Extreme hydrological events and their impacts on children's respiratory health in the Legal Amazon

Submitted by

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to the University of Exeter as a thesis for the degree of Doctor of Philosophy in
Geography, April 2014.

I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

Signature: ………………………………

Lauren Smith

Abstract

The majority of climate-health impacts are the result of extreme climatic events. In the Amazon region, hydrological extremes have become more frequent in recent years. Evidence exists about how these hydrological extremes affect the forest itself, yet little information is available on the impacts on human health. Hospitalisations for respiratory diseases are the leading cause of hospitalisations, excluding pregnancy related causes, for both Brazil, and the Brazilian Amazon. It has been shown elsewhere that during drought events and periods of intense fires there are statistically significant associations with respiratory health. Despite the increase in hydrological extremes and high rates of deforestation and fires observed annually in the Legal Amazon, there are limited studies linking such events and respiratory health.

The lack of explicit spatial understanding about these connections restrains the ability of policymakers to plan and implement regional mitigation and adaptation policies in order to cope with predicted effects of climate change in the Amazon, one of Brazil's poorest regions. Thus, this thesis explores the impacts of three large hydrological extremes: the 2005, and 2010 droughts and the 2009 flood, on children's respiratory health in the Legal Amazon. The research is two-fold; firstly to establish how the extremes and associated human disturbance impact respiratory health in the region. A Geographically Weighted Poisson Regression is adopted which allows for local spatial data analysis to identify any relationships between selected variables and children's respiratory health throughout the Legal Amazon. The second part explores local communities' knowledge of respiratory health and the links to the environment which has assisted in creating recommendations to cope with respiratory health and environmental problems in the Legal Amazon.

Acknowledgements

First and foremost I would like to thank my parents, Michael and Pauline, for their continual support throughout this PhD. Not only have they supported me during the duration of the PhD, but they have always encouraged me to do what will make me happy. When I told them I wanted to go back into education to complete a PhD they completely supported my decision and have always been there to offer emotional and financial support. A special thank you to my mum who was a 'rock' to our family through a difficult period; she got me through it yet continued her support and provided proof reading services for me even when more important events were happening. Also to my dad, who even during his worst months of being unwell never stopped pestering me to work hard - I think he saw through my offers to play 'Connect Four' and do exercises as an excuse to put off writing!

I was fortunate to have two excellent supervisors; Professor. Clive Sabel and Dr. Luiz Aragão, who were always patient in their support and advice. I would like to thank Clive for always being available to offer advice and encouraging me, but also for reminding me when research decisions required autonomy. This has helped me develop as a researcher over the years; becoming more independent and having more confidence in my research. Luiz has given continuous advice, encouragement and enthusiasm on the topic, as well as providing me with opportunities to be involved other projects which have helped with the advancement of my work. Despite the three of us rarely being in the same location during the past year, both Clive and Luiz have made time for me, whether it is over email, phone, or Skype, so thank you both. I would also like to thank Tomoki Nakaya, who provided invaluable advice and help with the Geographically Weighted Poisson Regression methodology.

The value of networking becomes very apparent when fieldwork was carried out. Without the help of researchers at FIOCRUZ, Brazil, my fieldwork in Brazil would have been almost impossible. For this, I wish to thank Sandra Hacon who facilitated fieldwork and offered invaluable advice about the region and general information about healthcare in Brazil which I would not have known from literature alone. Four of Sandra's students helped with translation of surveys, teaching me key words and phrases I may hear while collecting survey data, providing accommodation, and generally making my time in Brazil a fun experience, despite occasionally laughing at me for being pink rather than tanned! So thank you Karen, Poli, Gaby, and Dennys. I would also like to thank Jana and Nubia for assisting in carrying out the survey's in Porto Velho, and the participants of this research.

I would like to thank the Economic and Social Research Council, and the Natural Environment Research Council for funding this research through studentship grant ES/I026967/1. Also fellow PhD students and staff in the Geography department at Exeter University for supporting me through the duration of the PhD.

Finally, without great friends and my brothers these last three years could have felt like an eternity. They have had to put up with moments of stress and very little communication but have always understood. They have also provided fun times for when I have needed a break, I will always be grateful to some of the excellent weekends we have shared that continue to make me laugh now. So thank you to my brothers, Elliot and Fraser. Also to the girls: Lianne, Ilona, Amy, Steph, and Rachel.

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Author Declaration

Some of the work in this thesis has been published previously. Parts of the text in the 'Geographically Weighted Poisson Regression' section in chapter four has been used, and part of chapter five forms Figure 1 and some of the supplementary data in the published paper. Finally, chapter 6 is based on the published article but has been developed to include micro-regions and the 2009 flood event in the analysis.

The article is:

Smith, L. T, Aragão, L. E.O.C, Sabel, C. E, Nakaya, T. Drought impacts on children's respiratory health in the Brazilian Amazon. *Scientific Reports*. 2014. 4. doi:10.1038/srep03726.

Acronyms & Abbreviations

Acronym	**Definition**
AH%	Percentage of annual hours
AMO	Atlantic Multidecadal Oscillisation
AOD	Aerosol Optical Depth
ASR	Age Standardised Rate
COPD	Chronic Obstructive Pulmonary Disease
GIS	Geographical Information Systems
GWPR	Geographically Weighted Poisson Regression
GWR	Geographically Weighted Regression
HDI	Human Development Index
IBGE	Brazilian Institute for Geography and Statistics (Instituto Brasileiro de Geografia e Estatística)
INPE	National Institute For Space Research (Instituto Nacional de Pesquisas Espaciais)
IPCC	Intergovernmental Panel on Climate Change
ISAAC	International Study of Asthma and Allergies in Childhood
KAP	Knowledge, attitude, and practice
OLS	Ordinary Least Square
PDE	Percentage of Deviance Explained
SST	Sea Surface Temperatures

SUS	Unified Health System (Sistema Único de Saúde)
TRMM	Tropical Rainfall Measuring Mission
WHO	World Health Organisation

Chapter 1

Introduction

1.1 Rationale for research

It is generally acknowledged that our climate is changing (IPCC, 2013) and these changes have the potential to affect human health (Confalonieri, 2007) in various ways. Extremes in rainfall and temperature are directly and indirectly linked, causing a variety of health impacts: immediate physical injury, morbidity, mortality, and long- term mental health problems. They can alter the distribution of vector-borne diseases, cause malnutrition, create dust storms, create heatwaves, and affect the start and duration of the pollen season. Despite some of the consequences resulting in positive changes such as milder winters in temperate countries, the majority of health impacts from climate change are likely to be negative (McMichael et al., 2003). The direct impacts of extreme events such as droughts, floods, and landslides are likely to have the greatest effects on climate-health relations; however, health will also be influenced by indirect impacts such as poor air and water quality, a lack of services, and disruption of agricultural practices, for instance (Confalonieri, 2007). Moreover, extreme events may result in population displacement which can cause increases in communicable diseases and poor nutritional status (Haines et al., 2006). In almost every country today, governments aim to protect their citizens as well as ensure that the population has access to basic healthcare (Assan et al., 2009). Yet with limited understanding of the interaction between health and the changing environment, health care systems could face difficulties due to being ill prepared. The effects of climate on health will vary depending on the level of socio-economic development and the effectiveness of adaptive measures (Haines et al., 2006). If it is anticipated that extreme events are to become more frequent or more intense in the future, measures must be in place to cope with them, whether these are anticipatory measures or reactive measures (Adger, 2003).

The fourth Intergovernmental Panel on Climate Change (IPCC 2007) report states that the global mean surface temperature increased by 0.74°C ± 0.18°C between 1906 and 2005 (Trenberth, 2007). More recently, the summary for policy makers of the forthcoming IPCC fifth report states that average land and ocean temperatures showed a 0.85^{o}C (0.65 to 1.06) increase over the period 1880 – 2012 (IPCC, 2013). Based on the Special Report on Emission Scenarios (SRES), temperatures are projected to rise by between 1.8°C and 4.0°C, by the end of this century relative to a 1980 – 1999 baseline, depending on the scenario (Meehl, 2007).

One region of the world with global importance is the Amazon because not only is it vital for ecological reasons but it is also a driver of regional climate change and central to the global carbon cycle (Christensen, 2007). The impacts that climate change could have on the physical system of the Amazon are of regional, national and global concern because not only does the Amazon regulate weather patterns in Brazil but it affects atmospheric circulation in South America and around the globe (Marengo et al. 2011). In addition to these changes, the frequency and intensity of extreme events are anticipated to change and some types of extreme events have already been experienced (Christensen, 2007). Globally, approximately two billion people were affected by natural disasters in recent years, with 86% of them being affected by drought and floods (WHO, 2005), such as the heat wave of 2003 in Europe, the 2004 earthquake in South Asia, the flooding in Mumbai in 2005 and the Japanese tsunami of 2011.

Increases in hydrological extremes (droughts and floods) have also been observed in the Amazon region itself; on average, the Amazon experiences an extreme flood or drought once every ten years (Marengo et al., 2011). In recent years, however, the Amazon has experienced two droughts (2005, 2010) and three floods (2009, 2011, and 2012) (Marengo et al., 2013). Three of these events are conspicuous due to their magnitude and extent, with the 2005 and 2010 drought events being considered one-in-one-hundred-year events (Marengo et al., 2011) and the 2009 flood resulting in the second highest river levels observed since measurements began (Marengo et al., 2013). The above average rate of these events reinforces work by who Cox et al. (2008) shows that hydrological extremes may become more frequent and intense under future climate change.

Owen et al. (2005) suggest that traditional hunter-gatherer methods used by populations in forested regions in the past led them to become vulnerable to infections due to poorly cooked meat. Despite this method no longer being used in the present day, populations within forest regions remain vulnerable to infections (Butler, 2008). Thus, land use change and climate variability could be an explanation for the continued infections seen within forest regions. In the past decade, widely cited papers have drawn the comparisons between ecosystem change and human health (Patz et al., 2005; McMichael et al., 2006; Haines et al., 2006; McMichael et al., 2003; Assessment, 2005). There is evidence that both drought and deforestation can contribute to vector-transmitted epidemics, such as malaria (Gagnon et al., 2002), and poor air quality associated with forest fires can be harmful to the respiratory health of a population (Mott et al., 2005).

The Amazon, which contributes to around 40% of the total tropical forest area, is the largest rainforest in the world, with the majority located in Brazil. The Brazilian Amazon is referred to as the Legal Amazon, which is a federal planning designation that is more or less the watershed of the Amazon River within the Brazilian national border. This region, the Legal Amazon, is the focus of this thesis, which investigates the impacts of hydrological extremes on children's respiratory health. This region has been selected because of the observed increase in hydrological extremes and the combination of overexploitation, deforestation, previous environmental degradation, and the complex interplay of local and global climate variability changes, varying development levels and population structures (Paim et al., 2011). Moreover, existing threats within the region such as land use change, forest fragmentation and fire intensify the risk of climate variability and change (Marengo, 2011a). Haines et al. (2006) suggest that climate change does not happen in isolation; rather, population changes and other environmental factors also happen. The Legal Amazon incorporates these various factors.

A rich source of data available for the region provides a unique opportunity to quantify the relationships between environmental changes and human health. These datasets include satellite-derived rainfall measurements from the Tropical Rainfall Measuring Mission (TRMM) satellite (NASA, 2010), active fires and aerosol measurements from the Terra/MODIS satellite (INPE, 2012c) (NASA, 2011a), and deforestation rates (INPE, 2012a) from the National Institute for Space Research (INPE) database. In addition, geo-spatial information about socio-economic indices from the Brazilian Institute for Geography and Statistics (Instituto Brasileiro de Geografia e Estatística, IBGE) and the Firjan System, and hospitalisations from the Brazilian Health System (SUS) are freely available. National policy indicates that research on the impacts of climate change and human health is of importance. Two key commitments in the Brazilian National Climate Change Policy that reinforce this are:

- incentivising studies, research and training related to expanding knowledge about the impacts of climate change on human health
- strengthening communication and environmental education measures (Brazil, 2007).

There are numerous studies examining the impacts of climate change on the physical system of the Amazon, and studies assessing the impact of droughts (Cochrane et al., 1999; Marengo, 2004; Aragão et al., 2008; Malhi et al., 2008;

Cochrane and Barber, 2009). Cochrane et al. (1999) and Laurance and Williamson (2001) have shown that drought conditions increase the vulnerability of forests to fires due to water stress, leaf litter and leaf drying. A more recent study by Aragão and Shimabukuro (2010a) shows that forest flammability increases in drought conditions even when deforestation rates are declining within the Amazon. Studies regarding the forest itself are less conclusive in findings of drought and forest interactions; for example, there are reports of the forest greening-up as a result of the 2005 drought (Saleska et al., 2007). Samanta et al. (2010), however, suggest that there is no evidence of forest greening-up.

The impacts of hydrological extremes are not only an environmental issue, but also a health issue. Drought events cause a wide range of effects on health, including poor nutrition, infectious diseases, and respiratory health problems (Menne and Bertollini, 2000). Moreover, increases in forest fires can have negative impacts on human health, particularly respiratory diseases. This has been shown in studies carried out in Southeast Asia (Mott et al., 2005), Australia (Chen et al., 2006), America (Mott et al., 2002), and the Legal Amazon (Ignotti et al., 2010b). In contrast, flood events tend to cause immediate injury or mortality: they can reduce the availability of fresh water (Confalonieri, 2007), mobilise chemicals in soil, resulting in polluted water (Haines et al., 2006), or result in increases in diarrhoea and respiratory diseases (Siddique et al., 1991).

These associations found between hydrological extremes and associated conditions such as fires with respiratory diseases, and the lack of current research on the topic in the Legal Amazon led to the evolution of this present thesis – an examination of the impacts of the Legal Amazon droughts of 2005 and 2010 and the flood of 2009 on health in the context of respiratory tract diseases in children under five. Despite evidence from around the world which finds associations between hydrological extremes, fires, and respiratory diseases, there is currently no research on the impact that hydrological extremes have on the respiratory health of the Legal Amazon population as a whole. Thus far, studies on health in the Legal Amazon, e.g. mercury exposure (Hacon, 1995; Hacon et al., 1997; Passos and Mergler, 2008), vector-borne diseases (Rosa-Freitas et al., 2003; Olson et al., 2010; Olson et al., 2009), anaemia and iron deficiencies (Cardoso et al., 1994; Muniz et al., 2007), and respiratory diseases (Rosa et al., 2009; Silva et al., 2009; Carmo et al., 2013; Mascarenhas et al., 2008; Ignotti et al., 2010b), have not been examined in relation to hydrological extremes in the region.

In Brazil, respiratory diseases were the primary cause of hospitalisation, excluding pregnancy-related hospitalisations, from 2001 to 2010 (DATASUS, 2011b). The same is true for the Legal Amazon. During the ten-year study period of this research (2001 – 2010), more than two million hospitalisations for respiratory diseases were recorded in the Legal Amazon, 43% which were for children under five (DATASUS, 2011a). This concurs with literature showing that children under five are one of the groups most vulnerable to these diseases (WHO, 2005). The World Health Organisation (WHO) recognises respiratory diseases as a health threat from climate and environmental change.

1.2. Strategy

Research on health impacts of climate change have tended to address three main topics: current associations, effects of recent change, and the evidence base for projecting future impacts (Haines et al., 2006). Rahman and Bennish (1993) suggest that establishing baseline information on disaster-prone areas may be of particular importance, particularly for common infections such as diarrhoeal diseases and upper respiratory tract infections. Based on the main topics addressed in climate-health research, this thesis aims to create a baseline of conditions, to identify effects of recent hydrological extremes and to create suitable measures to deal with future change. Figure 1.1 illustrates the research stages suggested by Haines et al. (2006) which are adapted to this specific research in order to address the aim of establishing baseline conditions.

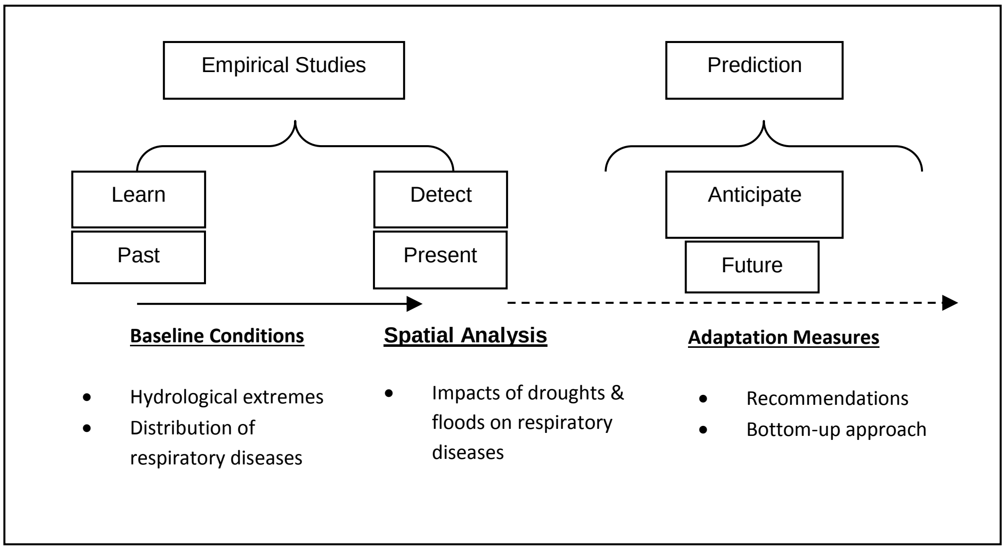


Figure 1.1| Research stages of climate and health in the context of this research. Adapted from Haines et al. (2000).

Given the evidence that the climate is changing, and the Legal Amazon is likely to experience environmental, climatic, developmental, and population change, the health impacts of hydrological extremes are of concern. Despite this, there are limited studies linking human health, climate variability and environmental change within the region. Therefore, understanding the impacts of hydrological extremes on respiratory diseases, which are the leading cause of hospitalisations (excluding pregnancy-related causes), is a significant research area which demands investigation. There is a need to quantify the extent to which hydrological extremes impact on respiratory diseases of children under five in the Legal Amazon population. In this regard this study has three general objectives:

1. to establish a baseline of the respiratory health hospitalisations and environmental events over the period 2001 to 2010
2. to determine the impact hydrological extremes have during their peak months on respiratory health in the Legal Amazon
3. to assess knowledge and understanding of local population in relation to respiratory diseases and their association with such events to assist with creating suitable strategies to deal with the impacts.

A large part of this research is quantitative, but primary data collection has also been included. Due to the vast region of the Legal Amazon, localised spatial analysis techniques will be used to assess distributions and associations. The use of remotely sensed data allows analysts to monitor environmental and climatic conditions which may affect the health of the population. Incorporating health data and remote sensing information into Geographic Information Systems (GIS) provides a tool for exploring connections between people, health and the environment in which they live (Barcellos and Bastos, 1996). Including primary data collection in the format of surveys will provide insight into the knowledge local populations have about respiratory diseases. Moreover, the use of surveys will help to construct suitable measures that the population can understand in order to combat demand on health services and create appropriate policies.

1.3 Research Questions

This research provides a unique opportunity to quantify the sensitivity of children's respiratory health to environmental changes induced by recent drought and flood events in the Legal Amazon. This was carried out by answering four research questions:

1. Where within the basin have the three hydrological extremes and associated human disturbances occurred?
2. What was the spatial and temporal distribution of respiratory diseases within the basin between 2001 and 2010 in children under five?
3. To what extent do strong correlations between hydrological extreme periods and respiratory diseases exist?
4. What does primary data collection tell us about people's knowledge of respiratory diseases and their link to hydrological extremes?

1.4 Thesis Outline

This chapter has provided a broad overview of the issue this research aims to address. Chapter 2 will provide details of the study region. It will describe countrywide policies that are currently in place to deal with the environmental issues discussed in this research, and offer detail on the healthcare system. A more thorough review of literature on past hydrological extremes, climatic predictions, the link between climate and health, respiratory diseases, and adapting to change is covered in chapter 3. Chapter 4 will explore the datasets specific to the hydrological extremes and respiratory diseases in the Legal Amazon, and introduce the methods employed. Three further chapters are results based; chapters 5 and 6 have been written as stand-alone chapters. A baseline of the current spatial and temporal distribution of climatic anomalies and respiratory disease is shown in chapter 5. Chapter 6 identifies relationships between hydrological extremes and respiratory diseases, through the use of Geographically Weighted Poisson Regression models. This chapter develops our recently published article, Smith et al. (2014), by including the 2009 flood and analysis at the micro-region level. Knowledge regarding respiratory diseases and environmental/social links are discussed of local populations are discussed in chapter 7. The final chapter provides a summary of the main findings and recommends possible further research.

Chapter 2

Setting the scene: The Legal Amazon

2.1 Introduction

This chapter aims to define the study region and provide some background to the environmental policy context in Brazil. Environmental policies relevant to the topics in this research are discussed, followed by a description of the healthcare system. A review of the literature in the climate change and climate-health context is provided in chapter 3.

2.2 Study Area Profile

2.2.1 Country and Legal Amazon

Located in South America, Brazil is the largest country of the continent and is the fifth largest country in the world, comprising 8,514,877 sq km, 0.65% of which is water, and spanning from 5° 16’20” N to 33° 44’32” S, and 34° 47’30” E to 73° 59’32” W (IBGE, 2010). Brazil is also the fifth most populous country in the world with approximately 190 million inhabitants, with a population density averaging 22 inhabitants per km^2, varying from 444,070 inhabitants/km^2 in the Federal District to 2.01 inhabitants/km^2 in Roraima (IBGE, 2010). As Brazil emerges as one of the largest economies in the world, internal differences mean that only some regions of the country are experiencing this growth. Improvements in the country as a whole have been seen over a period of time; for example, infant mortality rates have decreased from 123.55 (1970) to 15 (2010) per 1000 live births, and life expectancy has increased from 52.3 years in 1970 to 73.48 years in 2010. The rate of poverty has also decreased from 67.9% to 30.7%. Household living standards have generally improved as well, with 98% of households now being provided with access to clean water compared with 32.8% forty years ago. Provision of sewerage has increased to 59.5% from 17.46% (IBGE, 2010). Despite these overall improvements, striking regional differences exist in relation to areas such as differing demographic, economic, social, cultural, and health conditions.

