cases, this should help authorities to understand the amount of resources necessary to be devoted into leptospirosis risk management.

Ensuring the safety of relief workers and patients

The efforts to reduce the impact of floods on public health were commendable, but a few improvements can be made. This study showed that flood rescue workers are not provided with personal protective equipment (Figure 35). A recommended action is to make enough personal protection materials for people that directly exposed to flood water. Educating the relief workers on how to use those materials is equally as important. To ensure that relief camps do not become breeding or transmission sites for the bacteria, a high level of sanitation and hygiene measures must be in place.

Monitoring of risk areas and groups

Flood, poverty rate and population density are strong spatially linked factors for postflood incidences (Figure 28, section 6.3.4). Poorer and densely populated regions should be prioritized for interventions during this period. Evacuated persons must also be monitored closely for symptoms after returning to a previously flooded area.

Table 34 Recommended actions to reduce the risk of flood-induced leptospirosis in the study area

Disaster phase / Risk factor group	Clinical (Host-pathogen)	Social (Host-environment)	Environmental (Pathogen-environment)	Stakeholders to be involved
Preflood	Acquisition of diagnostic testing kits Training of health workers on methods Administration of prophylactic treatment to risk groups	Health education for risk groups in communities about the risk of leptospirosis after floods. Communication of risk areas for targeting interventions	Risk analysis for identification of Leptospira endemic areas through a multisectoral approach Production of epidemic risk maps through improved flood and climate forecasts	Research Institutes, Agricultural organizations; Citizens. Governmental Agencies; Educational Institutions; Media.
During Flood	Ensuring persons evacuated during floods are tested early and frequently.	Improvement of adequate personal protection materials for rescue workers during floods.	High-quality of sanitation and hygiene should be ensured in relief camps.	Governmental Agencies; Health authorities; KSDMA; NGOs; Citizens Media.
Postflood	Contact tracing for infected persons to suspect secondary transmission.	Poorer and densely populated regions should be prioritized for treatment and interventions.	Monitoring of people residing or retuning to flooded areas. Population living in vegetated areas should be monitored for indirect transmission from farm animals	Governmental agencies; KSDMA; Health Authorities.

7.5. Conclusions

This chapter has reviewed the local risk and condensed the results of this study into actionable recommendations. Here are the conclusive outcomes in response to the research questions:

i. The major risk factor of leptospirosis from a clinical perspective is the difficulty in diagnosing the disease. Occupation and environmental sanitation are other common contributing factors at local levels.
ii. There was a commendable collaboration among the stakeholders to reduce the health effect of floods, but their activities were mostly limited to the (during) flood phase. Stakeholders were also mostly from health and government sectors, other sectors such as agriculture and animal husbandry are suggested additions.
iii. Effective management of the disease requires activities by multisectoral stakeholders in all phases of flood. Recommendations include improvements to risk assessment and communication, clinical diagnostics and treatment, and monitoring of risk areas and groups.

8. DISCUSSIONS AND CONCLUSIONS

This chapter provides the interpretation and relevance of the results from chapters 5 – 7. The results are evaluated with previous research and the possible implications are explained. The limitations of this research and future research possibilities are discussed in detail.

8.1. Analyses of Incidences of leptospirosis

8.1.1. What was the impact of the 2018 and 2019 flooding events in the study area?

The impact of the flooding events was analysed based on the depth, discharge, duration, and geographic extent of the flood. In all four attributes, the 2018 flooding event was more severe than that of 2019. This result agrees with previous studies that have performed risk analysis for both flooding events (Mehrishi et al., 2022; Vijaykumar et al., 2021). The floods in Kerala occurred in the geographical areas considered in this study, especially in central Alappuzha. Although the extents of both floods were similar, many more people were exposed to the 2018 flooding event.

8.1.2. How are the flood events associated with the incidences of leptospirosis?

The trend of leptospirosis during the flood periods offers invaluable insight into the situation in Kerala. The peak of leptospirosis incidence occurred 17 days after the peak of the floods. This result is consistent with the findings by Sykes et al. (2022) that incidences occur 2 to 20 days after initial exposure to the bacteria. It should be noted that the date of occurrence of infection may be earlier because there was only information on the reporting date. Similarities in the trend of leptospirosis before the flood phase suggest the presence of seasonality of the infection in this study area.

The results indicate that flooded areas are more likely to experience incidences of leptospirosis infection. Higher incidences of leptospirosis were reported in Alappuzha during the postflood phase, The number of panchayats that experienced postflood incidences of leptospirosis exceeded the number of panchayats affected by floods. This shows that the spread of leptospirosis is not only limited to flooded areas. Other areas aside from flooded areas could be previously endemic areas or new settlements that evacuated people move into (such as relief camps).

Additionally, the results consistently show that incidences of leptospirosis are higher during the postflood phase than other phases. Indirect transmissions of leptospirosis are more common than direct transmission Goarant (2016). Although a small part of the population was directly exposed to the flooding event, the possibilities of secondary transmission cannot be ignored. For every 100,000 persons exposed to floods, 641 people got infected with the disease in the study area. This is notably higher than the global yearly rate of 14.77 cases per 100,000 estimated by the Leptospirosis Epidemiology Reference Group (LERG) (Costa et al., 2015).

8.1.3. How do the incidences of leptospirosis differ by flood phase and year?

The incidences in the three phases of floods are different means regardless of the year involved. The lowest cases are observed in the during flood phase. An evident reason is that the flood period is shorter in comparison with the preflood and postflood phases therefore infections during a flood upon incubation may be reported only after the flood.

Previous studies have shown that leptospirosis incidence is associated with flooding (Naing et al., 2019), this study further suggests that flood-induced incidences are dependent on the severity of the flood event. There is a clear difference between incidences in 2018 and 2019 despite floods occurring in both years in the study area: the incidences are different over the flood phases in both districts. This result indicates that the distribution and geographical spread of leptospirosis infections are heavily influenced by floods. Although floods can be a significant indicator for the prediction of future incidences of leptospirosis, less severe floods may not cause a spike in the number of leptospirosis cases.

8.2. Assessment of the risk factors of leptospirosis

8.2.1. Which geographic areas are associated with leptospirosis incidences in 2018?

The incidences of leptospirosis can be related to social and environmental construct. The result shows that more cases are reported in grama panchayats (rural areas) than in municipalities (urban areas) in all the flood phases. It supports two possible risk factors that are discussed in **8.2.2**, the population density and poverty index of each area. Nevertheless, previous studies have shown that leptospirosis can be very much linked to rural inhabitants in developing countries (Goarant 2016). This result also shows that incidences occur around small farmlands and not highly vegetated areas. A reason could be that people live around small farmlands than in thick forests. All elements in the epidemiological triad (as shown in Figure 4) must be involved before an incidence can emerge. This result suggests that occupations such as small-scale farming or agriculture, present more risk of exposure to the disease in this study area.

The impact of leptospirosis was evident at certain places in the different phases of the flood. Districts in Pathanamthitta have a higher incidence rate given that they have relatively lesser populations. In an area that has become endemic to leptospirosis, the pathogens live freely in their natural environment but can be spread to other areas through floods (Lau et al., 2010). The results of this study suggest that panchayats at the centre of Pathanamthitta are natural habitats for the pathogen, but panchayats in central Alappuzha become hotspots after the eventuality of floods. Similar to the findings by Mohd Radi et al., (2018), the incidences of leptospirosis in this study area were most clustered during the post-flood phase as compared to incidence in other flood phases.

8.2.2. Which risk factors of leptospirosis can be obtained in Kerala?

Despite the replete studies on the incidence of leptospirosis, the risk factors have been considered from different perspectives. Leptospirosis is a disease with a huge burden for centuries now, and several studies have been considered to establish risk factors (Wasiński and Dutkiewicz, 2013) Earlier studies concentrated on clinical factors to determine and classify the serovars of leptospirosis for the development of treatment methods (Adler, 2015; Gopi et al., 2021) The relevance of social factors was acknowledged as a result of observation of rise of incidence among the specific type of workers. Environmental factors are increasingly considered in recent studies given the influence of the climate and the environment (Cucchi et al., 2019; Wasiński and Dutkiewicz, 2013). This study has incorporated risk factors from the three given classes and assesses them using a mixed-method approach. The selection is impacted by data limitations as discussed in 8.4, however, the assessment is sufficient to fulfil the research objective.

8.2.3. What demography was affected by leptospirosis infections?

The results of this study show that male gender and older adults are more vulnerable to leptospirosis. Despite of more female population than male population in the study area, the male population is at a higher risk. Being male is a strong risk factor for leptospirosis, especially after floods (Naing et al., 2019). Natural incidence of leptospirosis is often associated with various social factors of such as occupation, and interaction with animals (Wasiński and Dutkiewicz, 2013). Agriculture is a very common but declining occupation in Kerala because even younger members of agricultural households prefer to work in non-agricultural sectors (Kumar and Abraham, 2021). An explanation of the incidence of leptospirosis among old adults may be that they work on farmlands and are more exposed to direct infections.

Although the age group varies affected in both districts, most cases during flood periods are reported among young adults. This may be due to a few different reasons. Volunteer workers and people involved in rescuing affected people in a flood situation are usually younger and stronger. They are therefore likely to be more exposed to the infection during this period than other age groups. It may also be possible that younger adults are exposed during the earlier stages of heavy rainfall through recreational or fun activities with water.