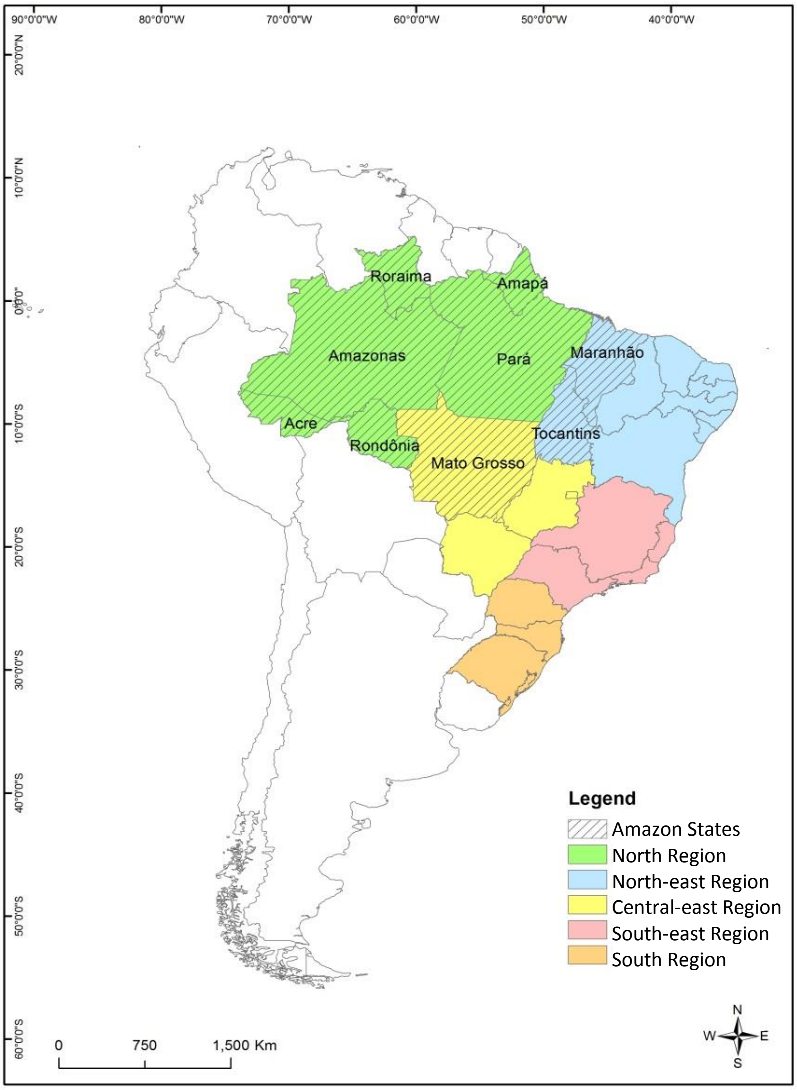


Figure 2.1| Geographical Regions of Brazil and the Legal Amazon Boundary

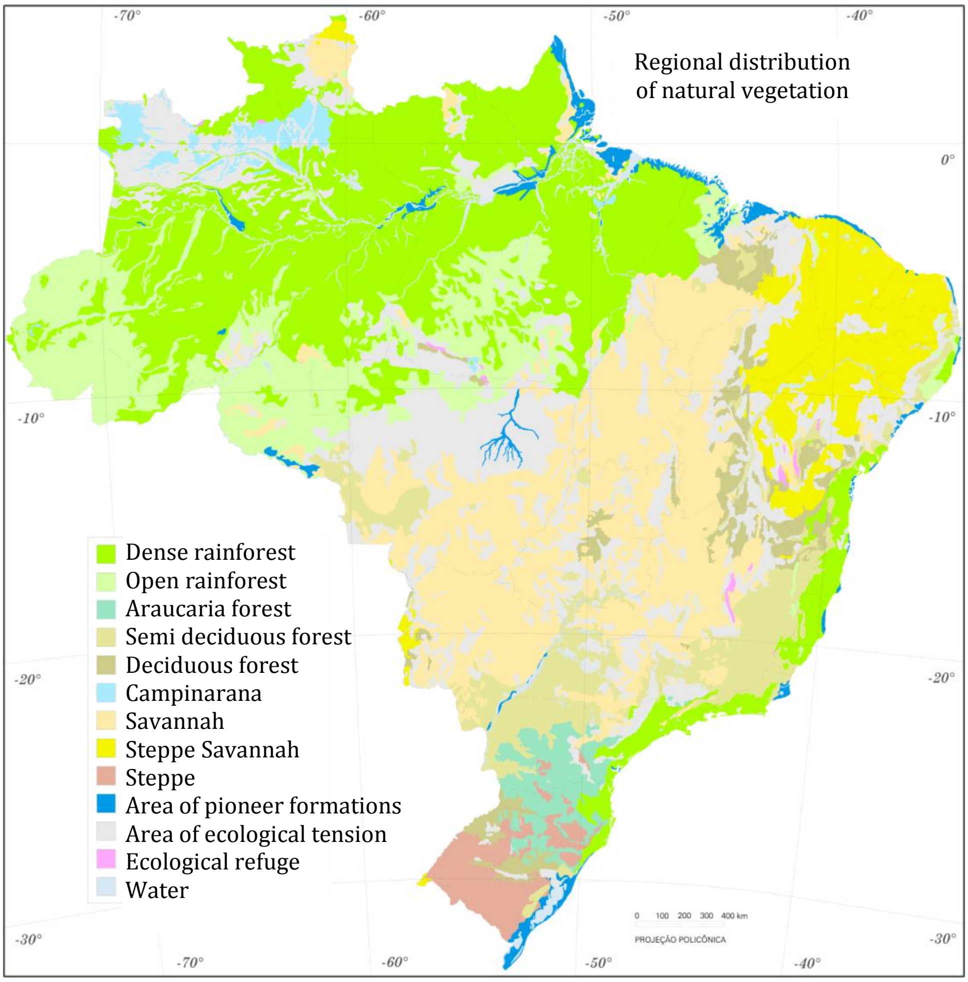
The country is divided into 5,564 municipalities in 27 states within five geographical regions: the north, northeast, centre-west, southeast and south (Figure 2.1), with the largest differences being observed between the rich regions in the south and southeast and the poor north and northeast regions (Hoffmann, 2000). The poorer north region encompasses the Legal Amazon which is the study region for this thesis.

The Amazon River drainage basin is approximately 6.5 million km^2 expanding across Brazil, Colombia, Ecuador, Peru, Bolivia, Guiana and Venezuela, with the majority (~ 3.8 million km^2) located in Brazil (Wood, 1998). There are various definitions for the geographical boundary of the Amazon. This research uses the political boundary defined as the Legal Amazon. This is a federal planning designation which is more or less the watershed of the Amazon River within the Brazilian national boundary. It consists of the North Region of Brazil; Acre, Amapá, Amazonas, Pará, Rondônia, and Roraima, Tocantins plus the states of Mato Grosso (Centre-west region), and Maranhão (Northeast region) west of the 44th meridian (Wood, 1998) (Figure 2.1). The nine States of the Legal Amazon which will include the whole State of Maranhão is used in this research. These States comprise 807 municipalities in 107 micro-regions. According to the 2010 census, there are approximately 25 million people living in the Legal Amazon (IBGE, 2010) with, on average, a population density of 6 persons per km^2, varying from 19.81 in Maranhão to 2.01 in Roraima (IBGE, 2010). In addition to social diversity within Brazil and the Legal Amazon, environmental differences are present; the Equator runs through the northern part of the Legal Amazon, creating opposite seasons and various vegetation types.

2.2.2 Land cover

Although the Legal Amazon predominantly comprises rainforest, various other vegetation types exist. Nine other vegetation types make up the Legal Amazon: open rainforest, savannah, deciduous forest, semi-deciduous forest, campinarana, and steppe savannah, pioneer formations (which are unique and specialised because of the rigorous growth conditions they face), ecological tension zones (which are transitional zones between two types of vegetation), and ecological refuge zones (Figure 2.2) (IBGE, 2012). The three dominant vegetation types are dense rainforest, open rainforest, and savannah. Dense rainforest is chiefly observed in central and northern States, whereas open rainforest is observed in the south-west areas. Savannah vegetation is located around the eastern and southern peripheries of the Legal Amazon in southern Maranhão, Tocantins and southern Mato Grosso. Smaller areas of savannah are also noted in the northern States of Roraima and Amapá.

Knowing the differences in land-cover across the study area helps to understand which locations are more vulnerable to rainfall deficiencies because locations with rainforest vegetation experience more rainfall than locations in the savannah regions. Therefore, any differences in the amount of rainfall across the area will have dissimilar impacts. Moreover, forest fire spread can be affected by the vegetation type: drier fuel such as savannah can ignite and fire spread more easily than a wet rainforest. Since the chemical compound of smoke released from biomass burning differs depending on the vegetation type (Farhat, 2005), knowing what type of vegetation is being burnt may help further understand the impacts that biomass smoke has on respiratory diseases.



Source: IGBE, 2004: ftp://geoftp.ibge.gov.br/mapas_tematicos/mapas_murais/vegetacao.pdf (edited text to English).

Figure 2.2| Regional distribution of natural vegetation

2.3 Brazilian Policies

2.3.1 Deforestation

Deforestation rates in Brazil have been high in the past because of government initiatives which encouraged the movement of people to the Legal Amazon. There were also incentives for those carrying out agricultural practices (Binswanger, 1991; Kirby et al., 2006). However, there have been significant improvements in monitoring deforestation in Brazil since 2004 because of the National Institute For Space Research's (Instituto Nacional de Pesquisas Espaciais, INPE) Real-Time

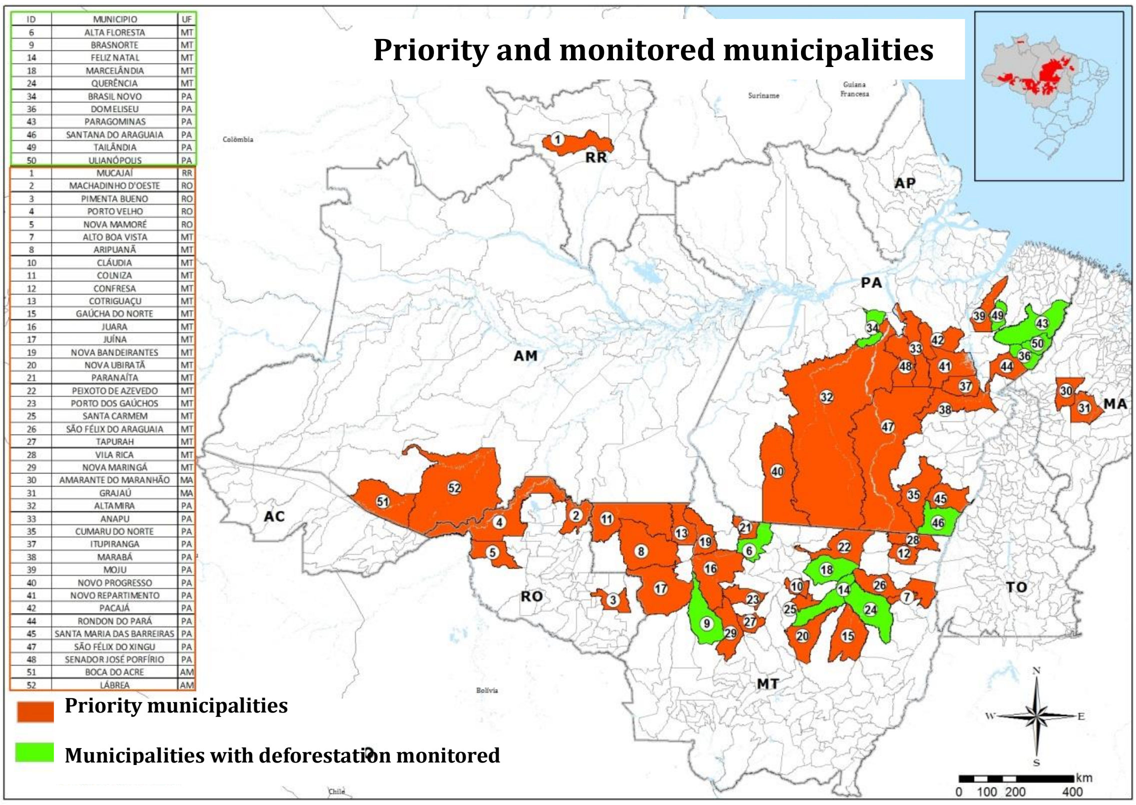
System for Detection of Deforestation (Sistema de Detecção de Desmatamento em Tempo Real, DETER) (INPE, 2010)

In order to combat illegal deforestation in the Legal Amazon, in 2004 the Federal Government implemented the 'Action Plan for Prevention and Control of Deforestation in the Amazon' (Plano de Ação para a Prevenção and Controle do Desmatamento na Amazônia Legal - PPCDAm) which is considered to be the first turning point for reducing deforestation in the Legal Amazon (MMA, 2013b). PPCDAm consists of more than 200 initiatives across 14 ministries which are focused on three main aims:

1. territorial management and land use, with particular attention to be given to land tenure disputes
2. command and control, as a means of improving monitoring, licensing and enforcement
3. promotion of sustainable practices, including a revision of economic incentives for sustainable agriculture and forest management, better use of already cleared lands, and development of sustainable transportation and energy infrastructure (May et al., 2011).

According to Assunção et al. (2012), the 'command-and-control' policy, which identifies and punishes those responsible for illegal deforestation and forest degradation, preserved over 59,500 km^2 of forest between 2007 and 2011. Hargrave and Kis-Katos (2013) also found that policies implemented through the PPCDAm project have been successful in curbing deforestation, with 'command-and-control' having the most impact. As a consequence of the success of the 'command-and-control', protected areas were created; from 2004 to 2009, 180,000 km^2 of land in the Legal Amazon were classified as protected. Moreover, significant progress was made in the official recognition of indigenous lands (May et al., 2011).

A second turning point, three years later, was the signing of the Presidential Decree 6.321 in 2007. Unlike PPCDAm, which is a conservation programme, the Presidential Decree 6.321/2007 established a legal basis for singling out municipalities with high rates of deforestation, and taking action against them (MMA, 2013b). In 2008, the Ministry of Environment (Ministério do Meio Ambiente, MMA) listed 36 municipalities which were responsible for more than 55% of deforestation in the Legal Amazon; these municipalities were classified as being in need of priority action to prevent, monitor, and combat illegal deforestation. This number has increased to 41 priority municipalities (Figure 2.3) (MMA, 2013a). Although the deforestation policies have helped in reducing deforestation rates in the Legal Amazon, it has also been suggested that in earlier years, changes in agricultural prices also affected deforestation rates (Hargrave and Kis-Katos, 2013).



ID	MUNICIPIO	UF
6	ALTA FLORESTA	MT
9	BRASNORTE	MT
14	FELIZ NATAL	MT
18	MARCELÂNDIA	MT
24	QUERÊNCIA	MT
34	BRASIL NOVO	PA
36	DOM ELISEU	PA
43	PARAGOMINAS	PA
46	SANTANA DO ARAGUAIA	PA
49	TAILÂNDIA	PA
50	ULIANÓPOLIS	PA
1	MUCAJAÍ	RR
2	MACHADINHO D'OESTE	RO
3	PIMENTA BUENO	RO
4	PORTO VELHO	RO
5	NOVA MAMORÉ	RO
7	ALTO BOA VISTA	MT
8	ARIPUANÃ	MT
10	CLÁUDIA	MT
11	COLNIZA	MT
12	CONFRESA	MT
13	COTRIGUAÇU	MT
15	GAÚCHA DO NORTE	MT
16	JUARA	MT
17	JUÍNA	MT
19	NOVA BANDEIRANTES	MT
20	NOVA UBIRATÃ	MT
21	PARANAÍTA	MT
22	PEIXOTO DE AZEVEDO	MT
23	PORTO DOS GAÚCHOS	MT
25	SANTA CARMEM	MT
26	SÃO FÉLIX DO ARAGUAIA	MT
27	TAPURAH	MT
28	VILA RICA	MT
29	NOVA MARINGÁ	MT
30	AMARANTE DO MARANHÃO	MA
31	GRAJAÚ	MA
32	ALTAMIRA	PA
33	ANAPU	PA
35	CUMARU DO NORTE	PA
37	ITUPIRANGA	PA
38	MARABÁ	PA
39	MOJU	PA
40	NOVO PROGRESSO	PA
41	NOVO REPARTIMENTO	PA
42	PACAJÁ	PA
44	RONDON DO PARÁ	PA
45	SANTA MARIA DAS BARREIRAS	PA
47	SÃO FÉLIX DO XINGU	PA
48	SENADOR JOSÉ PORFÍRIO	PA
51	BOCA DO ACRE	AM
52	LÁBREA	AM

Source: Ministério do Meio Ambiente (2013) (MMA, 2013a) (edited text to English)

Figure 2.3| Priority and monitored municipalities for high deforestation rates

The consequent reduction in deforestation rates followed these laws but in 2012, Brazil's Forest Law was weakened and it was feared that the change in the Forest Law could reverse the progress already made, making the objectives regarding deforestation in the Brazilian National Climate Change Plan difficult to meet. Landowners were previously required to maintain forest on 80% of their land (excluding hilltop areas) (Fearnside, 2009) and those who cleared it before July 2008 received amnesty from fines, although they are required to replant to the 80% level. Now, however, small land owners may be exempt from this level, and State governments can adjust the 80% rule (Rousseff, 2012). The Forest Law is considered to be one of the most impressive forest laws in the world and has contributed to declining deforestation rates (WWF, 2013). It was established in 1965 and meant that private properties had to preserve forests. Over the years, the Forest Law has undergone various changes designed to increase protection; however, enforcement and compliance have tended to be low (WWF, 2013). Since 2005, however, governance became more rigid, which may have been due to the creation of PPCDAm in 2004. Following a peak in deforestation in 2008, due to clear-cutting, new measures were put in place. The first of these related to credit being awarded to farmers which could only be accessed if they were in compliance with the law set out in the Presidential Decree (Rousseff, 2012). Secondly, farmers had to geo-reference the forest remnants on their properties so they were more 'visible' in order for the Law to be enforced (WWF, 2013). Recently released data has shown that deforestation rates have increased from 2012 to 2013 by 28% since the Forest Law changed, but these rates are still 79% below 2004 rates (INPE, 2012a).

2.3.2 Forest Fire/Air Pollution

In the late 1980s, it became publicly known that there were more than 250,000 active fires, burning more than 200,000 km^2 in the Amazon (IBAMA, 2013a). This led to the government creating the Commission for the Prevention and Combat of Forest Fires (CONACIF) in 1988 under the Brazilian Institute for Forestry Development (IBAMA, 2013a). This was the first action taken by the Federal Government relating to fire management, control, prevention and fighting fires especially in the Federal Conservation Units. Ten years later, Decree No. 97635 was passed, creating the ‘National Centre for the Prevention and Combat of Forest Fires’ (Centro Nacional de Prevenção e Combate aos Incêndios Florestais, Prevfogo) which successfully achieved its aim of promoting, supporting, coordinating and implementing educational activities, research, monitoring, control of fire prevention, and forest firefighting nationwide (IBAMA, 2013a). Due to the magnitude of problems caused by forest fires, a bylaw was passed in May 2002 that clearly defined the role of Prevfogo. Currently, Prevfogo’s mission is to promote, support, coordinate and execute activities of education, research, monitoring, control burning, and prevent and fight forest fires in Brazil, while assessing their effects on ecosystems, human health and the atmosphere (IBAMA, 2013a).

In 1999, the programme ‘Amazon without Fire’ was established, which has the ambition of delivering initiatives and control for fires in the Amazon. The programme aims to reduce forest fires through various measures for prevention and environmental education (IBAMA, 2013b). In addition to this, the programme aims to raise awareness of rural communities of fire risks and to train personnel to manage, control and combat fires to strengthen localised prevention of, and responses to, fires. Moreover, it tries to promote alternative agricultural practices rather than using fire as a land-clearing method (IBAMA, 2013b).

The assessment of the effects of forest fires on ecosystems, human health and the atmosphere is Prevfogo’s mission (IBAMA, 2013b), but there are no specific standards for air pollution caused by forest fires within Brazil. Although Brazilian air pollution standards (Conselho Nacional de Meio Ambiente, CONAMA) were established for human health in urban areas, they do not have specific values for Particulate Matter $(PM)_{2.5}$ (Ignotti et al., 2010b), which has been shown to affect both morbidity and mortality (Dominici, 2004; Kappos et al., 2004). The particles of Particulate Matter are identified by their size; PM_{10} and $PM_{2.5}$, aerodynamic diameter smaller than 10 μm and aerodynamic diameter smaller than 2.5 μm, respectively (WHO, 2005). The World Health Organisation (WHO) have a guideline for $PM_{2.5}$ which is 25 $\mu g/m^3$ 24-hour mean as dangerous to human health;

however, this level is for short-term urban exposure and is only a guideline rather than a standard (WHO, 2005). $PM_{2.5}$ has been shown to be released from forest fires, among other air pollutants (Naeher et al., 2007). Within the Legal Amazon, air pollution levels vary, with higher concentrations occurring along the 'arc of deforestation'. This area accounts for 85% of fires in Brazil during the dry season (Becker, 2005), where it is thought that 60% of the Particulate Matter emissions from burning in the Amazon are $PM_{2.5}$ (Hacon, 1995). Levels of $PM_{2.5}$ concentrations have been recorded up to 400μg/m^3 of $PM_{2.5}$ per 24 hours at the most fire-intensive sites (Artaxo et al., 1994) . Although the WHO guideline for $PM_{2.5}$ is not accurate for biomass burning, it highlights the severity of the levels experienced in the Legal Amazon. The only reference to $PM_{2.5}$ that is specific for forest fire smoke is defined by the Oregon Department of Environmental Quality; 55μg/m^3 is considered unhealthy (35μg/m^3 for sensitive groups) and >250μg/m^3 is considered hazardous (Oregon Department of Environmental Quality, 2013). As with the WHO guidelines, this shows the extent of the severity of Particulate Matter loads in the Legal Amazon during the dry season.

2.3.3 Climate

Between 1990 and 2005, greenhouse gas emissions in Brazil increased by approximately 60%, with the majority of emissions being released from land use change (UNEP, 2013). As a developing country, Brazil's commitment to reducing emissions is voluntary, despite its being the fourth largest contributor to emissions in the world (Brazil, 2007). However, in 2007, the government made climate change a national priority and, together with the 17 federal bodies and ministries, the National Climate Change Plan was launched in December 2008 and approved through Law No. 12.187/2009 (MMA, 2013c). The National Climate Change Plan has seven objectives:

1. to stimulate efficiency increase in a constant search for better practices in the economic sectors

2. to keep the high share of renewable energy in the electric matrix, preserving the important position Brazil has always held in the international scenario
3. to encourage the sustainable increase in the share of biofuels in the national transport matrix and also work towards the structuring of an international market of sustainable biofuels
4. to seek sustained reduction in deforestation rates, in all Brazilian biomes, in order to reach zero illegal deforestation
5. to eliminate the net loss of forest coverage in Brazil by 2015
6. to strengthen inter-sector actions concerned with the education of the vulnerabilities of populations
7. to identify environmental impacts resulting from climate change and stimulate scientific research that can trace out a strategy that can minimise the socio-economic costs of the countries adaptation (Brazil, 2007).

Although important for national climate change, objectives 4, 5 and 7 are also of particular interest because they are closely linked with this research; deforestation is shown in this research and in other literature to have a positive relationship with forest fires, and thus with human health. Moreover, objective 7 is closely aligned to the primary aim of this research.

Within the National Climate Change Plan, key commitments are also set out. In common with its objectives, some of these are significant in the context of this thesis:

- Phasing out the use of fire for clearing and cutting of sugarcane in areas where harvesting mechanisation can take place;
- Reducing deforestation in the Amazon by 80% by 2020 – saving approximately 4.8 billion tons of carbon dioxide;

- Implementing the National Public Forests Register – identification of public forests to be protected, preserved and managed;
- Strengthening environmental enforcement;
- Doubling the area of reforestation from 5.5 million ha to 11 million ha in 2020, 2 million of which will be native species;
- Preventing illegal timber being used in the building industry;
- Making available specific resources to fund adaptation and fight desertification;
- Incentivising studies, research and training related to expanding knowledge about the impacts of climate change on human health;
- Strengthening communication and environmental education measures;
- Stimulating and expanding the technical capacity of professionals in the public health system (SUS) in relation to health and climate change (Brazil, 2007).

In addition to the National Climate Change Plan, two national funds have been created to help achieve these targets. The Amazon Fund was created in 2008 and in the following year the National Fund on Climate Change was created. The Amazon Fund, supported by national and international funding, was created to finance actions concerned with preventing deforestation, among other purposes, whereas the Climate Fund is funded internally through a special tax on oil production (Brazil, 2007).

The Amazon Fund was created specifically to fight deforestation in the Amazon and reduce greenhouse gas emissions, and its funding is managed by the Brazilian National Development Bank. A total of £112 million was approved for 36 projects across over 300 municipalities (Amazon Fund, 2012). The Amazon Fund funds various projects, from recovering degraded land and maintaining protected areas to strengthening institutions and structuring government agencies to deal with environmental management (Amazon Fund, 2012). One notable project, approved by the State firefighters, is the support to combat fires and unauthorised burn-off in Acre, Tocantins, Rondônia and Pará (Amazon Fund, 2012).

2.4 Linking hydrological extremes and environmental variables

In this study hydrological extremes are defined by rainfall, these are then linked to three other environmental variables; fires, deforestation, and aerosol. In the Legal Amazon and other tropical countries, deforestation and fires are used for land clearing. During drought periods the lack of rainfall means the region experiences drier conditions which can lead to the spread of fires particularly when there is leaf accumulation when trees begin to die/wilt due to a lack of water, which acts as a source of fuel. Fires in turn produce smoke which in the Amazon is known to contain high loads of PM2.5 which has been associated with respiratory health problems elsewhere. In contrast, during a flood it is more difficult for fires to ignite and spread so although deforestation will still occur doing a flood, the increase in rainfall prevents as many fires and hence less air pollution.

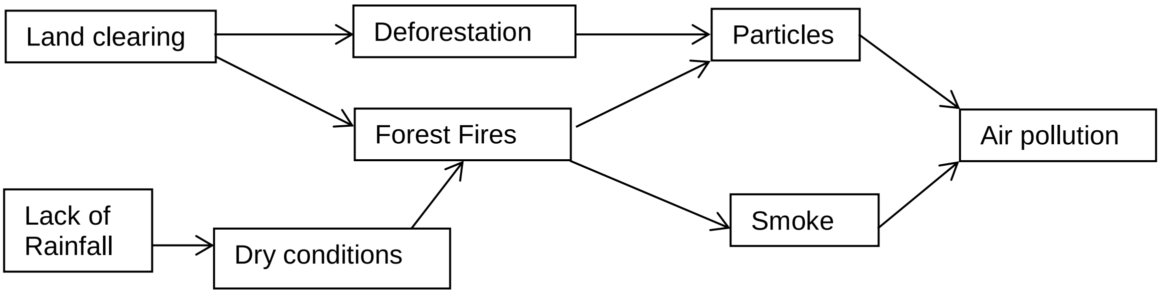


Figure 2. 4| Influence diagram showing the link between the environmental variables

2.5 The health care system

2.5.1 Introduction

The healthcare system in Brazil consists of public and private organisations which were set up in different historical periods (see The Lancet, Health in Brazil, series 2011 for more information (http://www.thelancet.com/series/health-in-brazil).