As shown in Table 35, the combination of the results from Tables 10 and 28 provides an overview of the individual risk to leptospirosis infection in 2018. The incidence rate per 100,000 shows clearly that flooding is a strong amplifier of the risk of infection regardless of location and gender.

Table 35 Incidence rate of leptospirosis for gender types and flood exposure

	Alappuzha				**Pathanamthitta**			
Categories	Total	Female	Male	Flood	Total	Female	Male	Flood
Number of cases (N)	253	99	154	192	312	100	212	187
Population	2,127,789	1,114,647	1,013,142	53,145	1,197,412	635,696	561,716	5,990
Incidence rate	11.9	8.9	15.2	361.3	26.1	15.7	37.7	3121.9

8.2.4. How do risk factors relate to the incidences of leptospirosis in the study area?

Flood plays an important role in the incidences of leptospirosis; it also exacerbates the importance of certain risk factors. Unsurprisingly, areas with existing waterbodies are likely to experience more incidences as a result of flooding. In addition, people living the vegetated areas have a higher chance of infections. When exposed to contaminated flood water, livestock animals in green areas can serve as reservoir hosts of leptospirosis to nearby people (Goarant, 2016; James et al., 2018)

Higher population density was found to be a positive risk after during the postflood phase. The occurrence of floods in densely populated areas may increase the chance of pathogenic transmission among the affected population. Population density is a significant risk factor for leptospirosis(Chadsuthi et al., 2022), especially in urban slums (Galan et al., 2021). Areas with poorer residents are also likely to have higher incident rates after the floods. This may relate to the quality and sanitation structure of the housing of these individuals, people with inadequate sewage drainage system are likely to be exposed to contaminated water (Hagan et al., 2016).

The occurrence of floods does not affect certain existing risk factors. In contrast to previous studies, leptospirosis incidence in Kerala shows a negligible association with temperature in both preflood and postflood phases. Leptospirosis can be easily treated with antibiotics if diagnosed early (CDC, 2015). It is not surprising that the amount of health care facilities does not play an important role in the number of infections after infections. Nevertheless, there is still a positive association with flood occurrence. Due to the difficulty in detecting leptospirosis infections, health centres that becomes overpopulated by sick people may become a harbour for leptospirosis transmission.

There are also a few results that show the contrasting influence of flood on risk factors. Precipitation becomes a positive risk factor for leptospirosis incidence during postflood phase despite a negative association with preflood incidences. An explanation could be as a result of the seasonality of the climatic factor. Rainfalls are received during the monsoon season (Vijaykumar et al., 2021), therefore in the preflood phase it may have been a drier season. In addition, higher elevations show a negligible but positive association with the preflood incidences of leptospirosis. This may be because the elevation across the districts not high enough to observe a significant variation. Anish (Appendix A.5) mentioned that from his observation of the cases in Thiruvananthapuram (a district in Kerala), areas below 50m are largely at a higher risk of leptospirosis because they are more frequently flooded. After the floods, elevation has a strong negative association with leptospirosis incidence because a lot of low-lying areas were not affected by floods. This result suggests that elevation may not be considered as a relevant indicator during postflood phase.

With respect to temporal changes, Precipitation and temperature show a negative association to leptospirosis infection. The relationship between the climatic factors seems to be a fluctuating one, that is leptospirosis occurs after there have been high precipitation and temperature. Assessing these factors with time lags would provide a better overview of the situation. The results suggest that duration of flood is a more important characteristic of severity in determining the incidence of leptospirosis. Similarly, the increase in flood discharge is strongly positively related to the incidences of leptospirosis after a 3-week lag period. Similar studies have considered lag period important to understanding the incidence of leptospirosis after floods (Dhewantara et al., 2018; Ehelepola et al., 2019)

8.3. Risk management of leptospirosis

8.3.1. What are the risk factors identified by local health experts?

The major clinical challenge in addressing the burden of leptospirosis in Kerala relates to the diagnosis of the infection. The diagnosis of leptospirosis is often delayed, wrong or not done at all in certain cases. A delay in the treatment of leptospirosis is detrimental (Lau et al., 2018), but it may not be directly linked to the inaccessibility to healthcare in Kerala. People also often resort to self-treatment when initial symptoms set in. Even when they present themselves in healthcare facilities, clinicians may also be unsuspicious of leptospirosis because of its similarity with other infections. Finally, there is a possibility of insufficient resources (in terms of testing kits as well as medical personnel) during an outbreak.

The surveys show that other social and environmental factors contribute to the risk of leptospirosis in Kerala. In agreement with Mishra (2022) and Pappachan et al.(2004) findings, occupational duties and sanitation of the environment are regarded as dominant factors that expose residents in Kerala to being infected with leptospirosis. Although these key factors are not directly evaluated in this risk assessment in Chapter 6, the results indicate a similar conclusion on the transmission patterns.

8.3.2. How should stakeholders be involved in managing epidemic risk?

Several actions can be done to mitigate the risk of leptospirosis, but these actions must be strategized into a management plan. Although there is a consensus between survey respondents on the knowledge and awareness of the public about leptospirosis infection. There is noticeable conflict of information on the availability of a developed framework to address leptospirosis infection after flooding. The KSDMA disaster management plan does not include a section for leptospirosis (KSDMA, 2016). Most stakeholders were only involved during the flood phase to rescue the affected population, but leptospirosis and other health issues should be combated throughout all phases, especially during the preflood phase. It is important to have a documented strategy for combating leptospirosis during the different flood phases. The recommendations of this study may be used to improve or initiate the development of an epidemic risk management framework.

The result shows that there is a very high level of collaboration among stakeholders to resolve the epidemic challenge after the 2018 floods, nevertheless, inclusion of actors from other sectors are recommended. Although this study has looked at improving the knowledge base for reducing the wicked problem of leptospirosis, the importance of stakeholders in effecting the solutions is not overlooked. The involved stakeholders span across various levels of the hierarchy of governmental bodies and organizations. The disciplines of actors involved are unfortunately very limited to disaster management, defence, and public health. Actors in other fields that relate to animal sciences are less involved. Local sources indicate that professionals who are experienced in these disciplines and fields could have supported the epidemic risk management by identifying most vulnerable regions. Although unforeseen, the academic experts could have carried out predictive studies on leptospirosis infection rates after flooding to improve the level of preparedness of affected communities.

8.3.3. How can the findings be used to minimize future risks?

Disaster epidemiology is about understanding health risks as a result of disasters in order to manage them better in the future(Liu et al., 2021). The study culminates into recommendations that may be used for reducing the burden of leptospirosis infection by mitigating its potential risk. Leptospirosis is the leading cause of death among communicable diseases in India (James et al., 2018). Given that severe floods can be expected in Kerala, the risk of infection must be better managed. There have been gaps in evidence about the risk factors needed for management of leptospirosis in India (Beri et al., 2021). Therefore, the study has suggested action points that should assist in the management of epidemic risk at different phases of the flood. This result is however not a fully developed plan or framework; the recommendations should be further contextualized to ensure its effectiveness and efficiency in the study area and beyond.

8.4. Limitations of the study

8.4.1. Epidemic information

Although the incidence data provided enough possibilities for the analyses of this study to be carried out, certain limitations were encountered. A higher level of precision would have improved the spatial granularity of this research, but due to ethical and privacy concerns, the incidence had to be summarized at panchayat's level. Additional metadata such as, the date of onset of disease, the date patient was seen at facility, laboratory test results, and mortality would have provided a better context into analyses. There is a high chance that the incidence of leptospirosis has been underreported (Varughese and Purushothaman, 2021), therefore there is an amount of uncertainty in the completeness of epidemic data provided.

8.4.2. Flood information

The available information about flooding event is limited by unavailable or unreliable data. The record containing the flood discharge (implied by the amount of river discharge) had many missing values. This was a result of damage to station gauges at certain times. Although an attempt was made to estimate the missing values through interpolation methods by comparing the trend in other stations, the data was insufficient for a more detailed temporal analysis.

8.4.3. Data unavailability

This study is also plagued by the unavailability of data to quantify some risk factors of leptospirosis. The inclusion of those risk factors could have improved the assessment of leptospirosis in flood phases. A relevant social factor is the density of dumpsites or an index score for water, sanitation, and hygiene (WASH) per panchayat. It is also important to note that the population density is treated as a static variable, therefore it did not account for the mobility of people during flood periods. People are expected to move during flood period either by evacuation or displacement. The density of farm animals is another notable omission in this analysis, it has been identified as a major risk factor for leptospirosis (James et al., 2018; Zhao et al., 2016).

8.4.4. Qualitative surveys

This study employed surveys to harvest local risk factors in the study area, but there are certain concerns about the survey respondents. The respondents of the interview are mostly not residing in the study area (Alappuzha and Pathanamithitta) but live in other districts in Kerala. Their experience and recommendations may therefore not exactly represent the situation in the study area. A higher number of respondents (at least 100) may provide a better overview of the situation. An interview was conducted with only a medical doctor, more stakeholders from different disciplines and sectors may provide a holistic view. Inclusion of agricultural workers, community heads may be more helpful (Vinetz et al., 2005).