Today the health care system in Brazil has three subsectors: the public, the private and the private insurance. The public health sector system is known as the Unified Health System (Sistema Único de Saúde, SUS) and is financed and provided by the state at federal, state, and municipal levels, and includes military health services (Paim et al., 2011). SUS accounts for around 75% of healthcare for the Brazilian population, while the private sector covers the remaining 25% (WHO, 2010). The private health sector is funded through both public and private streams. The private insurance health sector provides different forms of health plans, differing insurance premiums and tax subsidies (Paim et al., 2011). The public and private health sectors are interconnected despite being distinct from one another, so people can use services in all sectors depending on ease of access and their ability to pay. Since the creation of SUS, healthcare in Brazil has improved overall and regional disparities have narrowed, although some do still exist. This becomes evident in a study by Oliveira (2009), who showed gender, race, income and regional differences when data was aggregated to these sub groups. Another example of regional disparity is that child mortality rates are twice as high in the north and north east regions compared to the south and southeast (Victora et al., 2011a). Despite overall advances, and the fact that Brazil is one of the ten largest economies in the world, it has a long way to go before it reaches levels of health similar to those in the world's most affluent nations (Victora et al., 2011b).

2.5.2 Unified Health System - SUS

SUS was created in 1988 and is a universal, publically funded, rights-based health system (Cornwall and Shankland; Paim et al.). Its principles are equity, public financing, decentralisation and an integrated health system (Collins et al., 2000). Through this remit, it was tasked with health promotion, health surveillance, health education, and ensuring continuity of care to all Brazilians at the primary, specialist outpatient, and hospital levels (Paim et al., 2011). It operates through a three-tier system: Federal (1), State (27), and Municipal (over 5,500) which have 'equal status rather than having a hierarchical order' (Atkinson et al., 2005). These permanent bodies are in charge of formulating health strategies, controlling implementation of policies, and analysing health plans and management reports submitted by their respective level of government (Victora et al., 2011b). At federal level, through the Ministry of Health, the role has mainly typical macro functions, such as national health policy, but a limited role in the direct provision of curative services (Collins et al., 2000). State level is funded through the State Health Fund which receives money from both Federal and State sources. It runs its own network of health services; however, decentralisation has tended to pass over state level and go directly to municipality level (Collins et al., 2000). Funds for municipality level are received from both federal and municipal contributors to make the Municipal Health Fund (Collins et al., 2000). The municipalities operate their own healthcare system activities and they are expected to allocate approximately 10% of their total municipal budget to health. However, as this anticipated allocation is not compulsory, there is no guarantee this will be met (Collins et al., 2000).

2.5 Summary

Brazil is a complex country, with extreme wealth on one hand, but extreme poverty at the other end of the spectrum. The Legal Amazon is one of the poorest regions in the country and is further complicated by a varying climate, land cover and differing levels of development. Healthcare provision has improved in both Brazil and the Legal Amazon. The public health service nationally serves approximately 75% of the population. The Legal Amazon is of global importance; it is a large carbon store and does influence climatic patterns across South America and globally (which is expanded in Chapter 3). Policies to protect the region have only relatively recently been implemented, although they do focus on some of the key environmental issues in the region, namely deforestation and fires. Deforestation is considered to be the most important issue by the Brazilian Government, with the focus of both the National Climate Change Plan and The Amazon Fund being directed towards reducing deforestation rates. This chapter has also outlined the Brazilian fire control policy which aims to combat fires and also to educate people in prevention and response, and allows state level intervention; however, its enforcement power is not as evident as deforestation enforcement. It has been demonstrated, however, that these policies aim to deal with two of the biggest environmental issues in the Legal Amazon. Environmental issues need to be connected to the health impact. Whilst the National Climate Change Plan sets out the need for further research into the effects of climate change on human health, all policies are quite specific and separate from each other. The following chapters will discuss the environmental, climatic and health issues in the Amazon and thus the need for integrated policies.

Chapter 3

Climate – Human Health connections

3.1 Introduction

The aim of this chapter is to review the climate-health related literature relevant to this thesis. The first part will discuss environmental and climatic change with the focus being placed on the Amazon and describing the physical processes leading to hydrological extremes. The link between climate, environment and health will then be discussed, before focusing more specifically on respiratory diseases, and their links to the environment and climate. The discussion then will discuss adaptation, vulnerability and resilience to climate change. The final section considers previous respiratory health studies in the Legal Amazon.

3.2 Climate & Environment

Global surface temperatures have been shown to be increasing (Trenberth, 2007; IPCC, 2013; Meehl, 2007). When examining separate regions, there is 90% confidence that Central and South America will become warmer this century, with higher than global mean temperatures, except in the southern part of South America which will correspond to the global mean (Christensen, 2007). Despite uncertainty for both annual and seasonal global changes in precipitation, it is expected that precipitation is likely to decrease in South America as a whole. Uncertainties remain as to how annual and seasonal rainfall will alter over northern South America, including Amazonia (Christensen, 2007).

A gradual change in global temperatures has been recorded, and changes in extreme climate and weather conditions have been observed since the 1950s, with an anticipated increase in their frequency and intensity (Field, 2012). Despite uncertainties about how climate change will affect the frequency of droughts, the Intergovernmental Panel on Climate Change (IPCC) has projected that on the whole, more droughts will occur in the future. Some regions have experienced longer and more intense droughts such as southern Europe and West Africa, while other regions such as north-western Australia have observed a decrease in frequency and intensity (Field, 2012). Hydrological extremes are also being experienced in the Legal Amazon. The next section details three of these large events: the 2005 and 2010 droughts, and the 2009 flood. Before discussing the hydrological extremes, however, it is important to define what is understood by drought and flood.

Flood: It is not simple to give the definition of a flood event as they can take many forms. ‘Broadly speaking, however, a flood refers to an excess accumulation of water across a land surface; an event whereby water rises or flows over land not normally submerged. It is this abnormality that is key, and helps to explain why the phenomena can have such a severe impact on humans and human systems’ (Few et al., 2004: 7).

Drought: Droughts are somewhat simpler to define; they are considered to be periods of abnormally dry weather that cause serious hydrological imbalance in a specific region. However, the terms ‘serious’ and ‘abnormally dry’ depend on the extent and nature of the impact on local society. A precise definition for the Amazon has been defined by Shuttleworth et al. (1989) and Rocha et al. (2004). To constitute drought periods within Amazonia, rainfall levels are ≤ 100 mm a month. During this shortage of rainfall, it has been shown that the forest enters into water deficit.

3.2.1 Recent hydrological extremes in the Amazon

Both climate variability and climate change are being experienced globally, in addition to which there is pressure from environmental change as well as anthropogenic change. The Amazon rainforest is the largest rainforest in the world and influences global climate circulation (Obregón, 2011), yet these global climatic and environmental changes and variability are also impacting on the region itself. The climate and hydrological regimes of the Amazon are dependent on events in the Atlantic and Pacific Oceans. Although the region experiences drought and flood events as part of natural climate variability, within recent years it has experienced increases in large hydrological extremes (Espinoza et al., 2009). In addition to these events, there are high rates of land-use change in the area, which are also considered to have an impact on the climate in the region and elsewhere (Nobre et al., 1991; Fearnside, 2005). Precipitation in the Amazon is sensitive to variations in Sea Surface Temperatures (SST), and El Niño and La Niña events (Fu et al., 2001). During El Niño events, there is a warming of the East Pacific which suppresses wet season precipitation due to a modification of the Walker circulation and via the Northern Hemisphere (Nobre and Srukla, 1996). The majority of droughts in the Legal Amazon to date have been influenced by El Niño events, such as the 1926, 1982, 1987, and 1997/8 droughts (Marengo et al., 2008a). When strong El Niño events such as these occur, negative rainfall anomalies usually affect central and eastern Amazonia (Cox et al., 2008; Marengo et al., 2008b). However, the most recent droughts experienced in the Amazon did not occur in association with El Niño events; rather, it is thought that they were influenced by SST anomalies associated with the Atlantic Multidecadal Oscillisation (AMO) (Aragão et al., 2007b). In contrast, excess rainfall is observed in the Amazon during La Niña events. Most of the floods recorded have been associated with La Niña conditions, such as the 1908, 1976, 1989 and 2009 floods.

2005 Drought

During 2005, the warming of the tropical East Pacific which is experienced during an El Niño event was absent, suggesting El Niño was in a near-neutral state and, therefore did not contribute to the 2005 Amazonia drought (Cox et al., 2008). Rather, a warm anomaly in the tropical North Atlantic was experienced, linked to a reduction in rainfall (Cox et al., 2008; Zeng et al., 2008; Marengo et al., 2008b; Tomasella et al., 2011). The reduction in rainfall was exacerbated through an extended dry season with more unusually drier conditions, especially in the south-western and southern regions of Amazonia (Marengo et al., 2008b). Furthermore, Marengo et al. (2008b) believe that a reduction in the moisture transported into the southern region of the Amazon by the northeast trade wind, and a weakened upward motion over southern Amazon, resulted in reduced precipitation. Sena et al. (2012) provide a different account of the 2005 drought, suggesting that the drought may have been caused by land-use change rather than global climate processes. Although this is accurate in that deforestation can influence rainfall patterns, deforestation occurs every year in Amazonia and higher rates of deforestation have been observed in non-drought years. Unlike El Niño associated droughts, during the 2005 AMO associated drought, rainfall deficiencies were observed in the west and southwest of Amazonia. However, the impact spread as far as the central and eastern Amazonia (Marengo et al., 2008b). Although the 2005 drought had relatively small rainfall change compared with the 1997/98 drought, 48% and 63% of the basin suffered enhanced drought stress respectively (Aragão et al., 2007b), with the severity being greater due to its duration. The 1997/98 drought lasted a year and was followed by La Niña events which provided suitable conditions for the basin to recover quickly from the drought, whereas the 2005 drought had been preceded by another drought in 2002/03 with little recovery in 2004, thus rainfall remained below normal between 2002 and 2005 (Zeng et al., 2008).

2009 Flood

After the 2005 drought, there was speculation that the Amazon would develop a drier climate; however, five years after the drought, Amazonia experienced a flood resulting in record water levels and discharge of magnitude and duration that are rarely observed (Marengo et al., 2010). The leading cause of flooding is heavy rainfall for a long duration or intense period, creating runoff in rivers or build-up of surface water in areas of low relief. This occurred in the Amazon when heavy rainfall was observed in the northern and eastern areas during the austral summer of 2008/09, causing the swelling of Amazonia River and tributaries (Marengo et al., 2010). Similarly to the drought events, the intensity and spatial extent characterised the flood; in June 2009, water levels of the Rio Negro reached a peak of 29.75m, the second highest level since records began in 1903 (only the 2012 flood was higher). At other monitoring stations, the water levels were recorded at their highest level in the Rio Madeira at Fazenda Vista Alegre, and the Amazonia River at Obidos (Marengo et al., 2013). Marengo et al. (2010) show that the flood event was dominated by La Niña, which concurs with other studies that suggest that when cold SST anomalies in the eastern Pacific towards the end of a year are present, wetter conditions are generally experienced in the Amazon (Zeng et al.; Espinoza et al.). This is true for the flood events of 1908, 1976, 1989, and 2009, but not for two other floods experienced in 1922 and 1953 (Marengo et al., 2010), suggesting that not all floods are associated with cooler SST in the tropical Pacific. Although this 2009 flood was also the result of a La Niña event, there are differences which could be attributed to the magnitude of the flood. In comparison to the 1989 and 1999 floods, cooling of the equatorial Pacific was less; during these events, cooling was around 2-3^{o}C yet during 2009, it was barely below 1^{o}C. indicating that there was the presence of a weaker than normal La Ninã (Marengo et al., 2010). Warm SSTs were detected in the tropical Atlantic off the east coasts of Venezuela and Guyana in the austral summer of 2008/09 but they were not detected in other flood years (Marengo et al., 2010). Despite the 2009 flood being the result of a weaker and delayed La Niña event, and less positive rainfall anomalies being observed in comparison with the other La Niña floods, the effects were larger, due to the premature start of the rainy season in northern and north-western Amazonia which resulted in a longer wet season than had been present in the previous flood events.

2010 Drought

One year after the flood, another drought struck the Amazon, this time of a larger magnitude than the 2005 event. Few studies to date have assessed the causes of the 2010 drought in such detail as the 2005 drought. However, it is known that unlike the 2005 drought, the 2010 drought happened during a transition between an El Niño event early in the austral summer of 2010 and became more intense during a La Niña event in the austral winter (Obregón, 2011). It was similar to 2005 in terms of the meteorological severity, but hydrological impacts were more severe (Marengo, 2011b). The 2010 drought affected north-west, central, and south-west parts of the Amazon. The Rio Negro went from the second highest recorded level in 2009 to its lowest recorded level in October 2010, recording 13.63m (Marengo, 2011b). Since the 1970s, SST anomalies in the tropical north Atlantic have gradually increased, reaching highs during the drought years of 1980, 1998, 2005 and 2010 (Marengo et al., 2011). Compared to 2005 data for March, April, May (MAM), the seasonal temperature anomaly was 0.6^{o}C higher in 2010, which became a record. Moreover, the June, July, August (JJA) temperature anomaly was even higher, increasing to 1^{o}C based on a time series since 1902 (Marengo et al., 2011). These factors could explain why the magnitude of the 2010 drought was larger than that of the 2005 drought.

Impacts of hydrological extremes on the forest

Contrasting findings have been published regarding the impacts of these hydrological extremes on the forest. Prolonged droughts in tropical regions can kill trees, and some climate models predicted climate-induced forest dieback in the Amazon (Cox et al., 2004). However, it was also shown in 2005 that the forests ‘green up’ during drought periods and in dry conditions because of increased sunlight availability that boosts productivity (Saleska et al., 2007). Yet in 2010, another study used the same data as Saleska et al. (2007) and reported that the forest did not 'green up' during the 2005 drought; rather, 28%-29% of the forest showed browning or no change (Samanta et al., 2010). Droughts not only have a direct impact on the forest but they may also affect the regional biochemical and carbon cycle due to fires (Phillips et al., 2009; Aragão et al., 2007b). In addition to hydrological extremes, environmental human disturbances affect the Amazon, which can potentially alter the hydrological regime and damage the forest.

3.2.3 Land-use change in the Legal Amazon

Land-use change across the Legal Amazon in the last three decades has predominantly been characterised by intense exploitation of natural resources (Azevedo-Ramos, 2007). Around 18% of the Amazon rainforest has been converted to other land uses, principally transformed to pastures (INPE, 2012d). Government incentives for land conservation and migration to the region have encouraged this transformation. At the time, it was thought that land conversion would benefit economic growth because forests were seen as a barrier (Azevedo-Ramos, 2007), which led to increases in deforestation across the Legal Amazon. Policies regarding land-use change are discussed in Chapter 2.

Within the Amazon, deforestation rates are extremely high, accounting for 47.8% of global deforestation (Hansen et al., 2008). Deforestation has been occurring since European settlers arrived but it was not until the Trans-Amazon Highway was built in 1970 that rates intensified (Costa and Foley, 2000); before this, the Legal Amazon had remained largely intact. Almost all deforestation in the Amazon occurs around the eastern and southern fringes of the basin in the savannah transition region, termed the 'arc of deforestation', comprising the states of Mato Grosso, Pará, Maranhão, Rondônia, and Tocantins. Although the 'arc of deforestation' is the primary location for deforestation, the distribution varies from year to year (Laurance et al., 2001) and the causes in each state vary, so general conclusions cannot be made (Margulis, 2004). There are multiple causes of deforestation in the Amazon, although it is considered that one cause will dominate depending on the relevant period. Following the development of roads in the region, Fearnside (1986) shows that most deforestation occurs in the east and south of the Legal Amazon, where the majority of roads and highways are built. In a later study, Laurance et al. (2001) used remote sensed data to show that deforestation occurs near highways and near unpaved roads. Since then, Homma (1995), Margulis (2004), Fearnside (2005), and Nepstad et al. (2006) assert that deforestation is primarily related to agricultural practices. Homma (1995) suggests that the principal cause of deforestation is due to small-scale subsistence farmers and, based on data obtained from INPE, Nepstad et al. (2006), concludes that beef and soy are the primary drivers. While Fearnside (2005) and Margulis (2004) present findings that cattle ranching is the primary driver, with Fearnside (2005) quoting that 70% of deforestation is due to large-scale cattle ranching, Margulis (2004) suggests that increases in land use for cattle is the principal cause.

Statistics from the INPE show that deforestation rates were increasing until 2004, when deforestation policies were implemented (section 2.2). After 2004, although deforestation continued, a reduction in the rate has been noted, except for an anomaly in 2008 which showed an increase in the rate (NPE 2010). At the peak of deforestation in 2004, there was 27,000 km^2 of clearing compared to 6,500 km^2 in 2010 (INPE, 2012a), which suggests that rates have been reducing. Information for 2009/10 deforestation shows that there has been a 13.6% decrease in deforestation from the previous year; this is the lowest rate INPE have measured since 1988.

3.2.4 Active Fires: the consequence of drought and deforestation

A consequence of deforestation is fire; it is a main method for land clearing within countries in the tropics (Marlier et al., 2012). Where once fires in the Amazon were a rare and infrequent occurrence when left to the natural environment, human disturbance transforms non-flammable rainforests into flammable forests through manmade fires that accidentally spread (Uhl and Kauffman, 1990; Cochrane and Schulze, 1999). However, Sanford et al. (1985) state that fire is a historical element in the Amazon, and Nepstad et al. (1995) further this point by suggesting that after several years of low rainfall, fire may occur in natural forests. Initial forest fires tend to be understorey fires which affect a large area of the Amazon and move slowly, only consuming leaf litter (Cochrane and Schulze, 1999). Those areas that have been affected once by fire become more vulnerable to repeat fires and it is the recurrent fires that cause more damage because they are more intensive in flame depth and have faster speeds and residence time, all of which provide an environment that results in tree mortality (Cochrane and Schulze, 1999). In general, understorey fires share a similar spatial pattern to that of the sites of deforestation which tends to be where roads have been built and agricultural practices exist, indicating that fires predominantly occur at the 'arc of deforestation' where most development within the Amazon is located. Zeng et al. (2008) show that fires in the Amazon do typically occur in this location, and occur at the end of the dry season. Uhl and Kauffman (1990) show that land-use change through deforestation is one of the main drivers of fire dynamics in Amazonia and in a more recent study the risk of fire is associated with the dry season (Nepstad et al., 1999) because of the accumulation of leaf litter and leaf drying. Cochrane et al. (1999), and Laurance and Williamson (2001) have shown that drought conditions increase the vulnerability of the forest to fires due to water stress, leaf litter and leaf drying. Evidence of an increase in fire occurrence by around 30% has been shown during the 1998 and 2005 droughts of Amazonia relative to the 1998-2005 mean (Aragão et al., 2007b). During the 2005 drought, fires affected part of southwest Amazonia, with rates of fires several times higher than average in Rondônia and Mato Grosso during this period (Zeng et al., 2008).

3.2.5 Future projections

Although Global Climate Models (GCM) are dissimilar, with levels of projected change varying between models, they tend to suggest that the Amazon is going to become drier in the future, particularly in the north. There is also a higher probability of droughts occurring in the Amazon by the end of the 21st century in response to climate change (Malhi et al., 2008) (Christensen, 2007). Moreover, despite recent reductions in deforestation, deforestation is considered to be the most unquestionable threat to Amazonia (Betts et al., 2008). The feedbacks between climate change and land-use conversion are likely to reduce rainfall in the Amazon (Spracklen et al., 2012), with important implications for agriculture and water supply (Aragão, 2012). It is also suggested that if 40% of the original

Amazon is deforested, Amazonia will reach a tipping point where this causes further climatic changes, creating further forest loss (Marengo, 2011a). Soares-Filho et al. (2006) show that this tipping point of 40% of forest being eliminated may be reached by 2050 if deforestation continues as 'business as usual'. The link between drought conditions and deforestation as a land-clearing method and forest fires has the potential to transform Amazonia into a fire-prone system (Malhi et al., 2008; Nepstad et al., 2004), with amplified impacts upon ecosystems and humans.

The impacts of environmental and climatic change are not only associated with environmental aspects, but will be felt on the human population too. One aspect of human life that environmental and climatic change may impact upon is that of human health, with some positive impacts but others which will be negative. The potential impacts are discussed in the following section.

3.3 Climate - human health interactions

With the climate changing and more extreme events anticipated, evidence is growing that these changes may already be contributing to the global health burden and are likely to continue. The fourth IPCC report states that 'climate change is projected to increase threats to human health' (TEAM, 2001). It has been known for thousands of years that climatic and environmental change will impact upon human health and while the impacts of ecosystem change on health have been known for a long time and are considered to be diverse, their rate and geographical range have increased over the past few decades (Pattanayak and Yasuoka, 2008). The majority of impacts are anticipated to be adverse, such as a greater geographical range of infectious diseases (WHO, 2013), yet some impacts will be positive, such as milder winters in temperate countries which reduce cold-related mortality (McMichael et al., 2006), and increasing crop yields which provide more food (IPCC, 2001).

An overview of each of the main topics of climate-health relationships researched are presented: thermal stress, extreme hydrological events, and infectious diseases

(McMichael et al., 2006). In addition, there is discussion of land-use change and active fires, since this research assesses their impacts too. Outside the scope of this research, however, it should be noted that in addition to physical impacts, disorders relating to mental health and wellbeing such as depression and anxiety are common because of economic loss, loss of home, environment, and possibly family and friends, and isolation of communities during climatic events (Haines et al., 2006). Understanding the mental health of those affected by extreme events is important as it is another effect of climatic and environmental change on human health but tends to be less explored.

3.3.1 Thermal Stress: impacts on health

Populations adapt to the climate in which they reside; however, changes in temperature can affect them, and temperature-mortality/morbidity vary by their latitude and climatic zone (McMichael et al., 2006). For example, people in warmer climates are affected by colder temperatures and people in cold climates are affected by warmer temperatures. One aspect of thermal stress is heatwaves. These have been shown to have positive associations with mortality rates, particularly in elderly people, due to cardiovascular, cerebrovascular, and respiratory causes (Haines et al., 2006; McMichael et al., 2006). It has also been shown that mentally ill people (Ledrans et al., 2004), children (O'Neill et al., 2003), and people with pre-existing conditions are also vulnerable to heat-related deaths (McMichael et al., 2006). It is anticipated that climate change will be associated with increases in heatwave frequency. An example of the impacts of heatwaves is shown by that of 2003, when Europe experienced a major heatwave affecting western countries, with impacts worst felt in France. Temperatures in France reached levels not recorded since 1540, and around 14,800 excess deaths were recorded in the first three weeks of August, which were mainly of elderly people (Haines et al., 2006). During the 2003 European heatwave, more women died than men (Robine et al., 2007) and this gender difference corresponds with research carried out by the WHO which notes gender differences when assessing the impacts of climate change on health (WHO., 2011).

People living in urban centres are at higher risk of the effects of thermal stress because of the 'urban heat island' (UHI) effect. This occurs where urban centres experience higher temperatures than the surrounding more natural areas. This was noted in Paris during the 2003 heatwave, where a 142% increase in deaths was observed (Vandentorren et al., 2004), and in Shanghai, where higher excess mortality rates were recorded in urban locations (27.30/100,000) compared to exurban locations (7.0/100,000) during the 1998 heatwave (Tan et al., 2010). In addition to direct impacts of thermal stress, air pollution levels can also rise during heatwaves, and increases in humidity during events may cause ill health (Haines et al., 2006). Despite increases in mortality associated with heatwaves in most countries, it has been shown over a thirty year period in the USA that an overall drop in mortality associated with heatwaves in 28 cities was recorded, indicating that populations can adapt to climate change in order to reduce risks (Davis et al., 2003). Although overall reductions have been experienced, in extreme conditions increases in deaths will remain, however. The literature notes some benefits of a warmer climate; it is expected that there will be a reduction in the number of winter deaths and disease events in temperate countries (McMichael et al., 2006). Yet negative associations have also been observed with milder winters in some locations; for example in Texas, 2012, an outbreak of West Nile virus was recorded during an unusually mild winter (Murray et al., 2013).

This section has focused on thermal stress as it is a main topic of climate-health research; however it is also important to mention that cold temperatures/stress can also impact on the health of a population. It has been shown that an increase in mortality is associated with a colder temperatures rather than warmer temperatures (Jendritzky et al. 2000). Respiratory and circulatory diseases are the primary cause of death because of excessive cold temperatures, and as with thermal stress, elderly people are most vulnerable to cold temperatures.

3.3.2 Hydrological Events: impacts on health

Extreme hydrological events tend to be low probability but high impact. Floods tend to cause direct death through rapid rises in water level; slow rise floods can also cause fatalities (Haines et al., 2006). Drought events, however, tend to have wide-ranging impacts but not usually direct mortality. Both floods and droughts can cause water-borne and food-borne diseases. During flood events, excess rainfall can facilitate the movement of human sewage and animal faeces into waterways and drinking water supplies (Confalonieri, 2007; Haines et al., 2006). In contrast, drought events can cause water-borne diseases through a lack of clean water and thus poor sanitation and a lack of safe drinking water (Hales et al., 2003). Altering water availability also has an impact on vector-borne diseases as this can create or remove breeding grounds for vectors. For example, Bouma and Dye (1997) show that during droughts in Venezuela, the number of susceptible people increases, so that once drought breaks, the numbers of people affected by mosquito-borne diseases are likely to increase. Other areas may see an increase of mosquitoes during the drought itself due to a reduction in predators (Chase and Knight, 2003), and an increase in breeding grounds outside of homes due to domestic water storage.

In some instances, flooding can lead to the mobilisation of chemicals from storage or the remobilising of chemicals already in the environment, like pesticides (Haines et al., 2006). If a water source is nearby, these chemicals can enter the water and cause ill health to those using the water or they can poison fish for consumption. Increases in communicable diseases, particularly in diarrhoeal and respiratory diseases, have been observed in both high and low income countries during the aftermath of a flood (Reacher et al., 2004; Heller et al., 2003; Cairncross and Alvarinho, 2006). Droughts can lead to social insecurity, food insecurity and long-term health problems. For example, in 2010, the drought of Amazonia led to a 9 ton/month reduction in fishing production (Marengo, 2011b). Extended periods of drought are linked to a fuel source for fires, food and water shortages, conflicts, migration, increased poverty and an increased risk of fires. Limited access to health care may also occur since access to health care services can be restricted when rivers are the main transport mode and are dried up during drought periods (WHO, 2011a).

3.3.3 Infectious Diseases: impacts on health

Although there are many health impacts from climatic change, infectious diseases have traditionally been one of the most discussed topics, primarily mosquito-borne diseases. Mosquitoes are very sensitive to meteorological conditions, particularly temperature and rainfall (WHO, 2013). Associations between El Niño and La Niña events and vector-borne diseases have been observed around the world; in Colombia, Guyana, Peru, and Venezuela, increases in malaria epidemics have been observed during El Niño events (Gagnon et al., 2002). Extremes in temperatures, either hot or cold, can limit mosquito seasons and even kill eggs, larvae and adults, thus reducing risk of transmission (Epstein, 2000), while certain temperature ranges cause mosquitos to thrive, Anopheles mosquitoes, which transmit malaria, cause outbreaks when temperatures exceed 60^{o}F, while *Aedes aegypti* mosquitos, which transmit dengue fever and yellow fever, thrive when temperatures rarely fall below 50^{o}F (Epstein, 2000). Development of the mosquito is also affected by temperature, which can lead to increases in adult mosquitoes, and thus a greater risk of mosquito-borne disease. For example, at 68^{o}F, it takes 26 days for the mosquito to develop, yet at 77^{o}F this is reduced to 13 days (Epstein, 2000). Therefore, increases in global temperatures could result in the expansion of mosquito territories. There may be some benefits from a changing climate on infectious diseases, however, such as a reduction in the number of vectors because of altered rainfall, surface water for breeding grounds or excessive heat.

Water-borne diseases are also expected to be escalated through climatic change. El Niño events have already been shown to affect cholera cases; increases were noted in coastal areas in Bangladesh (Kunii et al., 2002; Siddique et al., 1991), and in Peru during the 1997 El Niño event (Checkley et al., 2000). Extremes in rainfall and water-borne diseases can also affect developed countries; in the USA, monthly outbreaks of water-borne diseases and high levels of precipitation have been recorded (Curriero et al., 2001). Extremes are not the only cause of water-borne disease, as seasonal changes can also cause increases in cholera which have been observed in Bangladesh and are associated with sea surface temperatures in the Bay of Bengal (Bouma and Pascual, 2001).

3.3.4 Land-use change and human health

Land-use change can magnify the impacts of extreme events, both directly and indirectly, and has implications for human health too. The primary land-use – human health impact discussed in literature concerns altering the transmission of vector-borne diseases. Land clearing activities such as deforestation can alter vector abundance due to reducing shade, altering humidity and altering rainfall patterns (Reiter, 2001; Vittor et al., 2006). Deforestation has been shown to coincide with increases of malaria and vectors in Africa, Asia and South America (Vittor et al., 2006). In some instances, forest clearance removes species that breed in tree holes, yet it provides suitable conditions for other species (Reiter, 2001). It has also been shown that in some parts of Africa, where land is newly exposed to sunlight, it promotes the development of temporary pools of water which create suitable breeding grounds for vectors (Pimentel et al., 1998). Moreover, where deforestation activity has occurred in order to create cattle ranches, there is an increased risk of vector-borne diseases as susceptible people from urban areas are attracted to these locations in search of work (Vasconcelos et al., 2001). In addition to affecting vector-borne diseases, land-use change can exacerbate respiratory health problems through particles entering the atmosphere (Pimentel et al., 2007). Moreover, similarly to flood events, deforestation can cause mobilisation of chemicals. Contamination of rivers with mercury has been observed because of soil erosion after deforestation in rainforest areas. For example, mercury levels have been shown to increase in rivers in Amazonia after deforestation and rain, causing fish to become hazardous to eat, and thus affecting the human population's health and food supply (Veiga et al., 1994).

3.3.5 Fires and smoke: impacts on health

Forest fires chiefly affect respiratory health, due to the smoke released which can cause irritation to the bronchial passage and lungs. Both morbidity and mortality have been shown to increase during periods of intense fires, for example as described in studies by (Marlier et al., 2012; Sastry, 2002; Mott et al., 2005). Further details of the respiratory impacts of fires and smoke from fires can be seen in section 3.4.

Smoke from forest fires can also cause a reduction in mosquito-borne diseases because it acts as a repellent to the mosquitoes (WHO, 2011b). Smoke has also been associated with increases in cancer; however, this tends to be from urban situations such as fumes from cars rather than forest fires. Forest fires themselves cause health problems, but it is argued that outdoor air pollution studies are not as useful as studies of air pollution indoors, as this is where people spend most of their time (Brunekreef and Holgate, 2002). Populations with low socio-economic status in developing countries tend to use wood as fuel for cooking and, as in most cultures; women are responsible for cooking and childcare. Thus, two of the most vulnerable population groups are exposed to smoke from burning (Wilkinson et al., 2007). Whilst this is important to note, based on the most recent data available (1991), only 27% of the population in Brazil are estimated to use solid fuel in the home (Smith et al., 2004). Moreover, government intervention has led to many homes using gas stoves (conversation with Dr. Sandra Hacon, April 2012), so the issue of solid fuel use in the home is not considered to be a prominent factor within the context of this research.

This section has provided an overview of the impacts of climate and environmental change on human health. Their potential to have an effect on respiratory health has been shown. The following section discusses this relationship between hydrological extremes and respiratory diseases.

3.4. The respiratory disease context

3.4. 1 Defining respiratory diseases

Respiratory diseases are defined by the WHO as ‘diseases that affect the air passages, including the nasal passages, the bronchi and the lungs. They range from acute infections, such as pneumonia and bronchitis, to chronic conditions such as asthma and chronic obstructive pulmonary disease’ (WHO., 2011). They tend to cause a narrowing of the airways; however, this is usually reversible either spontaneously or with medication (Rosa et al., 2009). Globally, respiratory health disorders are one of the most common causes of diseases, with pneumonia alone accounting for more under-fives' mortality than malaria, AIDS and meningitis combined (Wardlaw, 2006). The airways are hyper-responsive and constrict easily in response to a wide range of stimuli such as tobacco smoke, indoor smoke from cooking with biomass, vehicle emissions, industrial processes and biomass burning (Pimentel et al., 2007). Numerous factors affect the development of respiratory diseases: environmental factors such as climate changes, contact with dust, mould, pollen, animal fur, tobacco smoke (including second hand), indoor and outdoor air pollutants, biomass burning, consumption of certain foods; biological factors such as genetics, weight, sex, and presence of bronchial hyper-responsiveness (GINA, 2012); and socio-economic factors (Silva et al., 2009). These factors vary between the diseases and between people, and moreover there are different triggers for some diseases.

One major cause of respiratory diseases is considered to be air pollution; it has been identified as a causal factor in breathing disorders (Farias et al., 2010). The WHO states that air pollution is the 'contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere' (WHO, 2008b). There are five key air pollutants that cause major concern to public health, which are: particulate matter (PM), carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) (WHO, 2008b). There is evidence that particulate matter has greater adverse health impacts than ozone (WHO, 2003); it is known to affect mortality and morbidity, thus higher levels would result in significantly negative health outcomes. Dust and vehicle emissions are primary causes of air pollution; however, in rural areas of developing countries, indoor air pollution from the use of solid fuel and tobacco are equally lethal (WHO, 2008b). The WHO believes that these two activities are more harmful to human health than air, water and soil pollution (WHO, 2005). It is estimated that 4 billion people suffer continuous exposure to smoke due to the use of solid fuels (Bruce et al., 2000), and there are 1.3 billion tobacco smokers worldwide (WHO, 2005), with smoking being another major cause of respiratory diseases. Each of these activities produces smoke that has more than 4000 hazardous chemicals (de Koning et al., 1985).

A further cause of air pollution, of particular interest in this research, is smoke from forest fires. Moreno (2006) shows that smoke from fires is associated with irritation of the throat, lungs and eyes and Boman et al. (2003) suggest that particles from wood smoke are more injurious to human health than particles from other sources known to cause ill health. Forest fires emit particulate matter, PM_{10} and $PM_{2.5}$, amongst other pollutants and forest fires in the Legal Amazon emit large quantities of particulate matter, with higher concentrations occurring along the 'arc of deforestation'. This area accounts for 85% of fires in Brazil during the dry season (Becker, 2005). In addition to smoke, wind erosion can cause respiratory health problems by blowing soil particles and microbes into the air that can cause irritation and aggravate allergies and asthma (Pimentel et al., 2007). This factor is significant because within the Amazon, besides smoke from forest fires, there are periods of drought which result in more exposure of dry soil that can be transported, which compounds impacts from deforestation.

Air pollution is not the only factor contributing to the development of respiratory diseases; research suggests that as the climate changes so will the impacts of allergens on respiratory diseases by altering the spatial and temporal distribution of pollen and spores (Beggs, 2004). Croce et al. (1998) report that during the rainy season, an increase in humidity leads to an increase in the prevalence of funguses and mites that are significant allergens for the occurrence of asthmatic crises.

Respiratory diseases are not only affected by the environment and climate, but socio-economic factors also play an important role in their presence. There are contrasting theories about the development of respiratory diseases and the socio-economic context in which people contract them. One school of thought is that children from wealthy backgrounds are brought up in clean environments and are not exposed to allergens, so when they are finally exposed, they become ill due to not having built up immunity to fight the allergens (Strachan, 1989). This theory is known as the hygiene hypothesis. In contrast, though not confined to respiratory diseases, is the Socio Economic Status (SES) gradient. This suggests that there is a correlation between socio-economic status and health; in other words, in general, the lower a person's socio-economic level, the worse their health. It has been suggested that within the tropics, some diseases, such as acute respiratory illness, can be considered diseases caused by poverty rather reasons relating to rainfall and latitude (Butler, 2008). Asthmatic symptoms were found to be more severe in poorer areas in Latin America, thus suggesting that socio-economic status is a major factor for the high prevalence of asthma in Latin America (Mallol et al., 2000). Gonçalves-Silva et al. (2006) concur that low socio-economic conditions may increase asthma.

3.4.2 Hydrological Extremes and Respiratory Diseases

Droughts and forest fires

During drought periods, as soil becomes drier, dust is more likely to be circulated in the atmosphere, which has been shown to cause irritation and aggravate allergic diseases (Pimentel et al., 2007). A memorable example of this was in the USA during the 1930s when the 'dust bowl' drought struck. Hundreds, and possibly thousands, of people died from 'dust pneumonia' on the Great Plains because of the drought and exposed soil (IPCC, 2001). More commonly, it is the associated conditions of droughts that lead to respiratory health problems. As discussed in section 3.2.4, droughts can increase the susceptibility to fires. Smoke from fires emits a variety of pollutants; however, evidence suggests particulate matter (PM) affects more people than any other pollutant (WHO, 2008b). Smoke from fires tends to emit the finer $PM_{2.5}$ particles; these particles are more hazardous, since, when inhaled, they may reach deep in the lungs (Nel, 2005). Correlations between particulate matter, fires, and respiratory diseases have been observed worldwide using different outcomes: emergency service care, outpatients, hospitalisations, or school absences. For example, during 1997, Southeast Asia experienced the worst forest fires on record in Indonesia. Haze from the fires remained in the air for several months and the effects were widespread, affecting Brunei, Singapore, Malaysia, Thailand and Vietnam. Compared to previous years, increases in respiratory and cardiovascular diseases were seen in the affected regions, demonstrating the long-distance dispersion of smoke particles can travel (Mott et al., 2005). Similar effects have been observed in Australia and California during periods of intense fires. In Brisbane, Australia, daily hospital admissions for respiratory diseases were recorded between 1997 and 2000 in relation to PM_{10} levels. It was shown that admissions increased with increases in PM_{10} during bushfire periods and non-bushfire periods; however the relationship was stronger during bushfire periods (Chen et al., 2006). Mott et al. (2002) assessed the health effects of the fifth largest forest fire episode in the USA (California) during 1999. Exposure to PM_{10} during the fire event was measured against medical visits for respiratory health problems; it was found that on 15 days of the study period, PM_{10} levels exceeded the USA Environmental Protection 24 hour air quality standard, and on two of the days, levels reached 'hazardous' levels. This resulted in a 52% increase in the number of medical visits compared to the previous year, and a positive correlation (74%) was observed. Similar associations were observed in Darwin, Australia, during the fire seasons of 2000, 2004, and 2005. For the same day, and a three-day lag, increases in hospital admissions were observed in line with $10 \mu g/m^3$ increases in PM_{10}. The greatest increase was observed for Chronic Obstructive Pulmonary Diseases, followed by asthma (Johnston et al., 2007).

Floods

In contrast, floods impact respiratory diseases differently. Two main causes for the flood/respiratory disease relationship are humidity and mould. Moulds can develop within 24 and 48 hours in a wet or damp area in locations where areas affected by flooding have not been cleaned (EPA, 2012). These moulds can cause people to contract upper respiratory diseases, especially those with pre-existing allergies and asthma (GINA, 2012). Previous research examining the impacts of floods on human health has shown that respiratory diseases are affected, although they tend not to be the leading cause of health problems related to a flood. Illnesses during flood events are consistent in both high- and low-income countries; diarrhoea and respiratory diseases are the most common causes, in some instances showing an increased occurrence. This was the case in Bangladesh when, during the 1988 flood, diarrhoea and respiratory tract infections were the two most common causes of illness (34.7% and 17.4% respectively) and death (27.3% and 13% respectively). Of the deaths caused by respiratory diseases, just under 6% were from chronic diseases and the remainder were from acute diseases. Moreover, children under five made up the greatest proportion of these cases (Siddique et al., 1991). The same effect was found during the 1982 floods in Bolivia. Higher rates of respiratory diseases were observed immediately following the flood and the sharpest changes affected children under five years of age (Telleria, 1986).

There is evidence that extremes and environmental human disturbances can affect the respiratory health of a population. This evidence is particularly strong in forested areas when fires occur. These effects and other health effects will be modulated or amplified through socio-economic levels and the degree to which populations can effectively adapt to them. With little knowledge of the impacts of hydrological extremes, it is difficult for policy and health services to be well adapted to minimise the demand during such events. Discussion will now focus on the notions relating to adapting to climate change.

3.5 Adapting health outputs to environmental and climatic change

3.5.1 Introduction

Global temperatures have been warming over the past hundred years (IPCC, 2007a), suggesting that local weather has been altering gradually over time and, therefore, it can be assumed that communities have been altering their lifestyles in accordance with the already changing climate. It is now widely accepted that climate change is a reality, and future changes are anticipated; there is a need to examine how communities and nations cope with the changes. Available evidence describes how a changing climate will affect both the environment and the human population and it is known that reducing greenhouse gas emissions alone will not mitigate the impacts of climate change (Arnell et al., 2002). A common theme in climate change and vulnerability literature is the view that the effects will be disproportionately felt, depending on the country, region, or socio-economic group. Thus, the importance of understanding both vulnerability (determined by individual, community and geographical factors) and adaptation needs to be understood before effective management can be implemented, particularly when they influence and interact with each other (WHO, 2003).

This research concerns the impacts that extreme events have on human health and will, in consequence, focus on adaptation of human-environment/global change systems. While this in part includes natural resource systems, it does not include literature on applications relating to the physical or biological systems of adaptation nor of the Legal Amazon.

3.5.2 Defining Adaptation

Adaptation has been discussed in literature since the 1980s (see Timmerman (1981)); however, its re-emergence has been relatively recent. It is examined in various regards, for example; climate (Adger et al., 2003), political ecology (Folke et al., 2005), social justice (Adger, 2003) and disaster risk management (Wisner et al., 2003). In terms of human-environmental/global change, it generally refers to a process, action or change that an 'actor' undertakes, for said 'actor' to be better equipped to cope with, manage, or adjust to the changing situation (Smit and Wandel, 2006). The term 'actor' refers to the person or group it is affecting, for example a community, a household, a region, or even a country (Adger et al., 2005). Pelling (2011) suggests that adaptation is a relatively easy concept until the 'actors' and their interaction are introduced, which is when it becomes more complex. More recently, 'actors' have been called 'systems', and subsequently they will be referred to as systems here.

In terms of adaptation to climate change, there are various definitions but they tend to be based on a common theme. Pielke Jr (1998: 159) defines adaptation in the context of climate change as 'adjustments in individual groups' and institutions' behaviour in order to reduce society's vulnerability to climate'. In 2000, Smit et al. (2000: 225) refer to climate change adaptation as 'adjustments in ecological-socio-economic systems in response to actual or expected climate stimuli, their effects or impacts'. Brooks (2003a: 8) describes adaptation as 'adjustments in a system's behaviour and characteristics that enhance its ability to cope with external stress'. According to the third IPCC report (2001), adaptation is 'the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities'; this definition has been retained in the fourth IPCC report. Adger et al. (2005: 78) define adaptation to climate change in a similar way to the IPCC report; an 'adjustment in ecological, social, or economic systems in response to observed or expected changes in environmental stimuli and their effects and impacts in order to alleviate adverse impacts of change'.

These definitions show similarities and, in the more recent definitions, have incorporated social and economic aspects, which is important as it is accepted that poor populations are more at risk from adverse impacts. Regardless of definition, however, various spatial and societal scales and social agents play a role in adaptation (Adger et al., 2005). Adaptation can be performed by individuals, also known as autonomous adaptation, or by governments on behalf of society, known as anticipated or reactive adaptation (Adger, 2003). Anticipatory measures are considered more successful than reactive measures, although anticipatory measures should prepare for uncertainties as well as gaining equilibrium (Adger, 2003), particularly when there is considerable uncertainty in climate prediction.

Research on adaptation has concentrated on describing, categorising or analysing adaptive actions (Smit et al., 2000). In more recent years, there has been a parallel agenda introduced that aims to understand the human behaviour that underpins observed adaptations (Pelling and High, 2005). This does not mean, however, that adaptation research is limited, as there are four main research themes in adaptation in climate change. The first is based on modelled scenarios, where potential mitigation of the predicted scenarios is estimated (Parry, 2002). The second body of research on adaptation looks at particular systems and attempts to form specific measures for that one system. By doing so, this method creates possible adaptation methods that are then selected by ranking them based on observations and modelling outcomes (Niang-Diop and Bosch, 2004). The third research theme adopts vulnerability as the 'start point' rather than the 'end point' and, in doing so, explores relative vulnerability at country, regional or community level. This type of research identifies countries, regions or areas with the greatest vulnerability and, therefore, expects the findings will be used in policy making (Kelly and Adger, 2000). The final theme is much less explored; it focuses on 'bottom-up' approaches via an investigation of conditions that are important to the community rather than conditions which are assumed to be important by external parties. This allows for the researcher or policy maker to understand how the system or community experiences changing conditions and the process of decision making in the system. This should enable adaptation measures which are more appropriate to the system and/or enable an improvement in adaptive capacity (Smit and Wandel, 2006).

One theory that can be applied to this research is the analogue approach to adaptation and this is compatible with the fourth research theme of adaptation. This takes two streams: temporal analogues, which use detailed case studies of past responses to climate variability and extremes; and spatial analogues, which examine how current climate variability is dealt with in locations where the climate is similar to that which may develop elsewhere (Adger, 2003). It has been suggested that understanding the present-day effects and responses is a pre-requisite for studying the effects of, and responses to, future climate change and identifying the key determinants of successful adaptation in the future (Adger et al., 2003). A drawback of the analogue approach is that future climate change is likely to be of a different scale to that experienced in the past (Adger et al., 2003). This impact of climate change resulting in different futures has been referred to as 'non-stationary' (Milly et al., 2008). However, climatic conditions of the 2005 drought have been modelled as potential scenarios in climate models for the 21st century, therefore they may provide insight for future conditions in the Amazon (Phillips et al., 2009).

3.5.3 Elements of vulnerability and adaptive capacity

In scientific literature, vulnerability has been fixed in geography and natural hazards research, but it is now considered in a variety of other research contexts. With these various contexts, vulnerability is conceptualised differently between scholars from different themes, or even within them, and thus there is no consensus on its meaning (Gallopín, 2006). Here, I am concerned with vulnerability to climate change and indeed the natural hazards perspective as hydrological extremes fall under the natural hazard heading.

In the past, there has been confusion surrounding the meaning of the term 'vulnerability' in the context of climate change. Two interpretations of vulnerability in climate change have been discussed in literature: social vulnerability and biophysical vulnerability. Social vulnerability 'describe[s] all the factors that determine the outcome of a hazard event of a given nature and severity' (Brooks, 2003b: 5), whereas biophysical vulnerability 'is a function of hazard, exposure, and sensitivity' (Brooks, 2003b: 4). Hence, the main difference between these two concepts is that biophysical vulnerability includes characteristics of the hazard whereas social vulnerability does not. Moreover, traditionally there were two ways to examine vulnerability to climate changes: 'end point' and 'starting point'. Vulnerability according to 'end point' looks at the expected impacts of climate change, taking into account possible adaptation. Whereas according to 'starting point', the focus is on reducing internal socio-economic vulnerability to climatic hazards (Füssel, 2007).

These two interpretations can be seen through various definitions of vulnerability in climate change and natural hazards. Broadly speaking, the vulnerability of a system will be determined by both the likely responses of the resources and the availability of resources and, crucially, whether the systems can call upon these resources (Füssel and Klein, 2006). The IPCC state that vulnerability is 'the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity' (McCarthy, 2001). Blaikie's (1994: 9) definition of vulnerability is a sound starting point for defining vulnerability from a natural hazards perspective. They define it as 'the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard'. Kelly and Adger (2000) develop Blaikie's (1994) work and define vulnerability as 'the ability or inability of individuals or social groupings to respond to, in the sense of cope with, recover from or adapt to, any external stress placed on their livelihoods and well-being' (Kelly and Adger, 2000: 328).

When discussing vulnerability in terms of future changes, the term 'adaptive capacity' arises. This is the ability for a system, whether individual or group, to adjust to the potential risks by taking advantage of opportunities and coping with negative effects (WHO, 2003). The IPCC define adaptive capacity as 'the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences' (McCarthy, 2001).

3.5.4 Resilience

It is generally assumed that the more resilient a 'system' is, the better able to cope with the impacts of extremes it will be. For assumptions to be made however, it is important to understand what is meant by resilience. The term 'resilience' was first introduced by Holling in 1973 in relation to ecosystems, defined as 'resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist' (Holling, 1973: 17). Literature continued to explore resilience to ecological systems until Timmerman 1981 introduced the concept to climate change literature in terms of social resilience. He defines resilience as 'the measure of systems, or part of a system's capacity to absorb and recover from the occurrence of a hazardous event' (Timmerman, 1981: 21). Similar to the concepts of anticipatory and reactive adaptation, Dovers and Handmer (1992) suggest that resilience of society can be reactive or proactive. Resilience has become more commonly used in climate research, with the aim of attempting to understand what makes various systems resilient, establishing principles and processes that strengthen resilience and building case studies of successful examples. This is in contrast to adaptation research, which is 'system' based, meaning it is focussed on reducing vulnerability to a specific risk, but is limited, which is already apparent in areas such as population movement and migration (Nelson et al., 2007). Resilience in environmental change looks at social and ecological systems as a combined system where neither system can be considered without the other (Nelson et al., 2007). This is based on social and ecological theory, which is the perspective of social elements and the environment being interrelated.

Adger (2000: 347) developed on these ideas of ecological resilience and social resilience and investigated the links between the two. He defines resilience as 'the ability of groups or communities to cope with external stresses and disturbances as a result of social, political and environmental change'. Following this, an additional combined concept in socio and ecology systems literature emerged. Folke (2006) provides a robust review of the concept of resilience in his paper 'Resilience: The emergence of a perspective for social-ecological systems analyses'.

In common with the literature on adaptation and vulnerability, there are numerous definitions of resilience. The IPCC defines resilience as 'the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change' McCarthy (2001). Thus, resilience is about elasticity of a system, enabling the ability for it to 'bounce back' after any form of stress or shock (Pelling, 2011). Resilience to environmental change focuses on adaptive capacity and creating robustness and flexibility regarding uncertainties in the future, which is a factor that anticipatory adaptation lacks (Nelson et al., 2007).