8.5. Future scope of research

This research provides numerous possibilities for further studies in different directions. There is a need to investigate the relationship between incidences and omitted risk factors in the study area. Important risk factors such as residents' occupation and environmental sanitation should be examined to understand how they are affected during floods. The influence of flooding on the emergence of leptospirosis infections should be investigated in other study areas within LMICs and beyond. This would aid the comparison in different study areas to understand how similarities and difference in environmental conditions may be important in the flood-induced incidence of leptospirosis. Finally, a potential study could be on the development of agent-based model to configure the host-pathogen-environment interactions for better prediction of leptospirosis incidence. There are chances of recurrent floods in Kerala (Central Water Commission, 2018; Hunt and Menon, 2020; Shaji, 2019), therefore epidemic forecast can be useful for early warning and preparedness (Myers et al., 2000).

8.6. Conclusions

The risk of leptospirosis was examined through a mixed-method research design to translate global and local data sources into actionable recommendations. Despite the similarities between the flooding in 2018 and 2019, the impact of the events differed. Leptospirosis incidence in both districts varied across the flood phases but the incidences were highest in the postflood phase of both districts. While the incidences in Alappuzha appeared to be similarly clustered, Pathanamthitta varied significantly. A variety of clinical, socioeconomic, and environmental factors were considered in relation to flood incidences. Male adults are more vulnerable to infectious disease, however, younger adults become susceptible during the flood phase. Flooding exacerbates the existing the vulnerability factors among the population; flood extent population density and poverty are the strongest risk factors contributing to leptospirosis incidence after the flood. Flood duration is an important severity metric that explains how accumulation of flood water leads to a higher incidence of leptospirosis. Information from local surveys reveals that diagnostics of the disease was the strongest clinical factor enhancing the burden of the disease. Stakeholders from a limited number of sectors were involved in managing the 2018 infection risk from floods, also, health actions are concentrated on only the flood phase. Recommendations are therefore developed to address the disease in disaster phases based on the risk assessment.

This study connects to a larger spectrum of disaster epidemiology and shows the relevance of analysing dynamically changing health risks due to disaster events. It contributes to existing knowledge of leptospirosis after floods. It has employed interdisciplinary research methods to contextualize the societal problem by obtaining information from a group of local stakeholders. Despite the data limitations it has encountered, it provides a relevant baseline for future studies and investigation. The proposed recommendations if applied optimally may have positive impact in reducing the wicked problem of leptospirosis in Kerala.

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APPENDICES

A.1 Leptospirosis and Flood

A.1.1 Flood discharge estimation

The summary of the missing values and the total values estimated for 2018 flood discharge are provided in Table 36.

Dates for which estimation was done	Number of inputted values	Dates for which estimation was done	Number of inputted values
Q_Erappuzha		Q_Kurudamannil	
16th August – 20th August	5	25th February	1
12th September – 18th September	7	15th August – 19th August	5
26th September – 28th September	3		
Total missing values estimated	15	Total missing values estimated	6
Total number of records with missing values	193	Total number of records with missing values	6
Total number of daily records	365	Total number of daily records	365

Table 36 Summary of the estimation of missing values

A.1.2 Incidence rates and clusters of leptospirosis

Incident rates across the panchayats of the study area for 2018 and 2019 are shown in Figure 38. The incident rates in both years are varied across the flood phases, however the incidence rates in 2018 are higher than that of 2019. Most panchayats reported less than 20 cases per 100,000 people before and during floods, but that increased more than five times during the postflood phase. However, in 2019, the incident rates across all three flood phases remained below 20 cases per 100,000 people. In 2018, though panchayats in Pathanamthitta district appear to have higher incidence rates across the phases of the flood. Kainakary of Alappuzha district had the highest incidence rates during the postflood phase of both years (104.94 in 2018; 20.9 in 2019)

Figure 39 shows the clusters and outliers of the incidences during the three flood phases in 2018 and 2019. The clusters changed over the three phases of the floods. Significant clusters can be seen in the middle of Pathanamathitta before and during the floods. In both years, the hotspots of leptospirosis in Alappuzha are only realized after the floods. Unlike 2018, there are almost no hotspots during the flood phase in both 2019 and also, there were no hotspots in Pathanamthitta after the floods. In 2018, the high-high clusters the post-flood map suggest a combination of areas that experienced incidence before floods and the areas most affected by floods. The low-low areas are the outliers in the extreme south of Alappuzha that were not affected by leptospirosis incidence through the three phases.

Incidence rate in 2018 and 2019 in all three phases are shown in Figures 40 and 41. The clusters and outliers of the incidences for the postflood phases of 2018 and 2019 can be found in Figures 5 and 6.

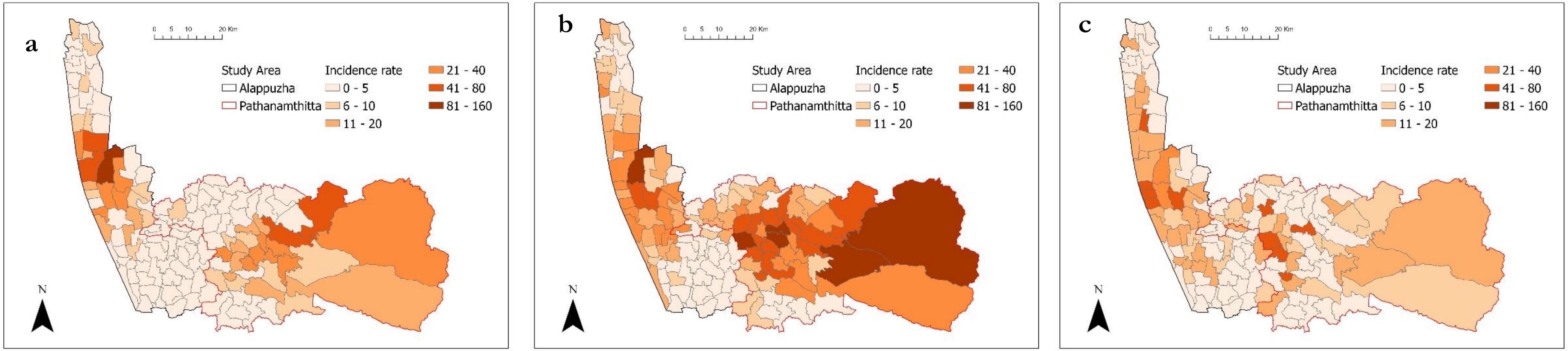
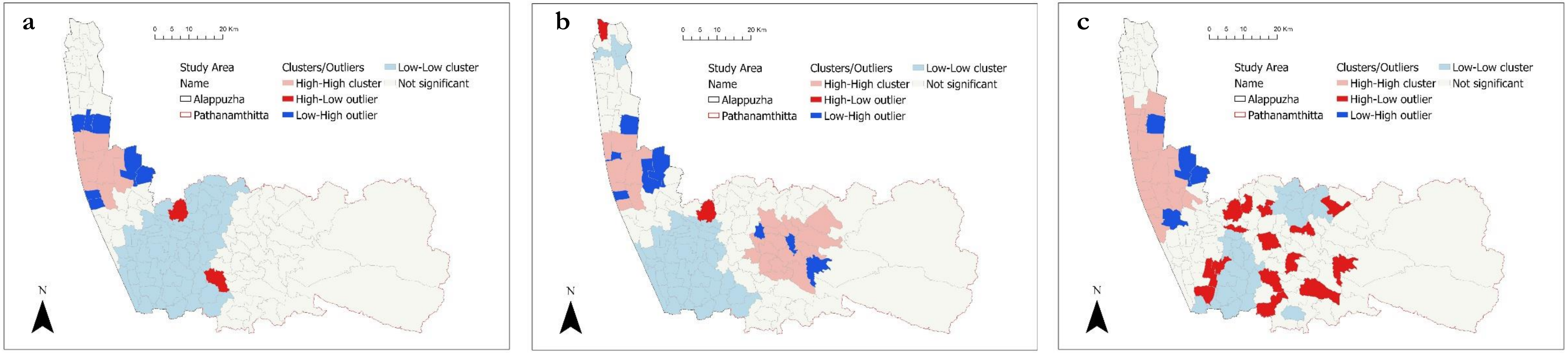


Figure 38 Incident rates of leptospirosis per 100,000 people across flood phases across all three years (a) 2017 (b) 2018 (c) 2019

Figure 39 Cluster and outliers of incidences across all three years. (a) 2017 (b) 2018 (c) 2019



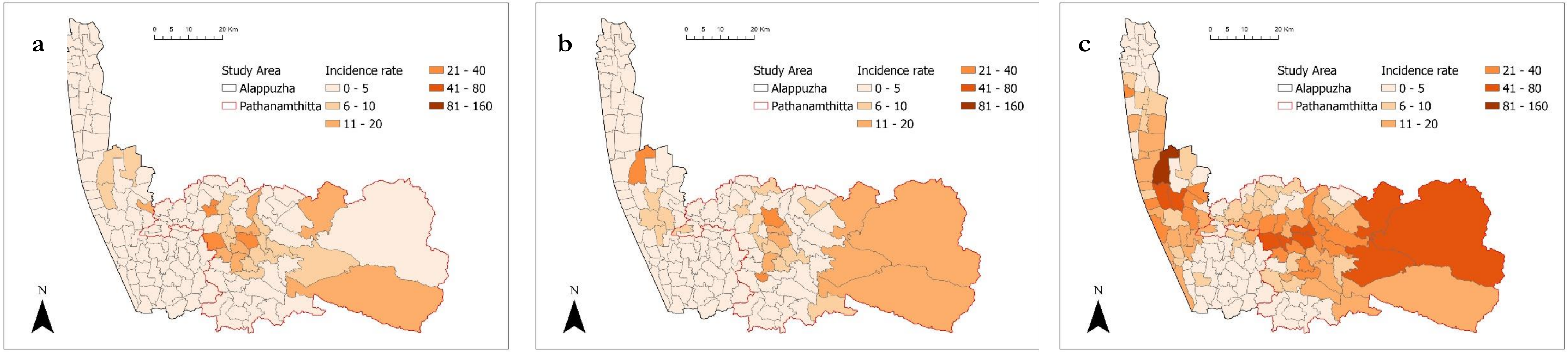


Figure 40 Incident rates of leptospirosis per 100,000 across flood phases in 2018 (a) preflood (b) during flood (c) postflood

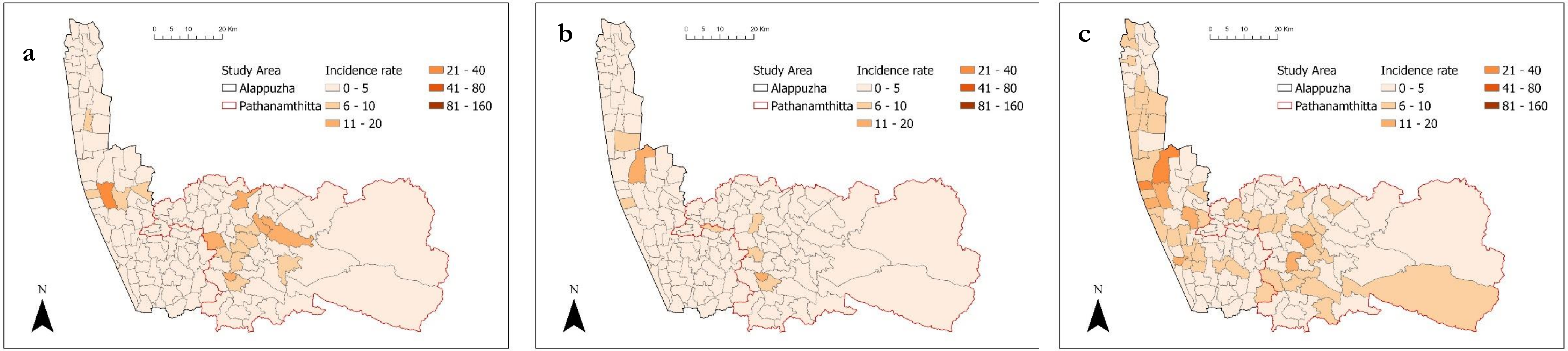


Figure 41 Incident rates of leptospirosis per 100,000 across flood phases in 2019 (a) preflood (b) during flood (c) postflood

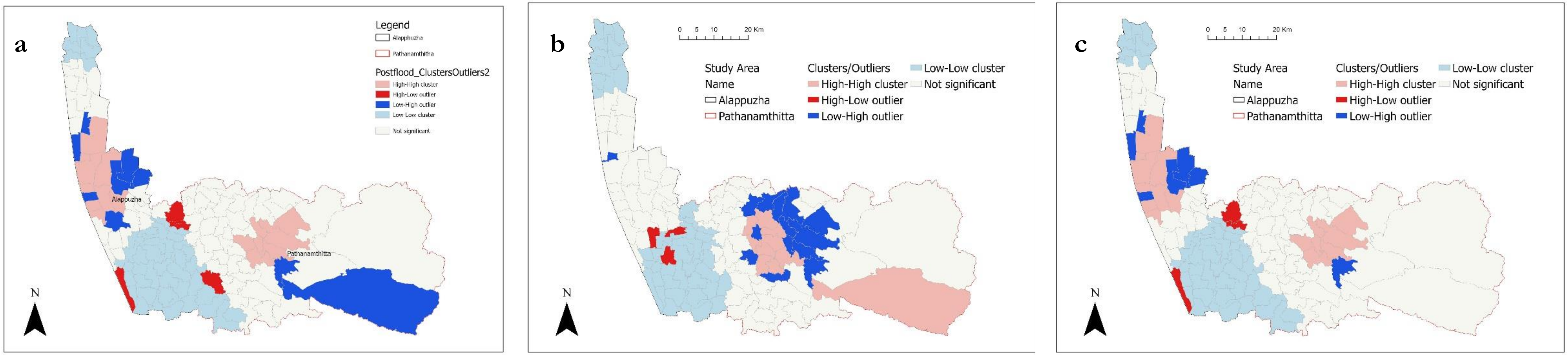


Figure 42 Cluster and outliers of incidences across flood phases in 2018 (a) preflood (b) during flood (c) postflood

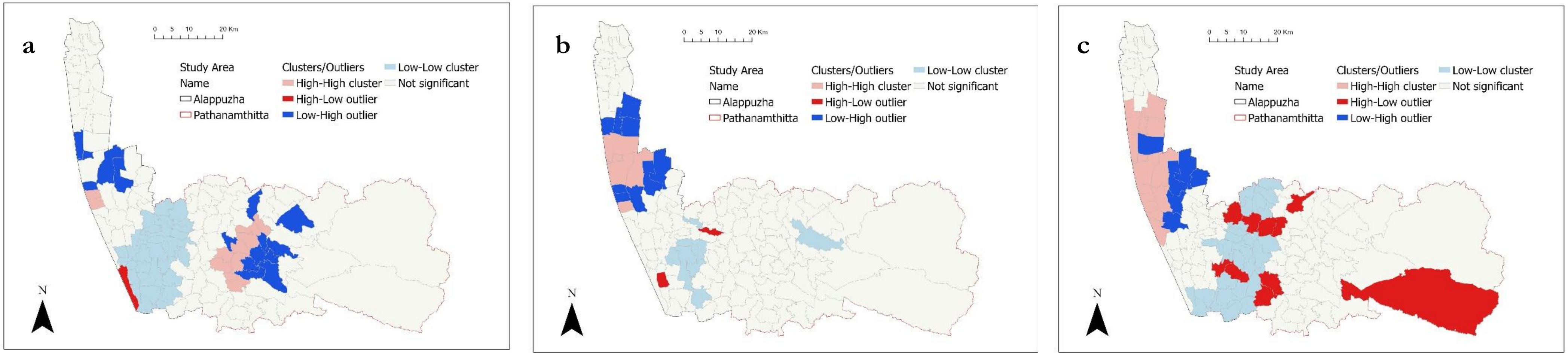
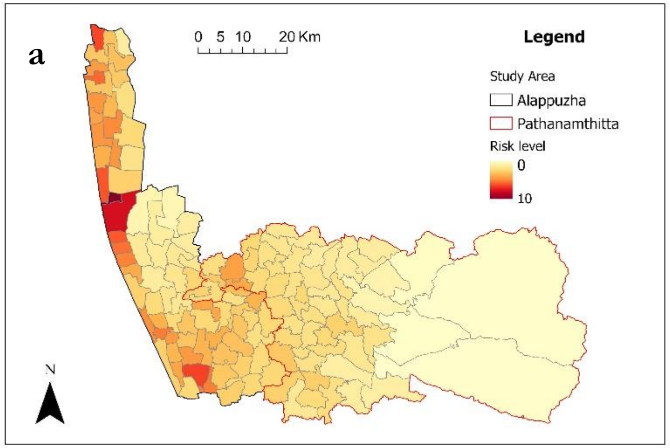


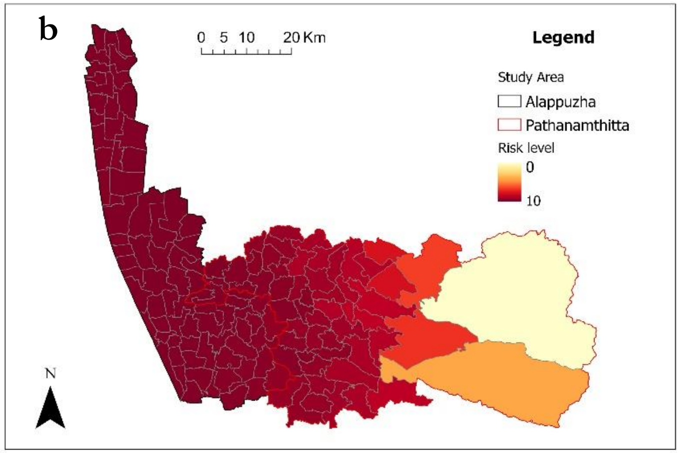
Figure 43 Cluster and outliers of incidences across flood phases in 2019 (a) preflood (b) during flood (c) postflood