3.5.5 Linking adaptation, vulnerability and resilience: The health context

As evidence of climate change and the potential impacts on human health is recognised, public health adaptation has become more important in the climate change agenda (Huang et al., 2011). It is thought that in order to manage climate change effects, integrated policies of adaptation to reduce vulnerability and increase resilience are required to deal with the anticipated changes. This is even more important in poor regions as it is expected that the effects of climate change will be disproportionately distributed globally, with populations of poor regions suffering the most adverse impacts. The Legal Amazon is already experiencing increases in hydrological extremes and is one of the poorest regions in Brazil, thus understanding how to cope with these changes is vital.

Generally, public health adaptations are either short- or long-term strategies which can reduce the adverse impacts or increase resilience to climate change (Huang et al., 2011). The importance of vulnerability is often raised when discussing adaptation measures to reduce the human health impact of climate change, since without this knowledge, approaches would be ill informed and could lead to maladaptation. Therefore, an understanding of a population’s vulnerability and capacity to deal with changing conditions is required. It is suggested that adaptation to public health can take two streams; building adaptive capacity and implementing adaptation actions (Huang et al., 2011). In order to assess potential health risks of climate change, the vulnerability of the population and its adaptive capacity need to be understood, particularly when the success of adaptation depends on adaptive capacity and how it is distributed (WHO, 2003). Vulnerability has been discussed in section 3.5.3, but in terms of health, Ebi et al. (2006) define health vulnerability to climate change as a function of three things: sensitivity, exposure to the climate-related hazard, and adaptation measures and actions in place to reduce the impact. Vulnerability in terms of health risks depends on numerous factors, including the local environment and quality of health services (Woodward et al., 1998). Therefore, it is imperative to know these factors and a population’s adaptive capacity to in order to assess the potential health effects.

Any adaptation to climate change may be difficult to advocate, depending on government input and knowledge; however, management of the health effects of climate change is a significant challenge due to the scale and complexity of how climatic changes may influence health. Costello et al. (2009) suggest that input from governments and society, as well as collaboration between academic disciplines, is needed to manage these effects. Moreover, the involvement of local communities is crucial to understanding how changes affect them. Involvement of local communities is referred to as a 'bottom-up' approach to policy. Another challenge in creating adaptation policies arises when including populations who may not fully understand the risks of climate change. It could be argued that educating populations about climate change, extreme events and their impacts may instil a type of panic in them. Moreover, educating them on the uncertainty of particular events and changes may result in mental health illnesses in populations (Costello et al., 2009).

3.5.6 Brazilian adaptation

Pelling (2011) suggests that not for the first time has the notion of sustainable development been used, since our current stage of adaptation follows a previous endeavour which failed. It is this notion of sustainable development which leads to this discussion on Brazilian adaptation. To date, policies in Brazil appear to be directed towards sustainable development, and any adaptation has generally been carried out by small-farm owners.

A range of sustainable development initiatives operate in Brazil, and many have been implemented in the Amazon. Projects included support for extractive reserves (RESEX), environmental management for selected areas, forestry and floodplain management, ecological-economic zoning, demarcation of indigenous land, fire prevention and control, support for science and technology, and protected area planning and creation of 'ecological corridors' (Fearnside, 2009). Further details of some of these examples can be found in chapter 2, section 2.2.

Hydrological events are common in the Legal Amazon as they are part of natural climate variability. Populations have learnt to adapt to the hydrological interannual variability, and have developed their livelihood strategies (Marengo et al., 2013). As noted previously, the effects of climate change and the ability to cope with them are disproportionately distributed, with developing countries lagging behind others. Barriers to adaptation can be found in the Legal Amazon, including a lack of awareness, a lack of understanding, and limited capacity to make decisions from both the scientific and policy-making perspectives (Marengo et al., 2013). Following the hydrological extremes of 2005, 2009, and 2010, the government provided food supplies, medical supplies and clean water to isolated populations; however, once the event ended, the government stopped providing these (Borma, 2013). Although this shows, to a certain degree, the government assisting, it can also be considered to be maladaptation because help was withdrawn immediately following the event, when in reality populations will need assistance for a sustained period of time. In terms of agricultural practices, Brondizio and Moran (2008) showed that when farmers in Pará State did try to adapt to drought events, this was achieved in small degrees, such as delaying burning and replanting, and talking more with neighbours about when, where and how to burn. If they needed to compensate for the impact of droughts, some would sell cattle. Interestingly, however, this study found that 50% of farmers interviewed in 2002 did not remember the drought of 1997/1998, which the authors suggest might explain why 40% of farmers have not changed their farming practices. This highlights the need for knowledge and understanding in order to be able to adapt. This is discussed in relation to respiratory diseases in chapter 7.

Costello et al. (2009) suggest that reliable, relevant and up-to-date information is needed to address the impacts of climate change. Further, they state that without political involvement and institutional capacity, information is worthless. Nevertheless, without information, political will and institutional capacity will achieve little (Costello et al., 2009). This issue of political involvement is reinforced by Pelling (2011), who suggests that adaptation is a social and political act, and Adger et al. (2009) also bring the concept of political justice to climate change adaptation. Although the Brazilian National Climate Policy has set out a number of actions (section 2.2.3), none of these look at measures to reduce the risk to health from climate change; they are much broader and aimed towards mitigating climate change. The need for climate-health research is written in the policy, but no action in the plan actually addresses this. This could be due to the fact that there is such a limited amount of research to date on the topic. It is suggested that multi-sector and multidisciplinary research and co-operation within government domains are needed to ensure climate-health research is carried out and suitable measures are put in place.

The climatic and environmental conditions in Amazonia, together with the climate, environment and health links, have been discussed. However, in the Legal Amazon, where it has been shown that extremes are becoming more common and human disturbances exist, it remains to be demonstrated how these issues interact. For example, no studies have assessed the impact of hydrological extremes on respiratory diseases in the Legal Amazon. The following section will discuss respiratory diseases in the context of the Legal Amazon.

3.6 The Legal Amazon Experience

3.6.1 Introduction

The previous sections have shown an evidence base for the link between the climate, environment, hydrological extremes, and human disturbances with respiratory diseases. In this context, the majority of worldwide studies assess the impacts of air pollution and respiratory health, but these are predominantly in developed countries and concentrated on larger cities. This is also the case in Brazil, where most studies on respiratory diseases have been carried out in large urban areas or areas of sugarcane production (Mallol et al., 2000), which, although important in their own right, have environments that differ from those of locations within the Legal Amazon. They tend to be more industrialised, densely populated, have a different climate and their seasonality is not as pronounced (Rosa et al., 2008b). Moreover, unlike urban areas where exposure to air pollution is characterised by chronic exposure, the Legal Amazon experiences acute exposure for three to five months during the dry season (Ignotti et al., 2010b), with smoke tending to be composed of ultrafine particles ($PM_{2.5}$) and likely to remain in the atmosphere for around two to three weeks. In the Legal Amazon, high levels of biomass burning takes place, releasing large proportions of particulate matter into the atmosphere, which is a key issue in terms of air pollution in large areas of South America (Ignotti et al., 2010b). This has the potential to impact upon both the local population in close proximity to any fire outbreak and the population away from the source, as smoke can travel thousands of kilometres (Ignotti et al., 2010b); dispersion of smoke has also been noted during the Indonesian fires of 1997 when countries as far away as Thailand felt the effects of the haze (Mott et al., 2005).

Despite respiratory diseases being one of the leading causes of hospitalisations in the Legal Amazon for the period 2001–2010 (DATASUS, 2011b), and high levels of air pollution being recorded, research has only emerged in recent years. Air pollution studies in the Legal Amazon began in 1998 through the Centre for Weather Forecasting and Climate Research (Centro de Previsão de Tempo e Estudos Climáticos, CPTEC)/INPE, but it was not until 2008 that the first findings, suggesting an association between air quality and respiratory health in the region, were published (Rosa et al., 2008b). Literature assessing the temporal and spatial trend of respiratory diseases tends to focus on asthma (five studies) rather than respiratory diseases as a whole (two studies). However, when assessing the impacts of air pollution or fire incidence on the respiratory health of the population, studies look at all respiratory diseases.

3.6.2 Respiratory health in the Legal Amazon

The initial study which was carried out in 2007 on respiratory diseases in the Legal Amazon created an indicator for selecting municipalities rather than linking respiratory diseases with environmental factors or air pollution. It was carried out in Mato Grosso because this region experiences a high number of fires and is within the 'arc of deforestation'. The indicator was created for municipalities for children under five years, based on the proportion of deaths, rate of hospitalisation, and proportion of admission for the period 2000 to 2004. Municipalities were ranked on the median of the mortality ratio and mortality rate, and then ranked on the proportion of deaths and admissions. The scores which each obtained, based on their ranking, were combined to show the municipalities with the largest respiratory health problem. Alta Floresta, Barra do Bugres, Barra do Garças, Juara, and Tangará da Serra were identified as the most relevant, and Alta Floresta and Tangará da Serra were selected because of their location within the Legal Amazon; they are both home to regional health services and have meteorological data available (Ignotti, 2007). This study seems to have set the scene for subsequent studies on respiratory health in the Legal Amazon as they are carried out predominantly in Alta Floresta, Tangará da Serra or Mato Grosso State. Several studies have assessed spatial distribution, seasonality, and gender differences in respiratory diseases or, more commonly, just asthma. More recently, studies have assessed the impact of air pollution, especially particulate matter, on respiratory diseases.

There is a lack of research on the spatial distribution of respiratory diseases in the Legal Amazon; the only two studies to date have solely assessed the spatial distribution of asthma. Silva et al. (2009) investigated the spatial distribution of asthma in children younger than 15 years old, and Rodrigues et al. (2009) assessed adults over 60 years old. Both studies identified higher rates resembling the configuration of the 'arc of deforestation', with a main hotspot being in Rondônia State. Rodrigues et al. (2009) found that hospital admissions were higher in the east and south of the Legal Amazon, with a hotspot in central south Rondônia representing 13.6% admissions, and the north central area of Amazonia experiencing much lower rates of 0.74% admissions. The high prevalence in the east and south of the Legal Amazon concurs with asthma prevalence of children and adolescents (Silva et al., 2009). Rondônia could be a hotspot for both age groups because it is known to experience high numbers of fires and high rates of deforestation, both of which have been shown to influence the development of respiratory health problems. Silva et al. (2009) also found a hotspot in Maranhão, which they linked to low human development levels within the state. A previous study conducted in Maranhão found that hospitalisations in children for any reason were more common in children from families with lower socio-economic status (Silva et al., 1999). This concurs with the work carried out by Mallol et al. (2000) and Gonçalves-Silva et al. (2006), which shows asthmatic symptoms were higher in locations with lower socio-economic levels.

Contrasting findings have been documented about the seasonality of respiratory diseases and asthma, even within the same study location. Rosa et al. (2008b) observed a 21% reduction in primary care visits for respiratory diseases during the dry season (May–October) in children under 15 years of age compared to the wet season (November–April) between 2004 and 2005 in Tangará da Serra. The greatest frequency of visits was recorded in March and April, which is at the end of the wet season; visits declined thereafter until a second peak in August. Interestingly, when examining hospitalisations rather than primary care visits, the peak also occurred in March; however, there were 10% more hospitalisations in the dry season compared to the wet season (Rosa et al., 2008a), suggesting that more serious cases happen in the dry season. Results for hospitalisations due to asthma in the same age group across the Legal Amazon concur with the findings of Rosa et al. (2008b) in Tangará da Serra, that a higher proportion of hospitalisations occur in the wet season (Silva et al., 2009). Silva et al. (2009) show that Rondônia State has the highest rate of hospitalisations for asthma and this peaks in May and June, while the other states peaked in March and May. Similarly to hospitalisations for respiratory diseases in Tangará da Serra, their study shows that on average across the Legal Amazon there is a 10% higher proportion of hospitalisations for asthma in the rainy season. The largest difference between seasons was observed in Mato Grosso State, where the number of hospitalisations of children was 17% higher in the rainy season when compared to the dry season. It is expected that in dry season months, there are higher rates of hospitalisations for respiratory diseases due to high levels of air pollution from forest fires (Silva et al., 2009). Although some studies have shown higher frequency of outcomes for respiratory diseases in the dry season, peaks occur at the end of the wet season, which could be due to higher levels of humidity and thus increases in moulds. Croce et al. (1998) reported that during the rainy season, an increase in humidity leads to an increase in the prevalence of funguses and mites that are significant allergens for the occurrence of asthmatic crises. Further to this, Pauliquevis et al. (2007) showed that there is a higher concentration of fragments of leaves, pollen grains, bacteria and funguses in the rainy season than the drought season. This concurs with the findings of Silva et al. (2009) that there is a relationship between hospitalisation for asthma and the months in the rainy season. In contrast to other studies discussed, which investigate asthma prevalence in children and adolescents, Rodrigues et al. (2009) studied hospitalisation rates for asthma among elderly people in the Legal Amazon. They too found peaks of hospitalisations at the end of the wet season; a greater proportion of hospitalisations occurred between July and October, with rates sometimes double or even triple, those seen earlier in the wet season. By contrast, Valença et al. (2006) found the highest rates of hospitalisation for asthma occurred in the rainy season.

Rosa et al. (2009) carried out a study in Tangará de Serra to analyse the prevalence of asthma and its symptoms among children and adolescents. Their findings suggest that there is a higher prevalence of childhood asthma than asthma in adolescents. However, unlike other studies carried out where there appears to be a higher prevalence in males in childhood and girls in adolescence, they did not find a statistically significant gender-based difference. Farias et al. (2010) found that the prevalence of asthma in Alta Floresta is higher among children than among adolescents, and in both age groups, males experienced higher prevalence than girls. This contradicts other literature on asthma, which suggests that prevalence of asthma is higher among boys in childhood and girls in adolescence, which is due to biological difference of these groups. However, when studying the International Study of Asthma and Allergies in Childhood (ISAAC) centres from phase 1 in Latin America, there appeared to be no significant differences in asthma prevalence between genders (Mallol et al., 2000).

The studies carried out on respiratory health in the Legal Amazon have been conducted using the ISAAC questionnaire or hospital records. Rosa et al. (2009) and Farias et al. (2010) used a descriptive population-based method using the phase one questionnaire produced by the ISAAC. This is an international standardised questionnaire and has been validated in Brazil, while Silva et al. (2009) and Rodrigues et al. (2009) used the health records from SUS. Although the ISAAC questionnaire is internationally standardised, it is a self-assessed questionnaire where either parents or adolescents answer questions that covered: the presence of wheezing in the last 12 months, frequency of wheezing attacks, frequency of wheezing preventing sleep, and wheezing after physical exercise. Considering that asthma is difficult to diagnose, and most of the cases are identified only when there is a relapse after the first hospitalisation (Silva et al., 2009), it may be unreliable to base asthma prevalence on a self-assessed questionnaire. Even among medical practitioners in Brazil, asthma is often diagnosed as pneumonia, bronchitis, or lower airway infection, due to the difficulty in diagnosis (Farhat et al., 2005). In addition to this, the questions in the ISAAC questionnaire do not allow for factors such as the physical state of the child, nor does it define meanings. Without defining the meaning, what one person may consider wheezing, another may not. A study carried out by Farhat et al. (2005) in 2005 used hospital data but they noted asthma and bronchitis were included in the same disease group due to the potential misclassification of wheezing. This furthers the need to understand the meaning of wheezing. By using data collected from SUS, data is likely to be more reliable and has a medical background to validate the diagnosis. However, data on hospitalisation rates may not give a true representation of prevalence because hospitalisation is influenced by a number of factors: the financial aspects, the availability of hospital beds, and the different practices, therefore the data is not strictly related to the need for healthcare (Silva et al., 2009).

The spatial distribution of asthma has been shown conclusively to resemble the ‘arc of deforestation’, while the temporal trend of respiratory diseases and asthma varies with location in the Legal Amazon and with age group. There is strong evidence around the world that air pollution and respiratory disease are associated. Studies in Brazil and the Legal Amazon also show this association, with most of the evidence being based on time-series analysis in both Brazil (Gouveia et al., 2003; Martins et al., 2002) and the Legal Amazon.

In 2005, Acre State experienced drought-related air pollution which was possibly the worst in 60 years (Mascarenhas et al., 2008). During the month of September 2005 in Rio Branco, the state capital, levels of $PM_{2.5}$ exceeded the suggested air quality levels established by the WHO (25µg/m^3 per 24 hours) on 23 days, with the highest concentrations observed between the 16th and 20th September, where levels reached 450µg/m^3. Mascarenhas et al. (2008) observed a significantly positive relationship between seven-day sliding $PM_{2.5}$ means and the number of emergency room visits for asthma during the month of September. Also a 3-4 day lag in peaks in $PM_{2.5}$ measurements and increases in the number of respiratory disease-related hospitalisations was observed. More recently, Carmo et al. (2013) investigated the impacts of $PM_{2.5}$ and humidity exposure on daily demand for hospital admissions for children between 2004 and 2009. They found that for the five year period, a two-day lag from exposure resulted in the highest statistically significant increase in hospitalisations; for increases of 10µg/m^3 in $PM_{2.5}$, a 5.6% increase in hospitalisations was observed.

Research primarily assesses the impacts on children and elderly morbidity rates in associations with $PM_{2.5}$ levels. Castro et al. (2009), however, assessed the relationship between fires and mortality rates for all respiratory diseases and just Chronic Obstructive Pulmonary Disease (COPD) in the elderly in the state of Rondônia. They showed that there is a significantly positive relationship between the number of fires and mortality rates for all respiratory diseases, in both 65-74 year olds ($r^2 = 0.73$, $p < 0.001$) and those older than 74 years of age ($r^2 = 0.94$, $p < 0.001$), with a stronger relationship in the older age group. In comparison, a stronger relationship was identified for COPD in the younger age group; 64-75 showed a significantly positive relationship of ($r^2 = 76$, $p < 0.001$), while 75+ for

COPD did not have as strong a relationship with fires compared to all respiratory diseases (r^2 = 87, p =< 0.001).

When assessing daily levels of $PM_{2.5}$ and outpatient data for children in Alta Floresta, Mato Grosso, Carmo et al. (2010) found a direct linear association between $PM_{2.5}$ and demand on outpatient services for children (14%); however, this was not observed in elderly people (2%). Statistically significant associations were observed between exposure and demand, showing a 2.9% increase in demand on the 6th day and 2.6% on the 7th day of exposure. A more recent study, also carried out in Mato Grosso by Silva et al. (2013), explored the relationship between $PM_{2.5}$ and hospital admissions in Cuiaba for both children and adults in 2005. Using daily data for hospitalisations and $PM_{2.5}$ level, they showed statistical associations throughout the entire year; a 9.1% (one day), 9.2% (two days) and 12.0% (five days) increase in hospitalisations in relation to an increase of $10\mu g/m^3$ in $PM_{2.5}$ for children. During the dry season, associations were greater, showing increases in of 11.4% (one day), 21.6% (five days), and 22.0% (six days). Although Castro et al. (2009) studied respiratory diseases in the elderly in relation to fires, rather than $PM_{2.5}$, they showed statistically significant associations. No statistically significant associations with the elderly were found in the study by Silva et al. (2013). This could be attributed to the different methodological approaches the two studies used, or to the different locations which may have different vegetation types and thus different compounds of air pollution.

These studies have shown the temporal impacts that air pollution can have on the respiratory health of the population. Despite using similar methods, results from these studies show how different locations can have a different effect on the development of respiratory diseases. These results highlight the need for spatial analysis in the Legal Amazon and the two studies to date that carry out spatial analysis will now be discussed. One study was carried out for the entire Legal Amazon and one was confined to Mato Grosso State. In 2010, Ignotti et al. (2010b) proposed a new method for assessing the impacts of $PM_{2.5}$ on respiratory diseases; they used the percentage of annual hours (AH%) that $PM_{2.5}$ was above 80 µg/m3, as defined by the Oregon Department of Environmental Quality. This was done for micro-regions throughout the Legal Amazon and analysed with hospitalisation data. Micro-regions in the 'arc of deforestation' showed the highest levels of exposure above 80µg/m^3, and had the smallest variation suggesting consistently high exposure to PM$_{2.5}$. Rates were also shown as percentages; for a 1% increase in PM$_{2.5}$, hospitalisations increased by 8% for under-fives, and 10% for adults over 65 years of age. A significant correlation between AH% and rates of hospitalisations for all age groups was observed, with the elderly showing the strongest correlation ($r^2 = 0.55$, $p < 0.01$), while in children under five, the correlation was weaker ($r^2 = 0.38$, $p < 0.01$). Moreover, Ignotti et al. (2010b) ran the analysis with childbirth as it is expected that hospitalisations for this would not be influenced by levels of PM$_{2.5}$; this was shown to be the case, thus suggesting the impact of PM$_{2.5}$ on respiratory diseases is a true association.

Silva et al. (2010) used the same method developed by Ignotti et al. (2010b) to assess the spatial distribution of PM$_{2.5}$ and respiratory diseases in the municipalities of Mato Grosso for children under five and adults aged 65 and above. When assessing the distribution of PM$_{2.5}$, they found higher levels were concentrated in the rainforest-type vegetation region of the state, with lower levels in the savannah-type part of the state. This was also the case when investigating which municipalities had the highest prevalence of hospitalisations. However, when assessing the correlation between variables, AH% and hospitalisations showed a weak correlation compared to other variables. A significantly positive correlation was observed between AH% and hospitalisations for both under-fives (11.8%) and 65 years and above (14.4%), but stronger correlations were observed between respiratory diseases and the presence of hospital admissions in both age groups, 28% ($p < 0.05$), and 35% ($p < 0.05$) respectively.

This section has discussed the current research on respiratory diseases in the Legal Amazon. As can be seen, there has been no evidence of research assessing the impacts of hydrological extremes, and few spatial analyses of the respiratory health of the population.

3.7 Summary

This chapter reviewed recent hydrological extremes and climate/environmental change impacts on health, before offering detail about the links with respiratory diseases. It has shown that hydrological events in the Amazon have become more frequent in recent years and has highlighted the vulnerability of the Legal Amazon to climatic changes. Not only is the forest vulnerable to these changes, but so is the respiratory health of the population living there. It has been shown that high rates of respiratory diseases persist particularly around the 'arc of deforestation' where high levels of air pollution have been recorded, and that during periods of high levels of $PM_{2.5}$, increases in various health outcomes for respiratory diseases have been recorded.

There is evidence from around the world on the relationship between hydrological extremes, human disturbances (particularly fires) and respiratory health, with research on the topic in the Legal Amazon becoming more common. However, apart from studies assessing the spatial and temporal distribution of respiratory diseases, studies are localised and none assess the impacts of large events, such as a drought or flood, which have been shown to be becoming more frequent and possibly the norm for the region. Localised studies are extremely useful in understanding the immediate impact of humidity, temperature, and air pollution, but the region is large, with vast environmental difference across it. In the literature, there is a lack of wide scale spatial analysis, particularly of large events. This thesis aims to contribute to the evidence, and the next chapter discusses the methods and datasets used to substantiate this evidence.

Chapter 4

Data and Methodology

4.1 Introduction

The aim of this chapter is to introduce the datasets and methods that have been used in this study. The datasets include remote sensed data and social data for developing a spatial data analysis to analyse the impacts of hydrological extremes on respiratory diseases in children in the Legal Amazon. The spatial data analysis is a significant component of this thesis because it assists in answering three of the four research questions which investigate *where* and *how*.

This thesis assesses the impacts of hydrological extremes on respiratory health and therefore is only looking at the variables considered to be directly associated to them rather than assessing a suite of possible environmental variables. In addition, it is known that socio-economic levels can influence the development of respiratory diseases thus two broad social variables are included. By examining only associated variables, the research begins to uncover how these events impact on the respiratory health of children under five and key locations within the Legal Amazon which can be investigated in more detail through future research. The datasets used in the spatial data analysis will be discussed first, followed by discussion of the primary data collection methods. The environmental and social variables were used because they are closely linked to both hydrological extremes and the development of respiratory diseases. Primary data collection was used to help to understand the local population's knowledge of the topics being addressed in this thesis.

4.2 Remote Sensed Data

This section presents the remotely sensed data that has been used throughout the research and details the method of calculating anomalies. All datasets were collected for the same time series (January 2001–December 2010) where possible – the rate of deforestation is an annual measurement rather than monthly like the other datasets used. Due to the nature of the research, when conducting spatial data analysis (section 3.4), all of the environmental datasets have been aggregated to the micro-region and municipality levels to correspond with the spatial units of social data. When aggregating the environmental datasets, mean values across the micro-regions and municipalities have been used. The gridded environmental data was converted to point data using the centroid of each grid. Following this the point data was spatially joined to each municipality and micro-region based on all points that fell within the boundary. AOD data has a larger spatial resolution so the grids were rescaled from 1° x 1° to 0.25° x 0.25° before the conversion to point occurred. This ensured there was at least one point for each municipality.

4.2.1 Datasets

It is known that various environmental factors can influence the development of respiratory diseases; however, this research is interested in the impacts of hydrological extremes and human disturbances and therefore is only examining the impacts of direct associations. Therefore, four variables are being used rather than looking at all possible environmental variables that could contribute to the development of respiratory diseases.