A.2 Leptospirosis and Risk Factors

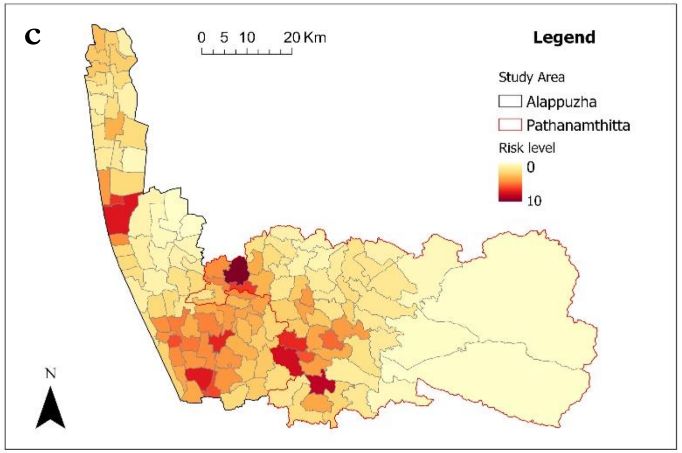
A.2.1 Risk level of indicators



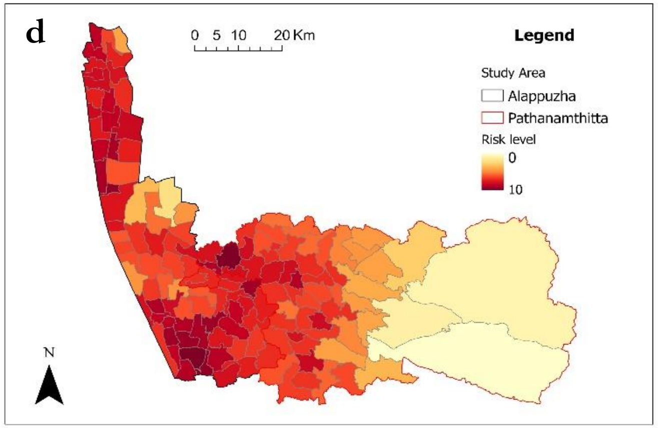
(a) Population density



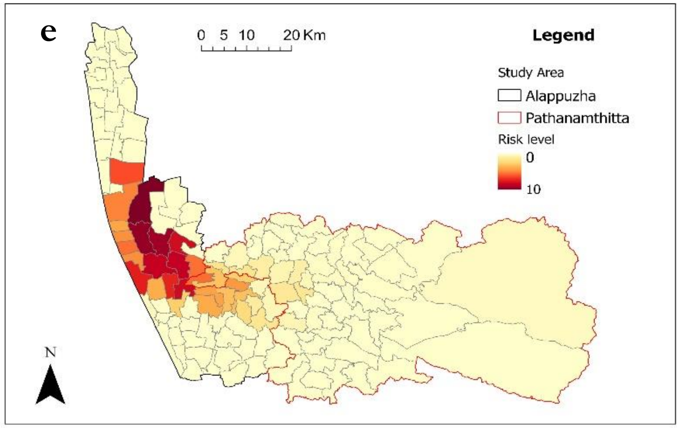
(b) Elevation (c)



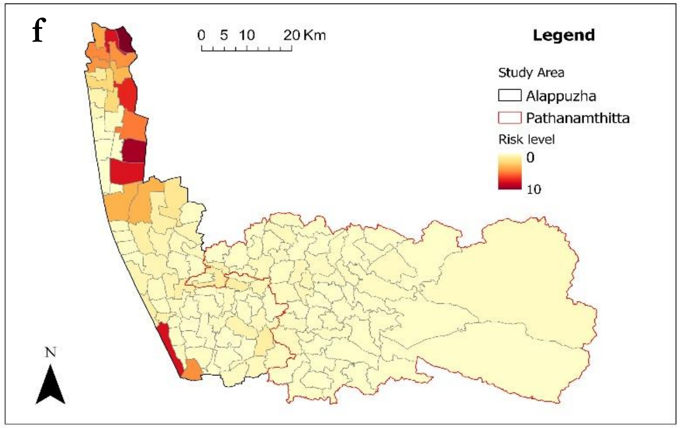
(c) Healthcare Density



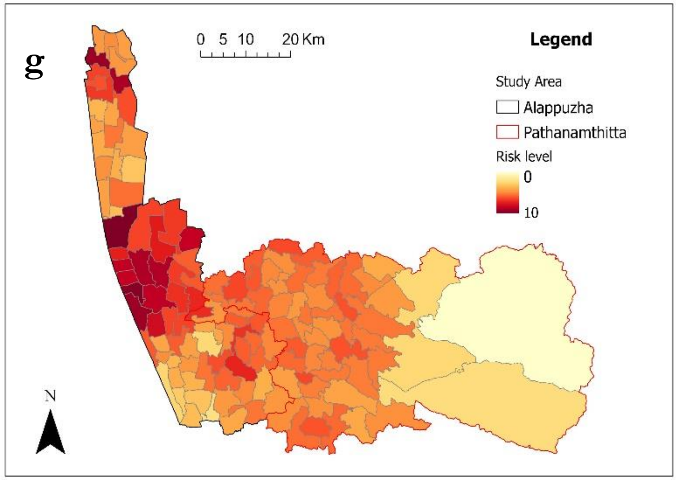
(d) Poverty



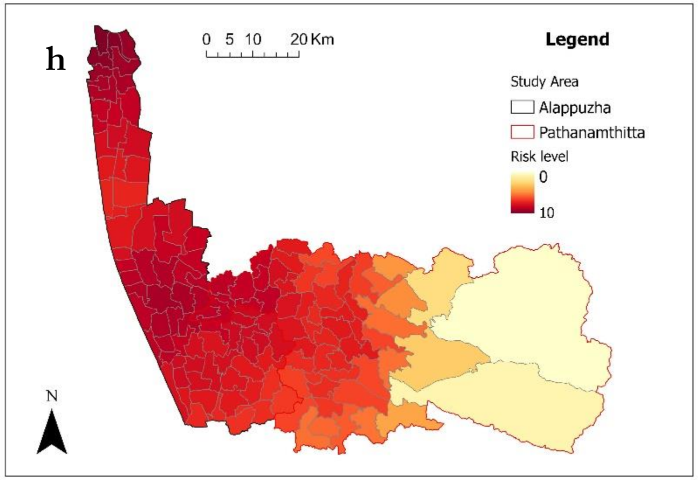
(e) Flood



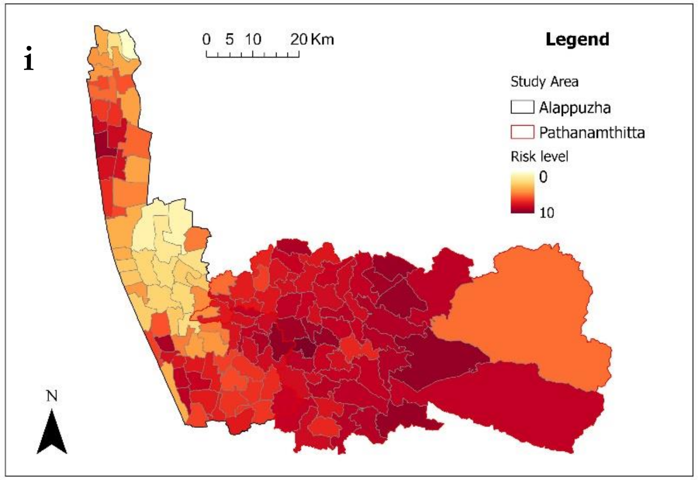
(f) Water bodies



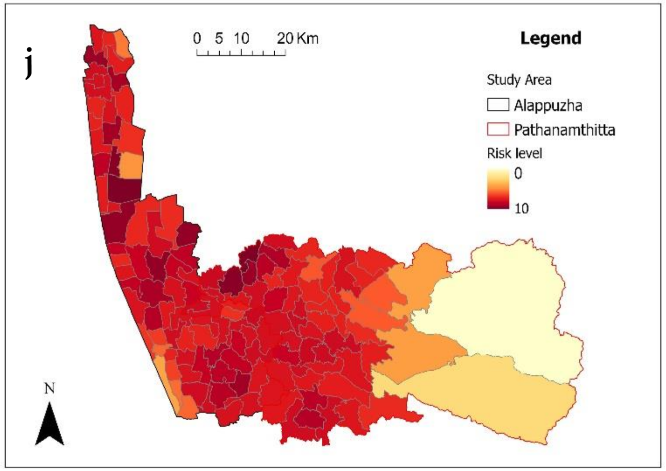
(g) Temperature (preflood)



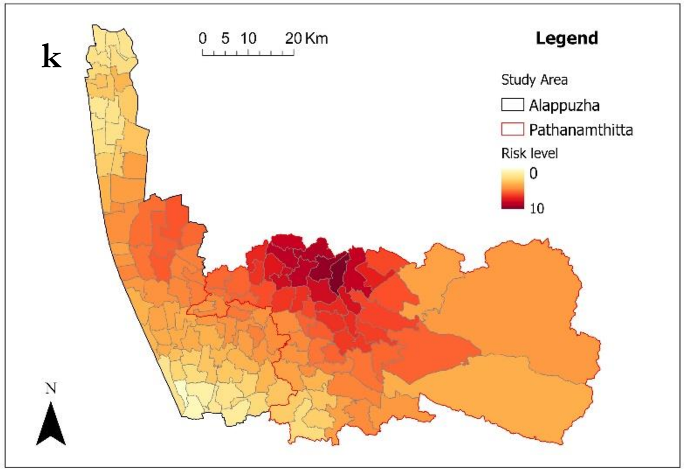
(h) Precipitation (preflood)



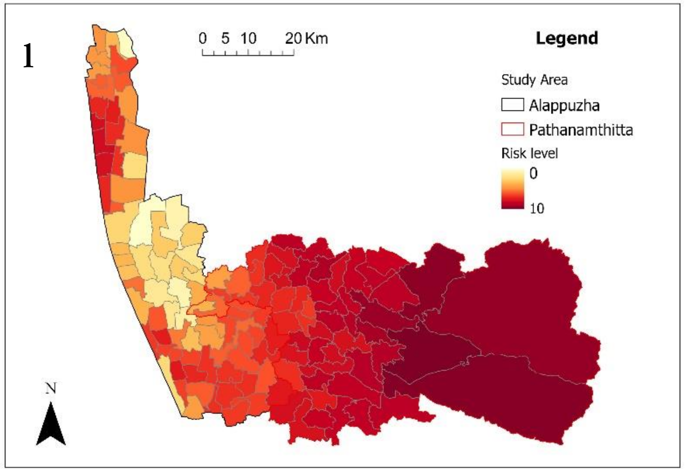
(i) Vegetation (preflood)



(j) Temperature (postflood)



(k) Precipitation (postflood)



(l) Vegetation (postflood)

Figure 44 Risk level of indicators for spatial regression (where 0 = low risk and 10 = high risk)

A.2.2 Average risk level at postflood clusters

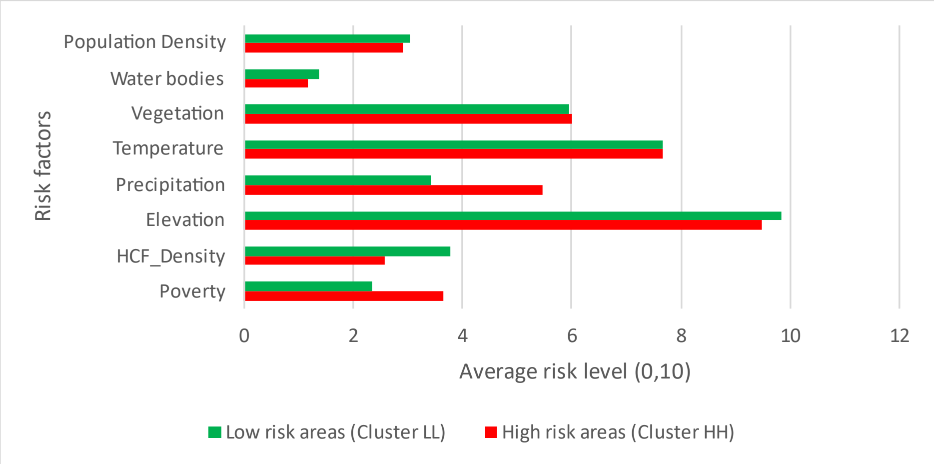


Figure 45 Average risk level of indicators at cluster of incidences during the postflood phase

A.3 Scripts used in R

A.3.1 SVC regression between for flood extents and postflood incidence.

```
library(spdep)
library(maptools)
library(raster)
library(rgdal)
library(sp)
library(varycoef)
library(sf)
library(tmap)
library(gstat)

#Set working directory and import the shapefile with values for flood extent and postflood incdence
setwd("C:/MSc_Thesis/Data")
factors_HARV <- readOGR("Index", "Indicators_p2", stringsAsFactors = T)
extent(factors_HARV)

#Print the headers to confirm the file and know how to call each column
names(factors_HARV@data)

#Covert mean centre coordinates to kilometres to reduce computation time
locs <- as.matrix(factors_HARV@coords[, 1:2])/1000

fit_svc_post2 <- SVC_mle(postfl2018 ~ Flood_18, locs = locs, data = factors_HARV@data)
summary(fit_svc_post2)

fit_svc_post3 <- SVC_mle(postfl2019 ~ Flood_19, locs = locs, data = factors_HARV@data)
summary(fit_svc_post3)
```

A.3.2 SVC regression for all risk factors

```
library(spdep)
library(maptools)
library(raster)
library(rgdal)
library(sp)
library(varycoef)
library(sf)
library(tmap)
library(gstat)

#Set working directory and import the shapefile with summarized values for each indicator
setwd("C:/MSc_Thesis/Data")
factors_HARV <- readOGR("Index", "Indicators_p3", stringsAsFactors = T)
extent(factors_HARV)
```

```
##Preflood regression

#Perform linear regression to have a first look at the distribution
fit_lm_pre <- lm(Prefl2018 ~ Poverty2 + HCF_Densit + Elevation2 + Pre_Prec
        + Pre_Temp + Pre_Veg + PopDensity + Water, data = factors_HARV@data)
summary(fit_lm_pre)

#Check the distribution of residuals to ensure the SVC model can be used
oldpar <- par(mfrow = c(1, 2))
plot(fit_lm_pre, which = 1:2)
factors_HARV@data$LM_res <- resid(fit_lm_pre)

#Covert mean centre coordinates to kilometres to reduce computation time
locs <- as.matrix(factors_HARV@coords[, 1:2])/1000

#Perform SVC regression
fit_svc_pre <- SVC_mle(Prefl2018 ~ Poverty2 + HCF_Densit + Elevation2 + Pre_Prec
          + Pre_Temp + + Pre_Veg + PopDensity + Water,
          locs = locs, data = factors_HARV@data)
summary(fit_svc_pre)

#Compare results of SVC model with linear regression
library(knitr)
kable(data.frame(
  Model = c("linear", "SVC"),
  # using method logLik
  `log Likelihood` = round(as.numeric(c(logLik(fit_lm_pre), logLik(fit_svc_pre))), 2),
  # using method AIC
  AIC = round(c(AIC(fit_lm_pre), AIC(fit_svc_pre)), 2),
  # using method BIC
  BIC = round(c(BIC(fit_lm_pre), BIC(fit_svc_pre)), 2)
))
```

```
##Postflood regression

#Perform linear regression to have a first look at the distribution
fit_lm_post <- lm(postfl2018 ~ Poverty2 + HCF_Densit + Elevation2 + Post_Prec + Post_Temp +
                 Post_Veg + PopDensity + Water + Flood_18 , data = factors_HARV@data)
summary(fit_lm_post)

#Check the distribution of residuals to ensure the SVC model can be used
oldpar <- par(mfrow = c(1, 2))
plot(fit_lm_post, which = 1:2)
factors_HARV@data$LM_res2 <- resid(fit_lm_post)

#Covert mean centre coordinates to kilometres to reduce computation time
locs <- as.matrix(factors_HARV@coords[, 1:2])/1000

#Perform SVC regression
fit_svc_post <- SVC_mle(postfl2018 ~ Poverty2 + HCF_Densit + Elevation2 + Post_Prec + Post_Temp + Post_Veg
                  + PopDensity + Water + Flood_18, locs = locs, data = factors_HARV@data)
summary(fit_svc_post)

#Compare results of SVC model with linear regression
library(knitr)
kable(data.frame(
  Model = c("linear", "SVC"),
  # using method logLik
  `log Likelihood` = round(as.numeric(c(logLik(fit_lm_post), logLik(fit_svc_post))), 2),
  # using method AIC
  AIC = round(c(AIC(fit_lm_post), AIC(fit_svc_post)), 2),
  # using method BIC
  BIC = round(c(BIC(fit_lm_post), BIC(fit_svc_post)), 2)
))
```

A.4 Questionnaire

INTRODUCTION

This survey is part of a research study titled "Assessing the risk of leptospirosis in Kerala" It is being conducted by John Ifejube together with Prof Dr Justine Blanford and Prof Dr Cees van Westen of the Faculty of Geoinformation Science and Earth Observation, University of Twente Disasters impact public health in many ways, The aim of this research is to assess the risk of Leptospirosis after a massive flood event in a community in Kerala. For the purpose of this study, we will focus on the flood that occurred in Kerala in 2018.

This survey is designed to gather information from health professionals and workers in health-related institutions. By agreeing to participate in this survey you will be asked to respond to a set of questions about your experience in your department. The survey should take approximately 15 minutes to complete. The foreseeable risks or discomforts to you are minimal. The sensitive nature of some of the questions may make you uncomfortable, therefore, you may skip any questions on the survey at any time. You do not have to complete this survey. It is completely voluntary, and you may skip questions or stop at any time and for any reason.

The outcome of this research could be published as a research article. No identifiable information will be recorded in any of the responses and your name, email address, and IP address will not be linked to your responses in any way. None of the data you share will be shared with anyone in your institution/unit. All anonymous data will be encrypted.

Should you have questions or complaints please reach out to me or the ethics committee at ethicscommittee-geo@utwente.nl

John Ifejube,
Faculty ITC, University of Twente.
Would you like to be engaged in a more in-depth discussion on this subject? Please contact me (o.j.ifejube@student.utwente.nl) and we can arrange a meeting.

Do you give your consent to participate in this survey
[ ] Yes [ ] No

QUESTIONS

GENERAL INFORMATION

Taluk: _______________

District: _________________

Institution – [ ] General Hospital [ ] Community Health Centre [ ] Private Clinic [ ] Other __

Health position – [ ] Medical doctor [ ] Public health officer [ ] Volunteer or Support worker [] Other __________

EXPOSURE INFORMATION

In this section, we would like you to share how you experienced the Kerala 2018 flood.

1. How do you recall the flood event of 2018?
   a. What do you remember about the flood height?
      i. Flood height was minimal
      ii. Flood height was 6 inches
      iii. Flood height was 12 inches (1 foot) iv. Flood height was between 1-2 feet v. Flood height was between 2-4 feet
      vi. Flood height was in excess of 4 feet
      vii. Do not recall
   b. What do you remember about the duration of the flood?
      i. Flood lasted a few days
      ii. Flood lasted a few weeks (1-2 weeks)
      iii. Flood lasted 2-4 weeks
      iv. Flood lasted 4-6 weeks (1 – 1.5 months)
      v. Flood lasted 6-8 weeks (1.5 - 2 months)
      vi. Flood lasted 2-4 months vii. Flood lasted 4-6 months viii. Do not recall

IMPACT ANALYSIS

In this section, we would like to know what the impacts of the Kerala 2018 floods are to public health. We specifically want to investigate the incidence of Leptospirosis as a post-disaster health challenge.