Rainfall

Rainfall data has been used because it provides information on where the hydrological extremes have occurred based on the criteria set out in section 3.2.3. It was obtained from observed gridded (0.25° x 0.25° spatial resolution) average monthly best-estimate precipitation rate data (mm/hr) from the Tropical Rainfall Measure Mission (TRMM) using product 3B43-v6 (NASA, 2010). The dataset is merged TRMM and other satellite estimates with measurements from 1998 to 2011 produced by the NASA/ Goddard Distributed Active Archive Centre (GES DISC DAAC). The TRMM calculated monthly data by combining the 3-hourly merged estimates with the monthly accumulated Climate Assessment and Monitoring System (CAMS) or Global Precipitation Climatology Centre (GPCC) rain gauge analysis (3A-45) (NASA, 2010). Further information on the product and the process of calculating the monthly data can been found at http://mirador.gsfc.nasa.gov/collections/TRMM_3B43__007.shtml.

Active Fires

Fire data allows the opportunity to examine the relationship between drought events and fire occurrence as well as suggesting locations within the Legal Amazon where air pollution may be higher, thus identifying locations with greater risk of respiratory diseases. Data was acquired from the INPE Prediction Centre of Weather and Climate (Centro de Previsão de Tempo e Estudos Climáticos, CPTEC) Queimadas database (INPE, 2012b). Active fire data or hotspots have been derived from monthly University of Maryland Terra and Aqua satellites at the spatial resolution of 1 x 1 kilometres. The satellites pass over the equator at 0300 and 1400, and 0400 and 1700 GMT.

Aerosol Optical Depth/Thickness (AOD/T)

Aerosol Optical Depth/Thickness (AOD/T) (will be referred to as AOD in the remainder of the text) data has been used to assess actual levels of air pollution across the Legal Amazon, as studies elsewhere (discussed in Chapter 3) have found associations between air pollution and respiratory diseases. MODIS Level 3 Monthly Atmosphere Gridded product (1° x 1°, MOD08_M3 collection 051) was utilised. A subset of this dataset: AOD at 0.55 microns for both Ocean (best) and

Land (corrected): Maximum of Daily Mean was used. It was obtained from NASA/Goddard Space Flight Centre Level 1 and Atmosphere Archive and Distribution System (LAADS Web) (NASA, 2011a). Values vary between -1 and 5 (adimentional); the higher the value, the more concentration of particles in the air. The dataset is calculated using the Terra platform that overpasses the equator at around 1030 local solar time in its descending (daytime) mode and 2230 local solar time in its ascending (night-time) mode. Further information on how the maximum daily mean is calculated can been found at http://modis-atmos.gsfc.nasa.gov/MOD08_M3/index.html.

Deforestation

Deforestation data has been used to identify possible locations of where fires may occur as well as locations where increased aerosol loads may be due to exposure of soil and the particles released during the process. Deforestation data has been obtained at the Coordination of Earth Observation (Coordenação de Observação da Terra/OBT) from INPE's PRODES project at the spatial resolution of 120 x 120 metres (INPE, 2012a). PRODES monitors deforestation in the Brazilian Amazon. Unlike the other environmental variables, the measurement for the deforestation rate is an annual count, calculated from August to August.

4.2.2 Limitations of remote sensed data

The data used here has been used in similar studies and, therefore, assumed to be good quality. For example, Aragão et al. (2007b) validated the TRMM dataset evidencing the relationship between satellite-derived rainfall and rain gauges data in Amazonia. There may be some limitations in the data which are worthy of note but these do not compromise the research. Hotspots are indicators of fires which, although they may be underestimated, do allow for patterns over time to be seen (Aragão et al., 2008). Particulate matter $PM_{2.5}$ and PM_{10} has been shown to have a positive relationship with respiratory diseases (Chapter 3); however, this study used AOD data because there are a limited number of air pollution monitoring stations within the Legal Amazon. CPTEC INPE have a particulate matter model and have validated it against the MODIS data being used in this research and confirmed it is similar if using mean maximum values, which have been used in this research based on their advice. The format of the CPTEC model data was not helpful for this research and time constraints for processing it to a useable format would have made this impossible. Another limitation is that deforestation data is recorded annually rather than monthly. Although this does not provide an accurate comparison between fires and deforestation, it is suitable for the analysis of spatial patterns and is the best deforestation data available.

4.2.3 Extreme climatic events & human disturbances

To quantify the spatial and temporal extent of the extreme climatic events, rainfall surfaces of TRMM data were grouped at 3-monthly intervals to show seasonal differences (January–March JFM, April–June AMJ, July–September JAS, and October– December OND). Rainfall anomalies were calculated for each year (y), each quarter (q) and at a cell by cell (i, j) level based on the departure from the 2001–2010 mean (TRMM 2001–2010) and normalised by the standard deviation (σ 2001-2010) (equation 1) (Aragão et al., 2007b).

$$TRMM\ anomaly, q(i,j) = \frac{TRMMy, q(i,j) - \ TRMM\ 2001 - 2010\ (i,j)}{\sigma\ 2001 - 2010\ (i,j)}$$

(equation 4.1)

Rainfall anomalies alone are not sufficient to identify areas of drought in the Legal Amazon. Work carried out by Shuttleworth et al. (1989) and Rocha et al. (2004) have shown that within the region, the forest enters into water deficit when monthly rainfall is 100 mm or less. For this reason, in this study, critical areas of drought within the Legal Amazon have been defined as micro-regions and municipalities with at least one anomalous cell (≤ -1 σ) and ≤ 300 mm of cumulative rainfall per quarter to ensure drought conditions were experienced rather than the normal climate for the micro-region/municipality as different vegetation types and climates are present in the region.

Defining areas of flooding for the region is more difficult as, unlike droughts, there is no clear definition. It was anticipated that data from the Brazilian Civil Defence could be used to identify municipalities which were in a ‘state of emergency’ because of the flooding in 2009 but this information was unavailable and, therefore, positive rainfall anomalies ($\leq 1\ \sigma$) alone are being used to define flood-affected micro-regions and municipalities.

Anomalies were also calculated for active fires and aerosol. Both were calculated using a similar method to the equation 1, where active fire density was based on the accumulation of hot pixel counts for each quarter and mean-maximum values for aerosol surfaces were grouped at the same 3-monthly intervals.

Data management was carried out using ENVI 4.8 and ArcGIS 10.

4.3 Social Data

This section details the social datasets that have been used throughout the research and the method of age standardisation that was used when answering research question two: what was the spatial and temporal distribution of respiratory diseases within the basin between 2001 and 2010? As with the remotely sensed data, collection was for the same time series, January 2001–December 2010, but with focus on 2005, 2009 and 2010. Three social datasets have been used:

- Hospitalisation data
- Population data
- Human Development Index (HDI)

Count data of hospitalisations for all children aged under five years was used for the number of hospitalisations for respiratory diseases per month and per micro-region and municipality. Population density (IBGE, 2010) was used to create Age Standardised Rates (ASR) (section 3.3.3), and previous studies have suggested variability in asthma prevalence could be due to population density (Mallol et al., 2007). Population density can also be used as an urbanisation index which may account for some types of urban air pollution. HDI (Firjan, 2013) was used as an indicator for socio-economic levels and development of each municipality because asthma studies in Latin America have identified that a low socio-economic level is associated with the disease (Mallol et al., 2000) (Gonçalves-Silva et al., 2006).

A large proportion of the Legal Amazon population uses the public health system – SUS – which was confirmed in discussion with health researchers from FIOCRUZ during a fieldtrip. Therefore the data obtained through the SUS system can be considered to be a reliable representation of the health problems of the population.

The database of SUS is managed by the Ministry of Health through the Secretariat of Health, together with the Health Secretariats of each municipality. Hospitals that participate in the SUS service send information to the municipality managers (if municipalities have full management,) or the state, which is then processed in DATASUS to provide information about the total number of hospital admissions in Brazil. It was noted that the original data used to be recorded by hand, so although the quality will be good, the re-recording on the computer system may be less reliable, depending on the staff employed at the time; for some years, the data capture might be better than others, depending on the quality of the employees. It has also been suggested that the larger municipalities are wealthier than the smaller ones and in turn the larger municipalities have better quality data.

Moreover, health researchers at FIOCRUZ in Brazil advised that in order to obtain more accurate data, one needs to go to the Health Secretariat directly, but this is only feasible when carrying out research in one or two locations. To obtain a large amount of health data remotely and for a large study region, SUS data is recommended.

4.3.1 Datasets

Health Data

Databases of the Hospital Information System (Sistema de Informações Hospitalares, SUS) of the Brazilian Ministry of Health were utilised to obtain information regarding hospitalisation data for respiratory diseases (DATASUS, 2011b). Chapter X, Diseases of the Respiratory System, of the International Classification of Diseases revision 10 was used for all disease codes (coded from J00 to J99), for people living in the Legal Amazon between 2001–2010. Hospitalisation data for all children aged under five years consisted of: primary cause of hospitalisation being coded J00 to J99, paid hospital admissions (Autorizações de Internações Hospitalares), micro-region/municipality of residence, year of admission, and month of admission. Cases were selected based on residence rather than hospital attended; this ensures a better representation of the spatial distribution of the exposed population to the environmental factors. It should be noted that the study population refers to those who are treated by the SUS (approximately 75%) so it does not represent total cases, since users of private health care are not included. Moreover, hospitalisation data represents the more severe cases, excluding those who attend outpatient or primary care.

The choice to study all respiratory diseases rather than specific diseases was made because the focus of similar studies in the Legal Amazon and elsewhere has been carried out in relation to all respiratory diseases not specific respiratory diseases. Moreover, there have been reported incidences of misclassification of respiratory disease diagnoses because the symptoms for many respiratory diseases are similar, particularly in young children (Farhat et al., 2005).

Population

Population data according to micro-region, municipality and age group has been obtained from the IBGE (IBGE, 2010). Population census data was used for 2010, while the other years are based on population estimates created by IBGE. In 2007, a population count was carried out so this data was used for that year.

Human Development Index

HDI is a United Nations statistic calculated per country that includes life expectancy, education, and income indices in order to rank countries. A countrywide value is not appropriate for this study because Brazil is a vast country with regional differences. Municipality values (IDH-M) have been produced in Brazil by the United Nations Development Programme (Programa das Nações Unidas para o Desenvolvimento, PNUD) for the 2000 and 2010 censuses. HDI values have been created for years in between the census years by Sistema Firjan, known as the FIRJAN Municipal Development Index (Índice FIRJAN de Desenvolvimento Municipal IFDM) (Firjan, 2013), based on income and employment, education, and health. The IFDM has been used in this study because it covers the years of hydrological extremes. When discussing the Sistema Firjan index in the remainder of the text, it will be referred to as HDI rather than IFDM.

4.3.2 Limitation of social data

It is important to set out the way in which any limitations of the social data used in this research were identified and treated in order to reduce any uncertainty in data validity. During discussions with FIOCRUZ researchers, it was intimated that monthly data for any cause of hospitalisation may be misrepresented because the government has set a financial quota for treatment per month for each disease. If the hospitalisations of a certain disease result in the cost of treatment exceeding the monthly budget, then cases are recorded in the following month. This tends to be only a small number of cases and rarely occurs, however. It has been suggested that this happens because municipalities may have some unease with regard to the government and would be anxious about the government asking questions as to why in some months there are high cases of certain diseases and thinking there is something wrong with the municipality. When examining the hospitalisation data used in this thesis, the time series of monthly data seemed to be consistent, with the exception of peaks in hydrological extremes, indicating there were no periods of time during the study period where this occurred, or a substantial movement of data occurred. Moreover, other studies on respiratory health in the Legal Amazon have used SUS data.

Duplication of data is another concern with hospitalisation data, although this is not unique to Brazil as it occurs in all countries. Here, data being recorded more than once is not the issue, but rather duplication in terms of people. A person could have a disease such as asthma, and have serious asthma attacks more than once over the year. This person is not recorded on the system as the same person with multiple admissions to hospital; instead they are recorded as separate admissions. Although this can be misleading as it can suggest more people have the disease than the true value, this was not deemed a problem in this thesis. This thesis is interested in investigating the impacts of hydrological extremes on children's respiratory health, and therefore it is not considered important if the hydrological extremes create new health problems in children or exacerbate existing health conditions.

Data was collected using the 'Tabwin' application provided by DATASUS, which provides individual data files in the format of month and state; however, within the files there is an overlap of dates and location for hospitalisation admissions. It appears that the files are based on the date the person was discharged from hospital and treatment was paid for, rather than the admission date. Therefore, some data files after the study period were needed, as payment tends to occur after the patient is discharged from hospital. Due to not knowing the background of the 'Tabwin' application, data files were imported into the Microsoft Office program, Access, and reorganised to create a new table showing hospitalisations by location of residence and month instead of the dates and states combined; one table per state for the period 2001–2011 was produced. This allowed for a comparison of the date of hospitalisation admission based on place of residence against the results from 'Tabwin'. The records of hospitalisations for both organisational methods were the same, thus providing confidence in the 'Tabwin' application and results in this research.

The data files for Acre September 2009 and Amapá October 2007 were not available; however, information regarding hospitalisation admissions for these months is shown within the nature of the file organisation. Therefore, it must be noted that during these times and a few months before (files have a three-month lag between the month and availability online), fewer cases are likely to have been recorded than actually occurred. Furthermore, there may be an issue with the Amapá July 2001 file because there are only 11 records compared to thousands in the rest of the months in 2001. This could either be due to a problem with the file itself or with inaccuracies when the data was transferred from paper copies to electronic storage. Despite the limitations of the health data, it is the best data available to researchers and policy makers without having to go directly to each health centre and ask for the data in person.

The HDI values are created for municipality and hence data was aggregated to include HDI values for micro-regions. Differences in development levels exist within micro-regions, so although this is not the most accurate HDI value for micro-regions, it does provide an overview and is the best way to ensure HDI can be included in the micro-region analysis.

4.3.3 Age standardised rates

In disease mapping, counts are usually shown as rates. The simplest form of a rate using the number of events and population is the *crude rate*; this divides the total number of events by the sum of a population in a year, expressed per 1000, or 100,000. The crude rate shows the actual experience of the population; however, this can confuse comparisons made between groups with different age structures or over time, through distorting the data. For example, some diseases are more prevalent in younger people and others in older people, thus the use of age standardisation will produce an artificial rate that allows comparisons.

To account for the differences in population structures and therefore the risk factors in different groups, analysis of stratum-specific rates can be used. The most common and important method of stratum-specific rates is the age specific rate (Bains). To adjust for fair comparisons for the different age structures either in a population or when comparing two or more populations over time or comparing different populations at one point in time, *age standardisation* can be used. This adjusts differences in population structures to a comparable rate (Schoenbach).

There are numerous techniques to age standardisation: direct and indirect standardisation, the geometric mean, equivalent average death rates, life table rates, Yerushalmy's index, cumulative death rates, absolute probabilities of death and the comparative mortality index (Ahmad et al., 2001). However, the most commonly used technique is the direct standardisation used in this research.

Direct age standardisation is defined as the observed cases (observed respiratory cases) in relation to the expected number of cases within a location (municipality) at a given time. The expected number of cases in each location (municipality) is calculated as the population within a location (municipality) multiplied by the overall annual observed risk (total number of cases divided by total population over the time period). The general equation for direct standardisation can be seen below:

$$\frac{\sum M_x \times P_x^s}{\sum P_x^s}$$

(equation 4.2)

where M is the morbidity rate, P is the population at risk, x is the age group, and s is the standard population (Meade and Emch, 2005).

Some authors advocate standardisation which involves adjustment to a common standard (e.g. incidence rate per 100,000 population) (Julious et al., 2001). This has been adopted for chapter 5, when ASR are used. Count data is used in chapter 6 rather than rates; details of the method of this are discussed in section 4.4.3.

The main criticism of age standardised rates is the need to select an arbitrary standard population (Bray, 2002); the choice of a standard population can be any, and the selection is somewhat subjective. Generally, the choice of the standard population does not tend to have a great effect on the relative levels of the adjusted rates, but it is important to ensure that the adjustment is applied to the same standard population, which is significant when assessing trends over time.

Although the choice of standard population is arbitrary, choosing a similar population structure to the one being examined is preferable otherwise results over time may not be an accurate reflection. For example, an older population results in a higher rate for the elderly and a younger population results in a higher rate for the young. Therefore, the standard population selected can affect the adjusted rate and perceived trends and must be chosen carefully as it can significantly affect the results (Choi et al., 1999).

The most widely used standard population is the Segi standard population; this is based on the age structure of 46 countries and was modified by Doll et al. (1966) (Ahmad et al., 2001). The Segi standard population is not considered representative of either the present or future age-specific world population, leading to, in more recent years, the WHO producing a world population standard; this is based on 'data of a two yearly population age structure for each country carried out by United Nations Population Division. Using this data, estimates have been produced from 1950 to 2025' (Ahmad et al., 2001). From these estimates, an average world population age structure has been created for 2000-2050. The fundamental difference between the WHO standard and other standards is that the WHO standard has fewer children and more adults aged 70 and above than the Segi standard, and is younger than the European standard. The WHO standard population is considered to be the most appropriate to use here because the results of any similar studies in other countries can be compared with those of the Amazon and it will not become dated as quickly as the census data. Moreover, the structure fits well between the 2000 and 2010 census data for the Brazilian population structure; therefore, it provides a good standard for this ten-year research period and beyond.

It is not uncommon to calculate age-sex standardised rates; however, it was felt that age-sex standardisation was not needed because the primary aim of this research is to understand the impacts of hydrological extremes as a whole, i.e. the potential demand on resources. Consequently, whether more males or females are affected or need treatment is not relevant at this stage. Further, literature already suggests boys are more susceptible to respiratory diseases in childhood (Rosa et al., 2009).

Temporal Trend

To investigate the temporal trend of hospitalisations for respiratory diseases, hospitalisation admissions were plotted through the study period. When examining changes during drought periods compared with the same period in different years, differences compared to the ten-year mean were plotted. Furthermore, seasonal trends were explored using a ratio of absolute values for hospitalisations and analysed using chi-squared at 95% significance level.

4.4 Geospatial techniques

In order to investigate the relationship between hydrological extremes and respiratory diseases in the Legal Amazon, geospatial techniques have been employed. According to Albert et al. (2003), there are three components to geospatial techniques – spatial analysis, geographical information systems (GIS), and Remote Sensing (RS). Spatial analysis can be defined as 'a study in depth of the patterns of points, lines, areas and surfaces depicted on maps of some sort or defined by coordinates in two- or three-dimensional space' (Hägerstrand, 1973). GIS and Remote Sensing are well-known terms; GIS is a computer-based system that provides tools for capturing, storing, manipulating, analysing, managing and displaying data (Bailey and Gatrell, 1995). Remote Sensing is 'the use of electromagnetic radiation sensors to record images of an environment' (Albert et al., 2003). The combined use of these two can provide a researcher with an unprecedented amount of data and data management capabilities. This section provides information on the spatial data analysis used in this research.

4.4.1 Spatial Data Analysis

Spatial data analysis is a narrower field than spatial analysis, involving the accurate description of data relating to a process operating in space, the exploration of patterns and relationships in such data, and the search for explanations of such patterns and relationships (Bailey and Gatrell, 1995). This definition, however, is not concerned with other forms of quantitative spatial analysis, such as the optimal location of facilities and network analysis (Gatrell and Bailey, 1996). Spatial data analysis involves more than simply analysing data that happens to be spatially referenced. Rather, the emphasis is on those techniques that give prominence to, or explicit consideration of, the spatial arrangement of the objects being analysed.

Bailey and Gatrell (1995) categorise the variety of spatial data analysis methods into those that are concerned with visualising, exploring and modelling. In seeking accurate descriptions of the phenomena we are studying, we require visualisation methods, encompassing a variety of graphical displays of our data. Exploring spatial data is largely concerned with summarising and investigating spatial patterns and relationships. Such techniques are characterised by making few *a priori* assumptions about the data. Modelling spatial data relies on the specification of a formal statistical model and the estimation of parameters. Bailey and Gatrell (1995) stress that there is no clear-cut distinction between the methods used in these three approaches; indeed, there is usually a close interaction of the three.

Spatial data analysis can be carried out using ‘global’ or ‘local’ measures. Traditional ‘global’ measures typically generate a single value (Fotheringham et al., 2002) that is an average of conditions through the study area, with the underlying assumption that the relationships are homogeneous (or stationary) (Matthews and Yang, 2012). ‘More specifically, [it] assumes that the same stimulus provokes the same response in all parts of the whole study region’ (Matthews and Yang, 2012). As we know that the Legal Amazon is a diverse region and population health has a spatial dimension, local approaches to spatial data analysis are being used to investigate the relationship between hydrological extremes and respiratory diseases. ‘Local’ measures are the most appropriate for used in this research because, in reality, relationships may be heterogeneous (non-stationary) (Fotheringham et al., 2002; Bailey and Gatrell, 1995; Matthews and Yang, 2012), and thus vary geographically; in other words, when the 'same stimulus provokes a different response in different parts of the study region' (Matthews and Yang, 2012). Localised measures relate the association between a value at one location and values for nearby areas.

Types of methods used in spatial data analysis depend on the data available, whether it is point or area data. Point data uses exact spatial location references based on geo referenced data to locate specific characteristics, whereas area data aggregates data to areal units. Health data from SUS is area data, at micro-region and municipality level. Initial analysis for area data usually begins with a simple choropleth map showing incidence or prevalence rates. Rates are calculated to account for areas with different population size and structure. Because this research examines numerous areas and in different years, age standardised rates have been calculated as discussed in section 4.3.3. Sometimes the use of choropleth maps can be misleading, depending on how the class intervals or colour scheme is selected (Cromley and McLafferty, 2002). Choropleth maps should be interpreted with caution, depending on where there are varying sizes of area units as the reader is drawn to the larger areas. This is known as the modifiable areal unit problem and is discussed in detail by Openshaw (1983). Although simple choropleth maps provide a good basis, they do not allow for more detailed analysis of data; rather, they merely map what is happening in individual locations without considering the surrounding environment.

It is known that health issues have a spatial dimension, influenced by both the environment and socioeconomic conditions (Cromley and McLafferty, 2002), with many diseases restricted geographically by landscape, climate and anthropogenic factors (Becker, 2005). The Legal Amazon is a vast area with varying land use, climate, population structure, and development, and understanding how these factors might affect the health of the population would be impossible without the use of remote sensing monitoring of environmental and climatic conditions. Incorporating health data and remote sensing information into GIS provides a tool for exploring connections between people, health and the environment in which they live, and thus an analysis of spatial data.

Using the SUS area data for micro-regions and municipalities, two approaches for different stages of local analysis have been used: Getis Ord Gi* to explore data and identify baseline information of where respiratory diseases are more pronounced within the Legal Amazon, and Geographically Weighted Poisson Regression (GWPR) to investigate the interaction between areas affected by hydrological extremes, associated conditions and respiratory diseases.

4.4.2 Getis Ord Gi*

Getis and Ord (1992) developed a group of statistics, G, that can be used to measure spatial associations in various circumstances. Local statistics Gi and Gi* allow for the detection of locations with spatial associations that may not be evident through the use of global statistics. As discussed in section 4.4.1, if there is spatial variation a local measure is more appropriate, where a global statistic is formulated to depict trends in the data around each spatial unit. Although Getis-Ord G* is a statistic, it involves several common GIS operations such as determining a neighbourhood based on adjacency or proximity and mapping the G* values. Moreover, by incorporating the method into GIS, it is possible to explore probable causes; for example, other spatial databases such as environmental, social, and facilities can be overlaid on the cluster map. The advantages of Getis-Ord Gi* is that it is ideal for defining hotspots, and limiting the spatial extent of them, which was found to be an issue when using SatScan, for example.

Further details about Gi* can be found in Getis and Ord (1992); Ord and Getis (1995) but in summary the equation for Gi* is:

$$Gi^* = \frac{\sum w_{ij} x_j}{\sum_j x_j} \text{ for all } j$$

(equation 4.3)

where G_i is the measure of local clustering of attribute x around i, x_j is the value of x at j, and w_{ij} represents the strength of the spatial relationship before units i and j which can be measured as either a binary contiguity variable or a continuous distance measure. In Gi*, w_{ij} must not equal zero. If high values of x tend to be clustered around i, Gi* will be high; if low values of x tend to cluster around i then Gi* will be low, and no distinct clustering of high or low values of x around i will produce intermediate values of Gi*.

The statistic has been implemented in a GIS environment by Ding and Fotheringham (1992), and developed for analysis in ArcGIS. Analysis was carried out in ArcGIS 10, and the details of the equation applied to ArcGIS 10 can be seen in equations 4.4 – 4.6.