2. What are the public health impacts of food in Kerala
   a. What are the general impacts of the 2018 flood on public health? (Tick all that apply) i. Deaths
      ii. Injuries
      iii. Communicable illnesses
      iv. Non-communicable diseases
      v. None of the above
   b. In your district, which areas were more affected by the floods? (Highlight the ward names)
      i. __________________
      ii. Do not recall any
3. In your district, what are the pre-flood and post-flood incidences of Leptospirosis?
   a. Was leptospirosis a problem during the Kerala 2018 flood?
      i. Yes

ii. No
iii. I don't know

b. Was leptospirosis a problem after the Kerala 2018 flood?
i. Yes
ii. No
iii. I don't know

c. Do you consider the number of cases to be underreported?
i. Yes
ii. No
iii. I don't know

d. How did the number of cases compare with non-flood years.
i. Number of cases were more than non-flood years
ii. Number of cases were less than non-flood years
iii. I don't know

e. What could be the reasons for under reporting?
i. Uncertainties in diagnosing Leptospirosis cases
ii. Not enough testing kits
iii. People resorting to self-treatment
iv. Other _______________

VULNERABILITY INFORMATION

In this section, we would like to know the social and physical conditions of the environment that made the population susceptible to flood-induced leptospirosis.

4. What are the key messages for vulnerability assessment?

a. On average, how long does it take patients to get health facilities to the affected people? i. Less than 5 minutes
ii. About 15 minutes
iii. Over 15 minutes iv. I don't know

b. What behavioral factors contribute to the population's social vulnerability to Leptospirosis? (Tick all that apply)
i. Occupational duties
ii. Personal Hygiene
iii. Environmental sanitation measures
iv. I don't know

c. What environmental factors contribute to the population's social vulnerability to Leptospirosis? (Tick all that apply)
i. Sanitation and waste disposal
ii. Proximity to water bodies
iii. Heavy rainfall and flooding

ACTION PLAN INFORMATION

In this section, we would like to enquire about the current bottlenecks and gaps that are associated with the risk governance of the problem. Stakeholders are the organizations that played some roles in the management of health risks

5. What is the risk perception and awareness of post-flood infections, especially leptospirosis? .

a. Do the general public understand Leptospirosis?
i. Yes
ii. Not really

iii. No iv. I don't know

b. Are people aware that floods could increase the risk to Leptospirosis?

i. Yes
ii. Not really
iii. No
iv. I don't know

6. What are actions to combat further outbreaks after floods

a. What community health actions are not yet in place during and after a flood? (Tick all that apply)

i. Effective Communication of risk
ii. Evacuation of affected people
iii. Early and periodic testing of affected people
iv. Immediate treatment of infected people
v. Provision of food and water
vi. Provision of safety wears to emergency workers
vii. Other __________

b. Is there a developed framework to specifically address Leptospirosis infections after floods?

i. Yes
ii. Not really
iii. No
iv. I don't know

c. Who are the current stakeholders that worked together to solve the health challenge from disasters?

i. _____________
ii. I don't know

d. Which other stakeholders should be involved?

i. _____________ ii. I don't know

A.5 Transcript of interview.

Interests/Expertise of Dr. Anish

- Infectious Disease Epidemiology, Investigation of Epidemics, Mathematical Modelling and Disease Forecast
- Neglected Tropical Diseases, Vector-borne Diseases, and Arboviral infections, Special focus on Dengue and Leishmaniasis
- Climate Change, Health related Disasters with a special focus on Nipah, Leptospirosis and Influenza
- Pandemic Science and COVID-19
- Health Policy, Economic Evaluation and Health Technology Assessment

Transcript

The flooding event in Kerala in 2018. It was really huge, and it affected thousands of people, but how do you recall the event?

Kerala has got 14 districts and Thiruvananthapuram is the least affected district among all the 14.I was working in Thiruvananthapuram at that point of time, so I have got minimal experience with the flood itself, but I happen to be in the state leadership, especially that of the health at that point of time. So I could witness what was happening in all other places of Kerala and I visited a couple of places where it was affected by flood and more or less my role was managerial and rather than affected, primarily affected by flood. Personally, I was part of the action, especially the health actions taken place at the time of flood.

So if you ask me, my personal experiences with front rather than just going and seeing or visiting the affected area, I do not have much expressional experience or front. But I got some experience in managing flood from the state capital and sending resources and surveillance of leptospirosis and management of data and all other things.

What were the general impacts of that flood?

Yeah, Kerala as you know, it is a very small strip of land and so many rivers, small rivers, the length being a few kilometers. They start from Western ghats and flowing to towards Arabian Sea.

A great flood occurred long ago in 1924., and the 2018 flood is somewhere very similar to a flood that happened almost 100 years before. Just like in 1918, almost all communities of Kerala was affected by flood because of the heavy rainfall that was happening. within two or three days in August, middle of August 2018.

So in a sense, it was unprecedented that the that kind of, uh, the indoor state was affected by flood, that was not very usual at the time of monsoon. Some areas will be flooded, especially those areas in the riverbanks or some areas within very hilly places. For some areas very close to seashore are usually affected by monsoon, but this time almost the entire state was affected.

That was the uniqueness of Kerala's flood in 2018.

What were the impacts to public health?

People get drowned in flood water, and people were also affected by landslides Thirdly, People were killed in maybe by injuries. The third mode is injuries that can happen after flood for example, electricutions can happen. Sometimes your house will be weakened because of the heavy rainfall, and it can in maybe after a week or so you can have some accidents. The major part of this issue is the communicable disease that can affect (maybe) after two weeks or after a month in affected areas affected by flood.

If you look at the statistics, you can see that with minimal number of people were affected or died because of drowning because there was an immense community response that helped to evacuate almost all people from the flood-affected area with the help of fisherman and the state governments. The response was very good and actually very minimal people drowned in flood water.

But as you know, Kerala has got a very special terrain, very environmentally sensitive. So the superficial layer of soil is very weak. therefore, many people were died in landslides. Nevertheless, the total number of individuals died in drowning as well as in landslides, it was hardly 500 individuals for the entire state of Kerala, where the population is somewhere very close to 30 million.

In terms of communicable diseases: we were expecting not number of communicable diseases including diarrheal diseases, malaria and so many issues can happen, but it was not happening in Kerala. The only big outbreak that we were experiencing is leptospirosis, the leptospirosis in incidence in 2017 led to around 1500 deaths. But in the year 2018, I think it was somewhere around 2500 deaths from leptospirosis. That means an additional number of deaths of 1000 (was caused by the flood).

The flood itself killed only 500, but the leptospirosis killed maybe a thousand or more. Definitely the death toll will be more than 1000 because definitely some people will be will not be counted in the state surveillance mechanism. Sometimes people will be admitted in private hospitals and if at death is happening in private hospital, sometimes it may not be counted as a death toll. So the message in a cracks is maybe double number of people died because of leptospirosis, rather than people died out of flood itself.

From my analysis, I see that the people infected by leptospirosis are mostly male adults, why exactly is this happening?

If you look at factors for usual incidence of leptospirosis, not related to flood. Males are more prone to leptospirosis because they may be exposed to contaminated water because of occupation. For example, people, people coming in contact with water, maybe to get sand from river or sometimes there will be accompanying their cattle to the river, or sometimes they may go to clean the water sources. Sometimes they may be working in sewage, so these occupations are more related to or more to towards male, especially the adult males. The children may not be that much exposed and elderly people are also not that much exposed, so that is one of the the interesting thing that you have mentioned that mail adults, especially in the age group may be 30 to 50 or more exposed to these kinds of kisses.

Other local risk factors?

Other than this thing, we realized some other factors also in leptospirosis. One thing is the another occupation that is cattle rearing. If you have got a cow in your home, then you have got an additional chance of getting your leptospirosis insurance because of many reasons. One thing is the cattle itself can act as a reservoir - sometimes you may be handling the cow dung, sometimes you may be handling cow urine. So presence of an animal in the household is a risk factor for leptospirosis.A second factor is that in Kerala, leptospirosis cases is is more distributed than that coastal area towards the lower laying area it is not that much prevalent in the high ranges. When the water is contaminated, and it flows towards the downstream then people will be exposed to contaminated water. Therefore, residing in downstream is is a risk factor for leptospirosis.

When we were analysing leptospirosis cases in Thiruvananthapuram in 2011. We found that people residing in areas with altitude 50 meters or below because Kerala has got different terrains, high ranges are maybe in the range of 1000 meters and maybe in the middle, Midland, maybe in the range of maybe 200 to 500 meters. Lower land area is somewhere 50 meters, and in some parts it is below the sea level. These there will be water logging in these areas that are below sea level, and you may be exposed to leptospirosis, but as far as I know, when flood occurred discuss slightly altered, everybody was exposed. Still, there was a risk factor, but this was factor gradient was reduced because of flood since everybody was exposed to flood water. The cases were concentrated on areas of flood. So then, if in the presence of flood, the only one question is very relevant whether you are place is flooded by water,

Your social economic status is also important. If you have a very bad house, then the house may be flooded. You might be exposed to floodwater to rescue your family members, or sometimes to safeguard your your valuables But ff you are a higher social status, sometimes the ground floor may be flooded and you are moving to the upper floor upper areas and you may not be exposed to flood water.Therefore, the two variables are important, one is the geographical location of your house whether it is flooded or not. Second one is the socioeconomic status. If you are a poor person, definitely you have got more chances to get exposed to flood water.