The Getis-Ord local statistic is given as:

$$Gi * = \frac{\sum_{j=1}^{n} w_{i,j}\, x_i - \bar{X}\ \sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{\left[n\ \sum_{j=1}^{n} w_{i,j}^{2}\ -\ \left(\sum_{j=1}^{n} w_{i,j}\right)^{2}\right]}{n-1}}}$$

(equation 4.4)

where x_j is the attribute value for feature j, $w_{i,j}$ is the spatial weight between feature i and j, n is equal to the total number of features and:

$$\bar{X} = \frac{\sum_{j=1}^{n} x_j}{n}$$

(equation 4.5)

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\bar{x})^2}$$

(equation 4.6)

The Gi* statistic is a z-score so no further calculations are required.

This technique was adopted to examine the distribution of ASR to ascertain areas within the Legal Amazon where clusters of high and low hospital admissions are recorded. The user is able to select various options in ArcGIS 10 to specify conceptual and scale aspects of the analysis. A fixed distance band to ensure every municipality had a neighbour was used; this means neighbouring features within the specified distance received a weight of 1, influencing the computations for the target, yet once outside of the distance, the weight becomes zero, having no influence on the target. The results of this analysis can be found in chapter 5.

4.4.3 Geographically Weighted (Poisson) Regression

Local spatial regression was originally introduced in 1988 by Cleveland and Devlin, and since then the use of local regression has gained prominence. Geographically Weighted Regression (GWR) is a local spatial statistical technique introduced to the geography sphere by Brunsdon et al. (1996) to study relationships in a regression model that vary geographically (Wheeler and Páez, 2009), or what is termed as parametric non-stationarity. Therefore, unlike traditional 'global' regression, Ordinary Least Square (OLS), which cannot detect non-stationary relationships, and thus only produces a single regression equation, GWR produces a local statistic for each different location (areal unit in this case).

GWR is considered to be relatively easy to understand as it is based on the traditional regression framework with which most people are familiar (Fotheringham et al., 2002) (equation 7, GWR model). The estimator for the model is similar to the weighting in OLS; however, the weights are based on the location relative to other observations in the dataset and hence they change for each location. These weights are based on the weighting scheme, *Kernel*. Typically a bi-square weighting kernel is used (Brunsdon et al., 1998) to account for spatial structure. There tend to be two general types of kernel function; fixed and adaptive. Fixed is when the points are reasonably regularly spaced in the study area. If the points are not regularly spaced but are clustered, it is generally desirable to allow the kernel to accommodate this irregularity by increasing its size when the sample points are sparser and decreasing its size when the sample points are denser; this is achieved through an adaptive kernel.

$$y_{i = \beta_0(u_i,v_i)} + \sum_{j=1}^{k} \beta_j \left(u_{i,v_i}\right) x_{ij} + \varepsilon_i$$

(equation 4.7)

where y_i is the value of the outcome variable at the coordinate location *I* where (u_i, v_i) denotes the coordinates of *I*, 0 and *j* represents the local estimated intercept and effect of variable *j* for location *I*, respectively.

The main advantage to using GWR in this research is that it incorporates local level data rather than 'global' data. If the study region had little variation, a global model would be acceptable; however, the Legal Amazon is a vast area with varying land use, climate, population structure, and development so variation across the region is expected, and using a 'global' model may obscure detail. Fotheringham et al. (2002) highlight detailed examination of data when they suggest 'GWR could be thought of, in fact, as a 'spatial microscope'.

The basic GWR follows a Gaussian distribution representing a normal distribution with continuous data values taking both negative and positive value (Fotheringham et al., 2002). A basic linear regression assumes a Gaussian distribution, which is also true for a basic GWR. The Gaussian distribution is appropriate for numerous studies, assuming the outcome variable follows the normal distribution; however, this is not always the case with health data which tends not to be continuous or have non-integer values. The issue of different distributions was addressed in the early 1970s by Nelder and Wedderburn (1972) with the creation of Generalised Linear Models; however, the model was a non-location model.

In order to address this issue of health data not tending to follow a Gaussian distribution, a Poisson regression model is needed, based on observed counts. Nakaya et al. (2005) developed a Geographically Weighted Poisson Regression (GWPR) based on the GWR model. Incorporating the Poisson regression into the analysis, it provides a more appropriate basis for analysing areal data where observed counts may include low count numbers, which can arise when working with health data (Lovett and Flowerdew, 1989). Another important advantage of using GWPR is that it allows for a combination of geographically varying and geographically constant parameters in the model (Nakaya et al., 2005). Although this function was not utilised in this analysis, it provides the opportunity for future work to be carried out using the same method if both geographically varying and constant variables need to be included.

The detail of the GWPR model is described elsewhere (See Nayaka et al. (2005)), but the GWPR model summary is shown in equation 4.8. Analysis for GWPR was carried out in the GWR4 software.

$$y_i \sim \text{Poisson}[N_i \exp(\mu_i)]$$
$$\mu_i(\{x_{k,i}\}) = \sum_k \beta_k(u_i, v_i) x_{k,i}$$

(equation 4.8)

where y_i, $x_{k,i}$ and N_i are, respectively, dependent variable, *k*th independent variable including the constant term and the offset variable at the location *i*; (u_i, v_i) is the x-y coordinate of the *i*th location; and coefficients $\beta_k(u_i, v_i)$ are varying conditional on the location. The local coefficients at the location *i* are estimated by fitting a usual Poisson regression model to the data subset around the regression point *i* with a geographical weighting function. A descriptive measure of goodness-of-fit for Poisson regression is percentage of deviance explained:

$$pdev_i = 1 - dev_i / nulldev_i$$

where dev_i is the deviance of the fitted model and $nulldev_i$ is the deviance of the null model having only a constant term. The equivalent measure for the local fitting at each location can be derived by the local weighting of the deviance of fitted and null models.

Although there are limitations of the method, these are related to units of observation which link to the various discussions regarding how best to display the results of GWR/GWPR. Fotheringham et al. (2002) state that 'given that a very large number of potential parameter estimates can be produced, it is almost essential to map them in order to make some sense of the patterns they display'. Yet mapping the results provides the user with the task of best displaying them to represent the spatial context and the characteristics of the study region (Goodchild and Janelle, 2004). To date, there is no standard way to map the results of GW(P)R, and thus the way they are mapped can affect the way results are interpreted. Some researchers have mapped the parameter estimates alone, which can be misleading as they do not show which results are significant and which are not. Another issue relating to displaying the results is the number of maps required to show both parameter estimates and areas of significance (z-value) (Mennis, 2006). Different techniques have been employed to resolve this issue, such as showing both maps, which results in many maps being needed and overlaying specific z values as contour lines on the map showing the parameter estimates. In this study, the approach suggested by Matthews and Yang (2012), is being adopted; Matthews & Yang suggest using one map with the parameter estimate surface and creating a mask over the top which shows only the significant locations. In other words, blocking out z values between -1.96 and + 1.96. Due to the potential issue of the requirement for a number of maps to display all the results when using a large dataset, this study is mapping adjusted z-values for significant levels based on the Bonferroni correction method. Further discussion of the mapping method is provided in chapter 6.

4.5 Moving from quantitative to primary data collection

Thus far, this chapter has discussed the selection of quantitative methods being used for answering research questions 1–3, which involve analysing the spatial and temporal distribution of hydrological extremes and respiratory diseases and how the two interact. The specifics of the methods are detailed in the results chapters respectively (Gi* in chapter 5, and GWPR in chapter 6). The final research question aims to explore people's knowledge, attitude, and practice to the topic and link with the results from chapters 5 and 6. In order to answer this, field-based research was carried out by collecting survey data, which will now be discussed.

The use of mixed methods in health studies has become increasingly common in recent years. The two approaches can complement each other; some studies begin with qualitative methods as a preliminary task before carrying out quantitative methods, while others use qualitative methods as a way to validate data obtained from quantitative methods. It is this latter approach that is used in this research, as collecting survey data provides a different perspective on the topic by exploring people's understanding and the meanings they attach to their experiences. It provides an opportunity to study subjects in their natural environment rather than in an artificial modelling environment. It was felt this would strengthen the research by adding an extra level to the analysis rather than purely basing results on modelled data with little knowledge of how local populations behave in terms of this topic.

4.6 Field-based Research

The collection of survey data allowed the results from the spatial data analysis to be developed and an opportunity to gain an in-depth understanding of how climate-health interactions are understood by communities being affected, rather than just mapping the problem with little understanding of the consequences for the local population. Policymakers need not only to understand where problems are occurring so policies and measures are implemented in the correct locations, but also to create appropriate responses to deal with any identified problem. Therefore it was felt that this element of the research was vital in creating suitable adaptation measures.

4.6.1 Establishing the research

The aim of the field-based work evolved during course of the PhD, as did the selection of field sites. Originally, the main aim was to discuss and exchange information with local authorities in order to understand potential environmental policies suitable for the region. However, as research developed and meetings in Brazil took place, it became more apparent for the need to talk to local communities to find out the level of knowledge about respiratory diseases. Without this local evidence, any strategies to deal with the situation could be ineffectual if the population has a lack of understanding. The efficacy of policy decisions could be jeopardised, with measures not being implemented properly or used in the correct way. Therefore, the new aim was to explore the knowledge and understanding of the local population about the climate, environment and, in particular, respiratory diseases.

The development of field-based research was facilitated through meetings with researchers at FIOCRUZ. Initial meetings in September 2011 led to meeting Dr. Sandra Hacon who specialises in respiratory health in the Legal Amazon. This provided the opportunity to discuss the research with someone who works on a similar topic, and to discuss the field methods. Following this meeting, the originality of this research became more apparent; very few studies have carried out geo-spatial analysis and, as literature in chapter 3 shows, no studies about the impacts of hydrological extremes on respiratory diseases exist. Moreover, to date, no work has been carried out that explores the population's perceptions and knowledge of respiratory diseases and the link with environmental and climatic factors.

Two methods were adopted to understand local communities' living conditions and knowledge of health problems and the links with environmental change; household surveys and **k**nowledge, **a**ttitudes and **p**ractice (KAP) surveys. These are discussed in sections 4.6.3 and 4.6.4 with greater detail on KAP surveys as they are less used in qualitative geography methods, as well as information regarding field sites and analysis. Details of implementation of the surveys and results can be found in chapter 7.

4.6.2 Establishing field-sites

Rondônia State experiences a high number of fires and high rates of deforestation; some of the municipalities are listed as priority municipalities. Some municipalities of the state were affected by the two droughts and the flood being examined in this research. Moreover, it has been highlighted as a hotspot for respiratory diseases in Legal Amazon and experienced the highest incidence rate for respiratory diseases during the study period (chapter 5).

The municipality of Porto Velho in Rondônia was selected for research, and household surveys and KAP surveys were administered in two communities within it – Belmont and Vila Nova de Teotônio. Figure 4.1 shows the location of both communities. The two communities were selected because they are different from one another and would facilitate an understanding of people's knowledge as one moves further away from the city centre. They are contrasted not only in their location but the structure of the community and housing. Belmont is located 10km from the city centre yet extends 15 km along the Rio Maderia and the sparsely distributed houses are predominantly made of wood. In comparison, Vila Nova de Teotônio is located 40 km south of the city centre, and consists of a centre with a grid-type arrangement of houses. The houses in Vila Nova de Teotônio are all made of brick, are contemporary, and are built to a modern standard; there is also a health centre located within the community. Vila Nova de Teotônio is an interesting community because while it has existed for many years, it was located elsewhere, known as Cachoria Teotônio, until the hydro-electric dam was built. With agreement from the community, Santo Antonio Energia, the hydro-electric dam company, moved the community to the new location because it needed the previously occupied land for the construction of the dam. Through this agreement, they built houses, schools, and a health centre. In addition, they are trying to attract tourism to the community as a source of income for the local people.

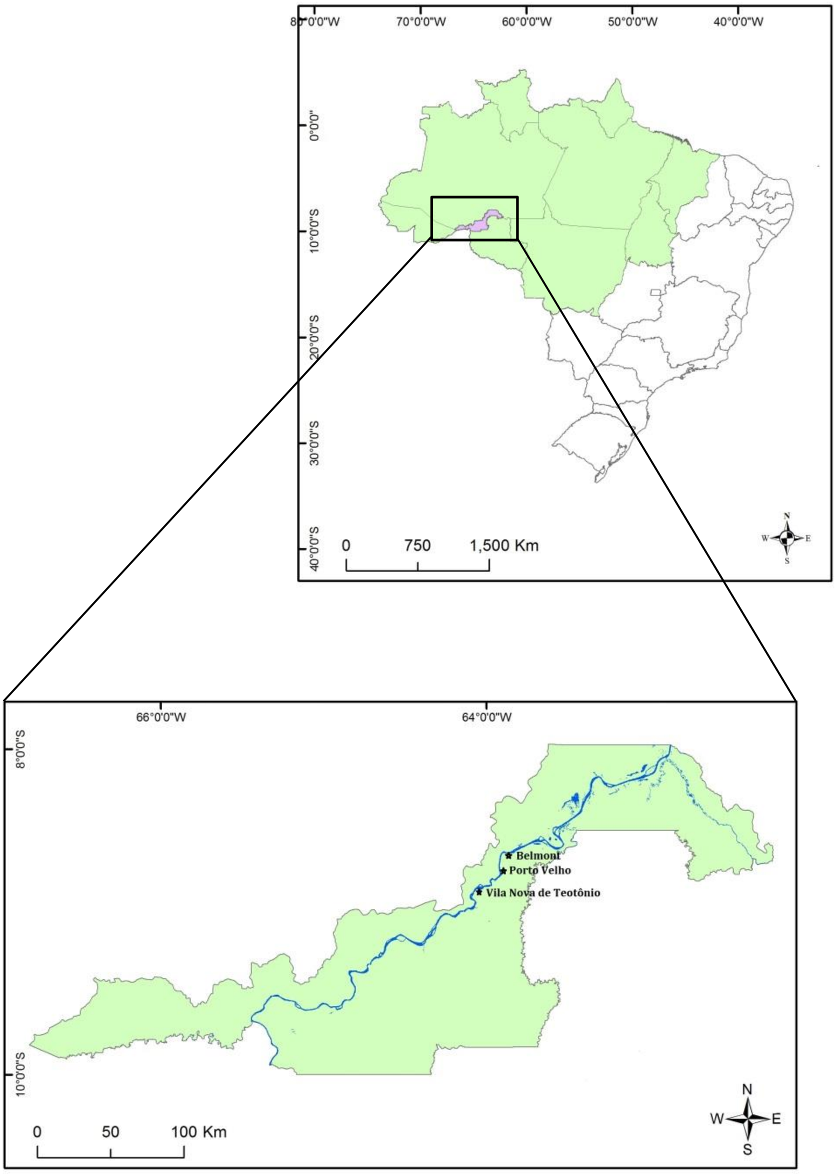


Figure 4.1| Location map of field based research.

Carrying out research in these communities was facilitated through relationships that had previously been formed with colleagues in FIOCRUZ. Without the help of researchers at FIOCRUZ and the relationships with communities, the fieldwork element of this research would have been impossible as approval is needed from both the research board in Brazil and from the head of the community. Vila Nova de Teotônio was selected for a field site as its accessibility made it a more pragmatic choice than other sites which would have been more remote e.g. Cuniã.

Nevertheless, Vila Nova de Teotônio proved to be an ideal community because it is the result of the development of a hydro-electric dam. Since more hydro-electric dams are proposed for Brazil, it gave me a valuable insight into the perceptions of the affected community in terms of their health since being relocated. This is explained in greater detail in Chapter 7, where I discuss people's knowledge and understanding.

4.6.3 Household Surveys

Household surveys are used to collect detailed and varied information, and have become a key source of social data in the last 70 years or so (Division, 2008). They can provide information at the household level about different variables that are influenced by, and can influence, policy (Deaton, 1997). Not only do they provide information on how policies are working but they provide information about the different demographics of people and families for whom the policies are intended and can, therefore, be adapted for different groups of people within regions.

There are different types of household surveys; budget surveys, employment surveys, fertility surveys, and general household surveys (Deaton, 1997). These can be used to form a baseline for research or for testing theories about household behaviour and households' response to changes (Deaton, 1997). For this reason, household surveys were employed in this research to identify a baseline of household factors that may affect the development of respiratory diseases, for example diet, smoking, cooking methods, and socio-economic levels. Furthermore, they provided information to incorporate with data from the KAP survey about respiratory diseases.

In this instance, a general household survey with sub-sections was undertaken to gain an overall understanding of baseline conditions. The sub-sections were:

- General information
- Information about the house

- Information about education
- Information about employment
- Information about health
- Other

With this information, the objectives of the household surveys were:

1. To gather socio-economic data to compare with the KAP survey;
2. To find out whether people's lifestyles were affecting the development of respiratory diseases as opposed to the effect of environmental issues.

The results from this survey are incorporated into the results of the KAP survey. Primary interest here is in people's knowledge and understanding obtained through the KAP survey and, as the use of household surveys is more prevalent and widely understood, literature will now focus on KAP surveys.

4.6.4 KAP survey

Improving the health of a population is increasingly being attributed to gaining adequate understanding of social, cultural and economic aspects of the context in which public health programmes are implemented (Launiala, 2009). Cross-sectional surveys have usually been used to collect this information; one of the most popular when looking at public health policy is the 'KAP' study that measures **k**nowledge, **a**ttitude, and **p**ractice (KAP) (Launiala, 2009; Hausmann-Muela, 2003). As described, the three themes of a KAP study measure Knowledge, Attitude, and Practice. The *knowledge* refers to the respondents' understanding of a given topic. *Attitude* refers to feelings and preconceived ideas towards the subject matter. The final aspect of the KAP study, *practice*, is the investigation of the way in which respondents demonstrate the knowledge and attitudes through their actions (Launiala, 2009; Hausmann-Muela, 2003; WHO, 2008a).

The method emerged from hostility to the idea and organisation of family planning services; however, as countries have implemented family planning without widespread opposition, the traditional purpose of these surveys has diminished (Cleland, 1973). As KAP studies have developed beyond family planning, they are used in a variety of applications. Today, they are used as a 'representative study of a specific population that aims to collect information of what is known, believed and done in relation to a particular topic' (WHO, 2008a). In addition, demographic data, material status, household structure, education and income are often collected (Cleland, 1973). In this research, this was established through the household survey rather than as part of the KAP survey.

In this research the use is twofold: exploring and establishing a baseline of information regarding respiratory diseases. Little is known about what the population of the Legal Amazon knows about respiratory diseases and the links to environmental/climatic change, despite it being a leading cause of ill health in Brazil and the Legal Amazon. Therefore, establishing a baseline of KAP at this stage is vital as no previous work on the topic exists. In the event of programmes or policies being implemented in the future, changes in KAP can be observed to monitor their success. Ideally KAP studies are administered regularly to monitor changes in KAP once a programme or policy has been implemented; following this research, they may be more widely employed in the Legal Amazon. Understanding a community's KAP enables a more efficient process of awareness creation as it will allow the programme to be tailored more appropriately to the needs of the community.

The objectives of the KAP survey in this study were:

1. To gather baseline information and explore knowledge, attitudes, and practices related to respiratory diseases in different communities, and
2. To combine with household surveys to assess socio-economic levels and knowledge of respiratory diseases.

The main advantages of KAP studies are that they are not difficult to design and interpret, they produce quantifiable data, and they enable cross-cultural comparisons to be carried out (Launiala, 2009). Moreover, the use of a KAP survey can provide information about gaps in knowledge, cultural beliefs, or behavioural patterns to researchers and policy makers (WHO, 2008a). This information gives researchers and policymakers the opportunity to understand and take suitable control of health problems. Furthermore, the data collected informs practice so that suitable measures can be put in place, in an effective way that the community understands, satisfying this aim of the research, which is to understand local knowledge on the topic so that suitable measures can be suggested.

Nevertheless, KAP surveys are sometimes criticised because there is a sense that some researchers may take for granted the fact that the data collected provides accurate information which can be used for planning purposes (Cleland, 1973). The individual features of the KAP study have sometimes been the subject of criticism. Taking the knowledge facet of KAP, for example, may present challenges for public health professionals who feel the topic has a narrow focus; they consider knowledge and belief as contrasting terms. Knowledge tends to be viewed as being based on scientific facts, whereas belief can be embedded within cultural beliefs and behaviours (Pelto and Pelto, 1997). Launiala (2009) suggests that attitudes are often not presented in the results of KAP studies, and Cleland (1973) and Hausmann-Muela (2003) suggest that there is a substantial risk from presenting these results due to falsely generalising respondents' opinions and attitudes. This may be the cause for the lack of research which presents results relating to communities' attitudes. Finally, the practice aspect of a KAP study may be difficult for some respondents to answer because often the questions are hypothetical (Cleland, 1973); for example, in this research, one question asks respondents if they think having a respiratory disease would affect their daily activities. General limitations of other qualitative methods that can also be perceived in relation to KAP surveys are discussed in section 4.5.5. Despite these criticisms, the KAP survey can easily provide information which has previously not been collected and any perceived limitations can be mitigated. For example, the issue of 'knowledge' or ‘belief’ was overcome by including all responses, whether or not a bias was observed. The reason for this mitigation was due to the fact that this is the first research of its type, so no baseline evidence of the community’s knowledge exists to compare ‘knowledge’ with ‘belief’.

4.5.5 Limitations to the surveys

Some limitations of the research are discussed here. Time and financial constraints meant that fewer communities were surveyed than had been anticipated. Despite this, the information collected in the two communities has proved invaluable as no research currently exists which explores these topics. The language barrier is also a feature to note. The use of translators potentially increases the risk of discrepancies between the translators’ account and the precise content of a respondent’s answer. This was somewhat overcome as many of the questions were closed, and a basic understanding of local dialect and typical responses gave more assurance that accurate responses were being recorded. Moreover, responses were recorded in Portuguese and translated once back in the office. However, it could be argued that even with brief responses, the full responses may not have been recorded so some information may be missed out.

The position of the researcher being an ‘outsider’ raises certain ethical issues; the most significant issue is that of ‘power’ (Skelton, 2001). There is a risk when carrying out research in a different culture that participants would give answers they believed were wanted rather than their honest response, as they were trying to be polite and say what they thought the researcher wanted to hear (Howard, 1994). Furthermore, it could be argued that positionality of the researcher results in subjectivity; for example, they have total freedom to select which villages to sample, what quotas to use, or the number of respondents to include in the sample population. Where possible, these constraints were mediated by the use of standard interview research methods. Participants were fully briefed as to the purpose of the research and it was explained that the research was unrelated to the government, but rather that it was an individual study. For each survey, signed participant consent was gained. Every survey which was conducted also included a repeated request for consent and an explanation of the research. The choice of which communities to be included in the research was dictated by financial constraints and it was influenced by those locations where relationships had already been established with FIOCRUZ researchers. Due to the nature of the surveys, and the fact that the communities were relatively small in the number of households, any issue about freedom to make choices about quotas was overcome by the fact that all households in each community were invited to be included in the study.

Specific limitations in relation to KAP surveys could prevail. For example, when a respondent is asked a question about which he/she has little knowledge or has never considered before, they may respond with caution, so it may be wise not to take their response at face value (Cleland, 1973). There is also a risk of falsely assuming opinions and attitudes. To combat this, any 'don't know' responses were accepted and recorded in the manner of Pool (1967). This prevented any false responses and also provided information about the level of KAP within the communities. Moreover, it is known that questions about events which occurred in the past may produce less reliable responses compared to those relating to the current situation because they may be remembered inaccurately. This is highlighted by Bernard et al. (1984), who state that 'on average, about half of what informants report is probably incorrect in some way'. Moreover, people are usually unable to predict their reaction to imaginary situations (Cleland, 1973).

4.5.6 Ethics

For each survey, approval was given by the ethical board at FIOCRUZ before commencing the research. The ethical board of the University of Exeter also approved the research. Each respondent agreed to an informed consent (Appendix A), and they had the right to decline to participate in the research. All surveys were allocated an ID code to provide anonymity and no names are published anywhere in the research.

4.6.7 Preparing the Data

It has been suggested that analysis of survey data begins during data collection itself because it is impossible for the researcher not to start thinking about what is being said, which will allow refinements in the questions if necessary. The research questions in this study did not need to be redefined. However, while gathering the responses, inevitably there were thoughts during the whole process about the research and any potential recommendations. These thoughts could be considered to be the precursor to the task of coding and analysing the data which requires much work in the office. Before the practice of coding the data, which is a vital part of the fieldwork process, Pope et al. (2000) suggest that immersing oneself in the data is the first step in data analysis. In other words, reviewing the data prior to any codes are applied so that nothing is missed.

Only when data review has been completed is it generally accepted that data coding begins. The process of coding allows the researcher to organise and identify patterns and themes in responses. Coding can be carried out by hand or using a software package. Here, the data was coded by hand as it was felt that this would provide a more comprehensive understanding of responses. Blunt (2003) agrees with the method of coding by hand as she believes it allows for the data to be appreciated, and gives more sensitivity to the themes. Once a decision on the coding method debate has been reached, there is also the matter of deciding who should code the data. Morse and Richards (2002) and Janesick (2003) argue that a single researcher is sufficient and preferred, while in contrast, Denzin (1978) and Pope et al. (2000) suggest that a team of researchers is best as it gives optimum analysis. Due to the fact that this research was carried out by me alone, I decided to code the data personally. This also provided me with greater confidence in the codes recorded because it gave me confidence in their accuracy and did not raise concern about the accuracy of others' work.