Another group, which became a risk at that point is the volunteers. So many volunteers were trying to rescue people from floodwaters, and some of them maybe having some injuries in their hands and foods.

Another risk factor that we have to think is the people's awareness about leptospirosis you. If you are going to be exposed to contaminated water, sometimes you may be knowing that you are at risk of leptospirosis and you may choose something to protect yourself. Also, the government of Kerala was distributing the tablet doxycycline and if you are consuming doxycycline before the exposure to contaminated water, it may also be helpful. If Leptospira bacteria managed to get inside your body, the presence of doxycycline in your body will kill this particular organism, so that would also be helpful. So, your knowledge your practice of maybe protective equipment or your practice of taking doxycycline tablets. These things might have help you protect you from exposure if you do not have that kind of a practice sometimes it might have ended up in a risk of getting exposed to leptospirosis.

Another thing is let getting leptospirosis and dying because of leptospirosis are two different things in my study. What I have observed is leptospirosis is a disease where the time taken for treatment is very crucial. If you diagnose it early and treat it early, the chance of death will be much lower. But if your internal organs are affected, for example, if you are getting leptospirosis and your kidneys are affected by leptospirosis or your liver is affected by leptospirosis, then the chance of death is high.

As you rightly pointed out, definitely two of them is one is maybe male gender and second one maybe your age that is between maybe 30 to 50 years.

Can you say something about the administration of doxycycline?

Administering left this doxycycline for people who are prone for leptospirosis is practiced in Kerala even before the flood. If you are exposed to contaminated water, doxycycline is going to help you. But if you look at the literature, you will see that there is no strong evidence that leptospirosis is going to help you to prevent leptospirosis and related death. There is conflicting evidence, some studies show that it is useful while others deny its usefulness. But the practical experience we have in Kerala we are located in the area where there is high chance of leptospirosis and then every year hundreds of people are dying because of leptospirosis. So the only thing that we can do is to give doxycycline if you are at a risk group. Therefore, that was there already practiced there even before the flood strike, Kerala,

When flood was striking Kerala, suddenly health department took an action to distribute this doxycycline tablets to counter leptospirosis, but I think the public awareness was not that much good at that point of time. So even if there was an initiative from Government of Kerala, people were not using it regularly and that might have entered in higher number of casualties.

But here I have to make two points very clearly. One thing is how doxycycline is acting, Doxycycline will act only after this leptospirosis enter to your body. Doxycycline won't prevent the entry of this organism to your body, so that is not a very good approach to allow the bacteria to enter you in your body before killing it. Sometimes you will be failing, and the bacteria will be creating serious infection. Doxycycline is not a magic bullet, you have to take care of the cleanliness you have to protect yourself from getting infected is important. Once you are getting infected and if you have got a high chance of getting infected, definitely doxycycline is going to help you so doxycycline will be acting as a second line management.

Another problem with the doxycycline is if you are considering doxycycline as a magic bullet. The problem is you will just give doxycycline for example in 1980 is flooded, then people will be communicated that the doxycycline is going to help you. You get the doxycycline from the primary hospital centres or private hospitals and get it consumed and you go to the flood water. You won't have or you want resulted in leptospirosis. That is a bad message, so definitely doxycycline is not a magic bullet. There are so many issues are just like you mentioned. There could be individual side effects as well as there would environmental impact of doxycycline.

We are living in an era where there is antibiotic resistance can happen. If so, people are consuming so many amounts of doxycycline then there is chance that small doxycycline will go to the environment if in future the leptospira bacteria can itself may be exposed to doxycycline and the bacteria can have some kind of a resistance against this antibiotic. So.the usage of doxycycline is a double edged sword. Then as you have mentioned Doxycycline has side effects. It is a drug with serious side effects especially gastric related side effects, but as far as the experience of Kerala is concerned, it is definitely helpful at the time of emergencies.

What does doxycycline prophylaxis mean?

It is a different type of dosage is different. Administration of doxycycline for treatment require daily (twice in a day) dosage while for prophylaxis, it is a weekly dose in every week. Doxycycline by treatment, your body is full of this bacterium and this antibiotic is used to kill the bacteria. Yyou have to be get cured because you it's in the disease process has already started, but in prophylactic it is only to kill if a bacteria is managed to get into your body before it's multiplication. People who are not infected or people are about to be infected use the prophylactic dose and if you have got a evidence of disease then only we will use the treatment dose.

Do you also agree that the number of cases are under underreported?

Reporting leptospirosis is usually a a clinical disease. Most of the test that is that is prescribed for leptospirosis is IGM based (IGM is an antibody), so it will take time. The test will get positive, maybe in the second week only the clinical presentations maybe in the first two week and sometimes that patient will die even before tested positive. So definitely there will be under reported. Therefore, looking at the clinical profile my assumption is that the total number of cases would be at least five times that was that reported case even including death also. And now, government of Kerala started another diagnostic methodology that is PCR testing polymerized chain reaction that facilities available in all districts now. So if there is another flood is going to happen in future, I think the diagnostic facilities away will be better and the reporting will be better.

Are there enough diagnostic kits for this new technology already?

I am not sure. I think it the system is going to be established and it may happen in future. There may not be enough kits now.

The survey respondents says that it takes over 15 minutes to get to nearest health facilities Do you think this contributes to the uh incidences of leptospirosis by any means?

Time delay might have happened because of many reasons. One thing is the patience themself will consider this as a mild fever and they won't go to the hospital. Second one is even if the patient happened to be in the hospital, sometimes the physician may not suspect leptospirosis. Sometimes there may not be the diagnostic ability in that particular area, so sometimes the physician may refer the patient to higher sentence. So, it all these things will contribute to a delay, and in my Trivandrum experience, my Trivandrum study also it is a delay in treatment is a detrimental it was identified as detrimental in leptospirosis it do happen.

Now let's talk about how to improve the situation. Do you think people have already very aware of leptospirosis?

Leptospirosis as it is becoming an emerging issue, if you are able to invest, warn the public awareness, if you can include leptospirosis also in the maybe in the list of the things that the people have to be aware, then definitely the impact of this problem will be getting reduced.

What other community at actions can be done that are not yet in currently in place that you could recommend for the next event.

I think as most of the people are telling, there is enough awareness has created in Kerala community regarding the Prosperos SIS brisk after flood. One thing is in health department unnecessarily importance is given to doxycycline as we have already discussed, people think that doxycycline is a magic bullet. Doxycycline is a secondary prevention.

Second one is the people, especially volunteers, they are not practicing enough protective measures, just like Gumboot Claus and all the these two things are very important. Protect your hands and protect your legs.

Is it that they don't protect themselves or they are not provided with in enough materials?

That is a very interesting question that this we supposed to provide that for people, but that kind of a mechanism is not actually there in Kerala. So our panchayati Raj system, that is the decentralized planning is very strong. So this decent asset, part of decentralized planning, this local self governments can provide this protective equipments but it is not given importance.

Do is there a specific framework that has been developed to address laptop experiences after flood?

No, I don't think so. Kerala, the real problem with our system is we are good at firefighting, but we won't have any protective, very, very strategic planning. So I don't think they'll be something has very specifically developed to prevent leptospirosis outbreak in future.

Could you summarize some of the actors that were involved in 2018 and then mention the new ones that you think should be included?

OK, I will consider this as two stages: during the time of flood, and after flood. In the time of flood there will be so many volunteerisms because in Kerala there are recurrent floods are there. We have got the experience of this fighting against infectious diseases like Nipah, so there is community volunteerism is in time of flood. People from the coastal area, the fisherman where acting as volunteers and they are moving to the high ranges to save people because they have got an experience to fight against the partner. The local self-government mechanism was very much acting and locally. They were taking leadership and the government of Kerala was taking the leadership role, especially our Chief Minister and State Disaster Management authority, but mainly the people were taking action at that point of time. But soon after the flood, these people disappeared because the flood issue is managed itself. But at the that point of time, the public health emergencies were raising, and only the Department of Health and the local self-government. These are the two agents that is acting at the time of the public health issues, so local PHC's that is Primary Health centers were pivotal in managing the leptospirosis cases after flood.

Which stakeholder would you recommend being included? A lot of persons mentioned people who are into animal science, animal husbandry, veterinary were not as included. Do you think this this would be useful additions to the management team?

Definitely because one of the major lacunae, as you have mentioned is leptospirosis after flood is considered as an issue of health. That is, the public health only human health. But as if you look at the specificity or peculiarities of this particular problem, it is highly linked to animals. For example, what the Kerala we have got very large number of stray dogs. What is the role of this trade docs in transmitting leptospirosis? Nobody knows! What is the role of catalyst? Nobody knows. People think it is only rodents or rats that are spreading leptospirosis and we do not have any evidence for that. It may be a major reservoir for this disease, but there could be more reservoirs. Therefore, including all these sectors are very important to manage the leptospirosis and many other diseases are there in Kerala very much linked to the animals.

For example, Nipah that we have already experienced, and we have got Kyasanur forest disease and dengue. We have got so many other diseases which has got very much linked to animal population and their environment. Now Kerala is moving for a one health approach. That means you have to consider infectious diseases.

You have to take care of infectious diseases by multi sectorial approach from animals. Maybe from animal husbandry, this agriculture and so many other developmental sectors are very important, I think.