The next stage of coding and data analysis involves the cleaning of data. This requires checking the data for any abnormal answers, any answers which do not relate to the question, or any errors in the coding. Therefore the analysis can be completed with confidence and ease.

Although it was originally felt that a thematic approach would be adopted in this survey data collection analysis, it transpired that a more quantitative approach was used, because responses given in the KAP surveys were short and many responses were 'don't know'. Other studies which utilise a KAP survey as a source of data have not created themes (Shah et al., 2011; Radhakrishnan et al., 2000), and nor are themes discussed in the literature concerning the analysis of KAP surveys (WHO, 2008a; Kaliyaperumal, 2004). Instead it has been suggested that KAP survey findings are usually presented using descriptive statistics and, where possible, utilise data from household surveys in addition. The analysis of this KAP survey has used the same method and an analysis of the survey data was carried out in SPSS 19. The results are shown in chapter 7.

4.7 Summary

This chapter has presented the datasets, limitations and processes used for both quantitative and primary data collection methods. In doing so, it has provided an understanding of the methods used and the location of the field sites. In order to quantify the impacts of hydrological extremes on respiratory diseases and potential measures to reduce the impacts, the following chapters will use these datasets and methods to answer the four research questions. The next chapter will begin by establishing a baseline of the spatial and temporal distribution of hydrological extremes and respiratory diseases in the Legal Amazon. I have written chapters 5 and 6 as stand-alone chapters.

Chapter 5

The spatial and temporal distribution of climatic extremes and respiratory diseases

5.1 Introduction

This chapter is concerned with addressing the first two research questions; where within the basin have the three hydrological extremes and associated human disturbances occurred, and, what was the spatial and temporal distribution of respiratory diseases in children under five within the basin between 2001 and 2010

Seasonal climatic fluctuations in the Legal Amazon are common in well-defined wet and dry seasons. In recent years, these seasonal changes have become pronounced, resulting in more intense events and, in some cases, extremes. During the study period for this research, 2001–2010, the Legal Amazon was struck by three hydrological extreme events. In 2005, large areas of the basin were hit by a historic drought that caused devastation both to the trees and livelihoods of the affected population (Phillips et al., 2009; Marengo et al., 2008a). In contrast, 2009 experienced flooding which resulted in river levels reaching the second highest levels since records began (Marengo et al., 2013). Just a year later in 2010, another drought struck the region, of greater magnitude than the 2005 event (Marengo et al., 2011; Lewis et al., 2011). In addition to natural climate variability resulting in extreme events, the population of the Legal Amazon, as in other countries in the tropics, uses deforestation and fires as a land clearing method (Marlier et al., 2012). Increased anthropogenic activity over the years in the Legal Amazon has been concentrated along the 'arc of deforestation', resulting in this area releasing high loads of air pollution. Air pollution varies between areas of the Legal Amazon, with higher concentrations occurring along the 'arc of deforestation'; this area accounts for 85% of fires in Brazil during the dry season (Becker, 2005). It is thought that 60% of the particulate matter from burning in the Legal Amazon is $PM_{2.5}$ (Hacon, 1995), which is known to cause ill health. Air pollution associated with forest fires has been shown to have positive associations with respiratory diseases elsewhere around the world (Mott et al., 2005; Chen et al., 2006; Emmanuel, 2000; Aditama, 2000). Within the Brazilian context, studies have also shown an association of sugarcane burning and urban pollution with increases in respiratory disease (Arbex, 2004; Arbex et al., 2007). With regard to the Legal Amazon, studies have shown there is climatic seasonality with respiratory diseases, or just asthma (Rosa et al., 2008b; Silva et al., 2009; Rosa et al., 2008a; Rodrigues et al., 2009).

Respiratory diseases are 'diseases that affect the air passages, including the nasal passages, the bronchi and the lungs. They range from acute infections, such as pneumonia and bronchitis, to chronic conditions such as asthma and chronic obstructive pulmonary disease' (WHO., 2011). During the study period (2001–2010), the Brazilian Unified Health System (Sistema Único de Saúde, SUS) recorded more than two million hospitalisations for respiratory diseases in all age groups (DATASUS, 2011b). These were the primary cause of hospitalisations in the region, excluding pregnancy, childbirth and puerperium, according to data based on the records of the IT Department of SUS. Of these hospitalisations, 43% were for children under five years of age (DATASUS, 2011b).

The fate of the Amazon is widely debated, with climate models projecting future change. This research seeks to contribute to an understanding of where extreme events occur together with knowledge of the temporal and spatial distribution of respiratory diseases in order to begin to comprehend how the two interact. Gaining this understanding of where events have been occurring and where hospitalisations for respiratory diseases are worst within the region will allow for an identification of changes in the relationship between the two and thus aid in mitigating the health impacts during extreme events.

5.2 Materials & Methods

5.2.1 Study Design & Location

This is a descriptive study of the distribution of extreme events and hospitalisations for children under five with a respiratory disease in the Legal Amazon for a decade between 2001 and 2010. The study area is the Legal Amazon (defined in section 2.2) which consists of nine states; Acre, Amapá, Amazonas, Pará, Rondônia, Roraima, Mato Grosso, Tocantins, and Maranhão, comprising 807 municipalities. According to the 2010 census, approximately 25 million people live within the region, with approximately 2.5 million being under five years of age (IBGE, 2010).

5.2.2 Data Sources

To identify baseline conditions during 2001–2010, several databases were utilised. Detailed information and a description of the quality of each database can be found in Methods, Chapter 4. A monthly time-series (2001–2010) of Tropical Rainfall Measuring Mission (TRMM) (3B43-v6) data at spatial resolution of 0.25^{o} was used (NASA, 2010). The same time-series for active fires was used, which is produced by the University of Maryland (UMA) from the Brazilian Institute of Space Research (Instituto Nacional de Pesquisas Espaciais, INPE), Queimadas project database (INPE, 2012b). It is suggested that the pattern of fires tends to follow the pattern of deforestation. To explore this, land use change data from INPE PRODES was used (INPE, 2012a). As discussed in Chapter 3, high loads of aerosol are associated with burning periods. To establish whether this is mirrored in the Legal Amazon, Aerosol Optical Depth/Thickness data (AOD/AOT) for Optical Depth Land and Ocean at 0.55 microns was used, from the MOD08_M3 collection 051 (NASA, 2011a).

Databases of the Hospital Information System (Sistema de Informações Hospitalares, SIH/SUS) of the Brazilian Ministry of Health were utilised to obtain information regarding hospitalisation data for respiratory diseases (DATASUS, 2011b). Chapter X, Diseases of the Respiratory System, of the International Classification of Diseases revision 10 was used (coded from J00 to J99), for children under five years of age living in the Legal Amazon between 2001–2010. Population data for each municipality in the Legal Amazon was obtained from the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística, IBGE) (Estatística, 2010).

5.2.3 Data Analysis

Environmental Anomalies

To quantify the spatial and temporal extent of the drought, rainfall surfaces were grouped at three-monthly intervals to show seasonal differences. Anomalies for 2005, 2009 and 2010 were calculated, based on the departure from the 2001–2010 mean (TRMM 2001–2010) and normalised by the standard deviation (σ 2001–2010). This was done for each year (y), each quarter (q) and at a pixel by pixel (i, j) level (Aragão et al., 2007b) (equation 5.1). This analysis was carried out in ENVI 4.8 and mapped using ArcGIS 10.

$$TRMM\ anomaly, q(i,j) = \frac{TRMMy,q(i,j) - TRMM\ 2001{-}2010\ (i,j)}{\sigma\ 2001{-}2010\ (i,j)}$$

(equation 5.1)

Anomalies for active fires were calculated using hot pixel density based on the accumulation of hot pixel counts for each three-monthly interval. Aerosol anomalies were also calculated using mean maximum values for the three-monthly period. These anomalies were calculated following a similar method to the TRMM data (equation 5.1).

The environmental anomalies have been calculated based on the reference mean of 2001–2010 for consistency with the health data and availability of MODIS data. During discussion with FIOCRUZ researchers during my field trip to Brazil, it was commented that the quality of health data from SIH/SUS improves from 2001 which is why this is the chosen start year, and ending the time series in 2010 meant both drought events were included in the analysis.

Health analysis

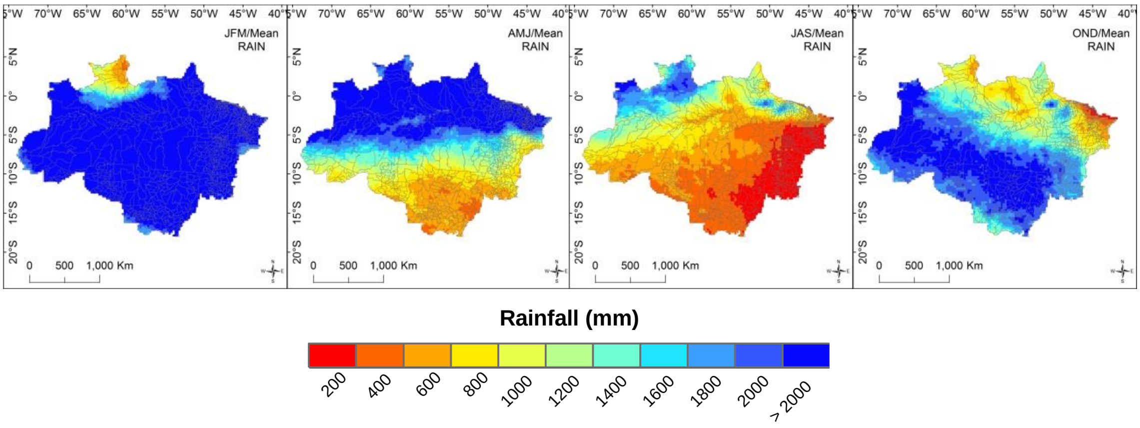
In order to identify disease patterns, the local statistic Getis-Ord Gi* has been used. Further information about Getis Ord-Gi* is in Chapter 3; in summary, it is a method of identifying spatial clustering and spatial outliers, or in other terms, hot and cold spots, i.e. locations where there are significantly high or low values. It detects where high or low values exist but not both. Unlike global cluster statistics, local statistics can answer where the pattern occurs rather than just querying if there is a pattern. The analysis for Getis-Ord Gi* was computed in ArcGIS 10 using Age Standardised Rates (ASR) of hospitalisations.

The cumulative monthly time series of Age Standardised Rates for hospitalisations has been presented to identify when peaks in hospitalisations generally occur. To assess climatic seasonality comparisons between the wet and dry seasons, a ratio of absolute hospitalisations of respiratory diseases and the chi-squared test for comparison at 5% significance was used. The seasons are defined as May–October for the dry season, and November–April for the wet season. It is important to note the Legal Amazon has distinct seasons, due to the Equator passing through it; when the area north of the Equator is in the dry season, the area south will be in the wet season.

5.3 Results

In 2005, large negative rainfall anomalies (≤ -1 σ) affected the south-west part of the Amazon. The negative rainfall anomalies intensified during the wet-to-dry season transition of April, May and June (AMJ) and peaked in the dry season months of July, August and September (JAS), when 41% of municipalities had at least one anomalous grid-cell (Figure 5.1). Four years after the 2005 drought and just a year before the 2010 drought, the Amazon experienced a flood. It appears that the two seasons had been reversed in 2009. The onset of heavy rainfall began during October, November, December (OND) 2008, when positive rainfall anomalies were observed (≤ 1 σ) in the northern and central parts of the Legal Amazon (Appendix B shows OND 2008 rainfall anomalies). This continued into January, February, and March (JFM) in the north, while a decrease in precipitation was concentrated in the south during the same months (wet season in the southern states). An increase in precipitation (≤ 1 σ) was concentrated in the wet-to-dry transition of AMJ, affecting large areas of the basin (69.5%) (Figure 5.1). During 2010, a large area (41.5% of all grid-cells) of reduced rainfall during the wet season months of January, February, March (JFM) covering the north-east flank of the Legal Amazon was observed. Similarly to 2005, the intensity of the negative rainfall anomalies increased in JAS (anomalies ≤ -1 σ) around the Rio Negro and the south of the Legal Amazon (52.3% of all grid-cells) (Figure 1). The 2010 drought was more widespread and sustained, affecting almost the entire basin at different times of the year; the north-east earlier in the year followed by the north-west and southern parts of the basin later in the year.

a) Mean Rainfall Values



b) Rainfall anomalies

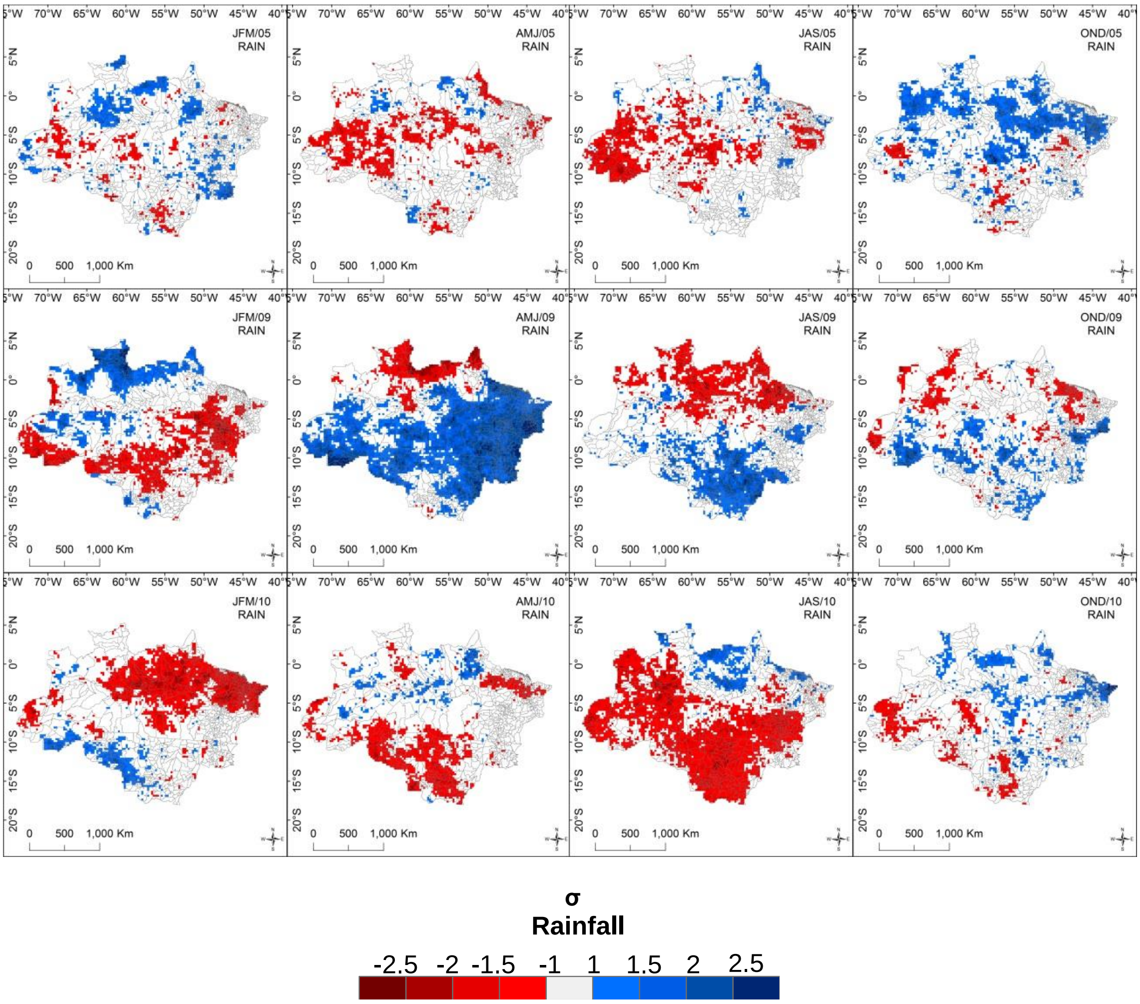


Figure 5.1| Standardised anomalies as a departure from the 2001 - 2010 mean. **a**) mean rainfall values (mm) (2001 – 2010), **b**) standardised rainfall anomalies.

Deforestation predominantly occurs around the eastern and southern fringes of the basin, known as the ‘arc of deforestation’ (Figure 5.2). In relation to the previous year, deforestation was 32% lower in 2005, 42% lower in 2009 and 2010 saw a 6% reduction (Figure 5.3). However, compared with the 2001 – 2010 mean, 2005 was 15% above the mean, 2009 was 55% below the mean and 2010 was 58% below the mean. Annual deforestation has, on the whole, reduced year on year, with the exception of 2008, indicating that deforestation rates are generally decreasing in relation to the ten-year mean of this study.

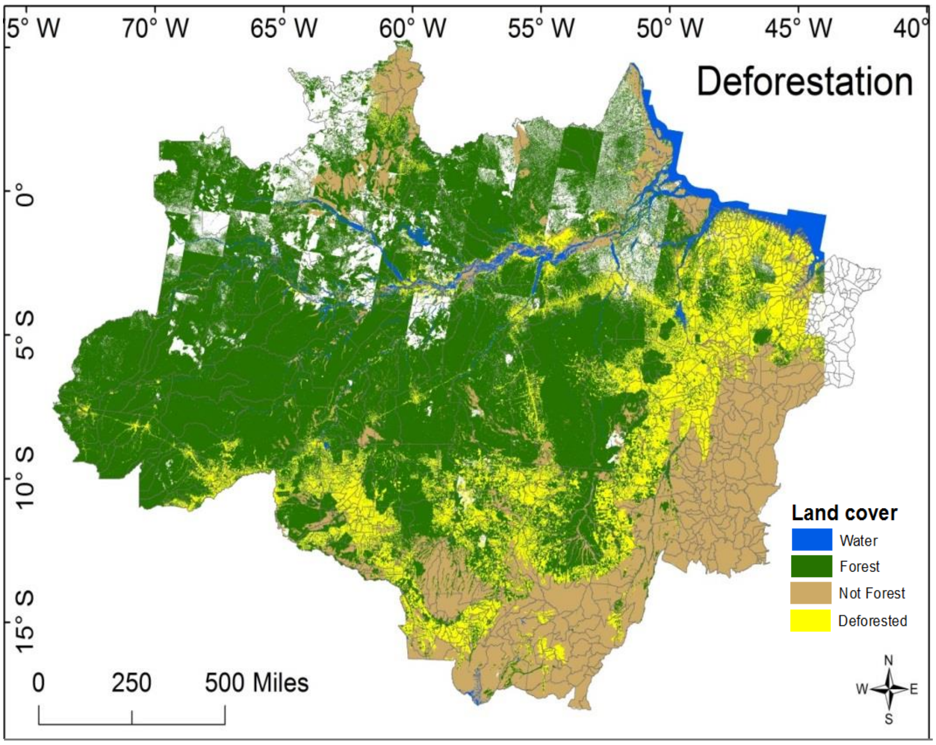


Figure 5.2| Location of deforestation in the Legal Amazon

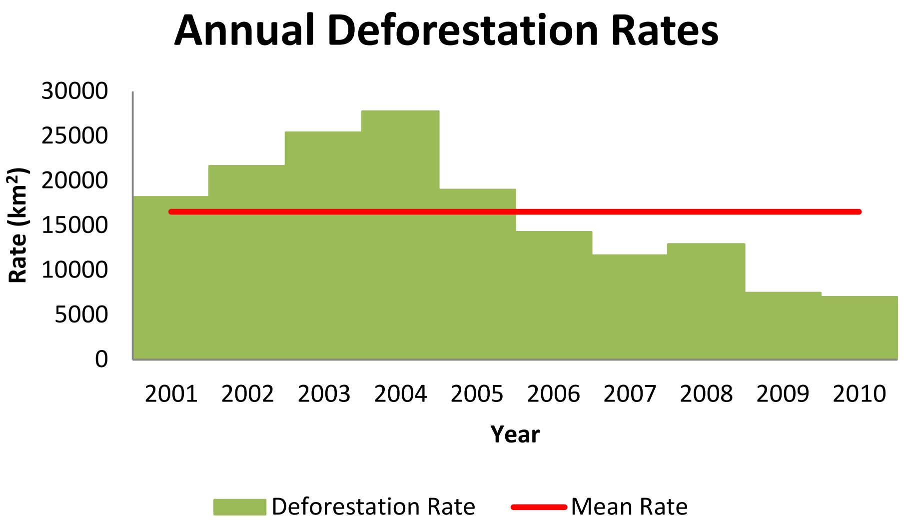
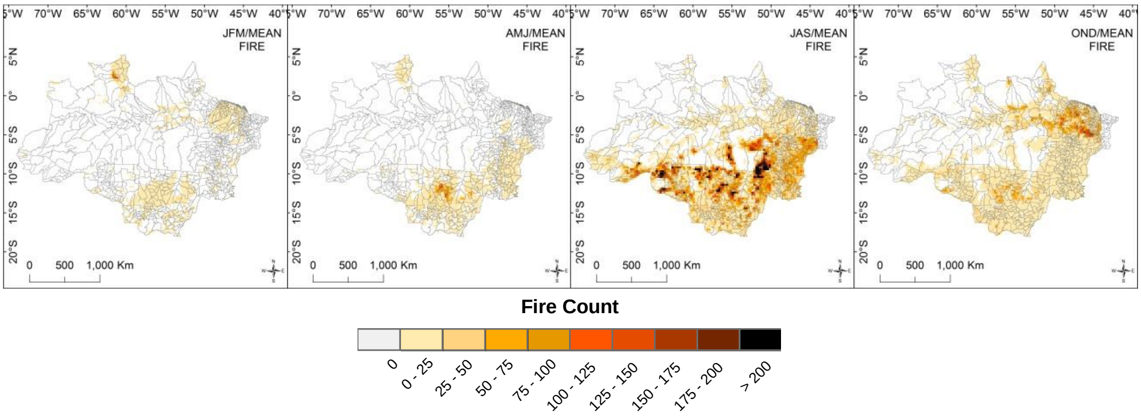


Figure 5.3 Annual deforestation rates 2001 – 2010

It is considered that fires within the region follow the pattern of deforestation; mean fire counts show a general trend around the 'arc of deforestation' which concurs with the literature discussed in chapter 3 (Figure 5.4). Moreover, it has been shown that the number of fires increases during periods of intense drought (Aragão et al., 2007b), which is confirmed in this research by assessing anomalies and the number of fires. During 2005, a clear anomalous increase (≥ 1 σ) in active fires' frequency was observed in the epicentre of the drought (south-west of the Legal Amazon) during the JAS period (Figure 5.4). There were also notable positive anomalies in active fires around the east and south peripheries of the study area, corresponding to the 'arc of deforestation'. Within Acre, the epicentre of the 2005 drought, a 338% increase in active fires was observed from JAS 2004 to 2005, and within Rio Branco, the micro-region of the most intense fires, a 214% increase in active fires was observed from 2004 to 2005. Across the whole Legal Amazon, the cumulative number of active fires in 2005 was 39% higher than the 2001–2010 mean. Fire frequency was lower in 2009 than in the adjacent years when compared with the 2001–2010 mean, when there was a 42% reduction in the number of fires. Negative anomalies (≥ - 1 σ) were observed particularly in JAS 2009, which may be because conditions for ignition of fires were not present following the heavy rain in AMJ. Some positive active fire anomalies are observed which could be due to new locations of forest fires beginning to emerge. These occur later in the year (OND) compared to the drought months of JAS. In JAS 2010, the intensity of active fires around the ‘arc of deforestation’ increased, following the spatial pattern of drought-affected areas. Areas in southern Maranhão, Tocantins and Mato Grosso States were subject to the greatest positively anomalous grid-cells (≥ 1 σ) (72.8%) (Figure 5.4). Overall, the cumulative number of active fires in the Brazilian Amazon was 36% higher than the 2001–2010 mean during the 2010 drought.

Increases in air pollution are associated with fires; this is shown clearly during the 2005 drought, where a high number of positive aerosol anomalies (≥ 1 σ) are shown to be concentrated in Acre. In JAS 2005, these correspond to areas of drought and high fires (Figure 5.5). Intense anomalies are also observed in OND in the north-east; although this was not the drought period, a cluster of positive fire anomalies is observed in the same location. Interestingly, there were fewer active fires during the 2010 drought, which has resulted in fewer positive aerosol anomalies (≥ 1 σ). Moreover, the 2010 positive anomalies are observed further to the west in the Legal Amazon than the anomalous active fires (Figure 5.5). In contrast to the two drought events, the 2009 flood saw a greater number of negative aerosol anomalies (≥ - 1 σ). During the peak of the flood in AMJ, more negative than positive anomalies were seen. However, because this period is usually less fire-intensive, resulting in mean levels of aerosol which are generally lower, AMJ were not conspicuous in the analysis, unlike the months of JAS in 2009 were. The negative aerosol anomalies in JAS extended over almost all of the Legal Amazon. Although this was not the peak of the flood, it is distinctive because of the extent of the negative anomalies and in comparison to the JAS 2001–2010 mean (Figure 5.5).

a) Mean Fire Count



b) Fire anomalies

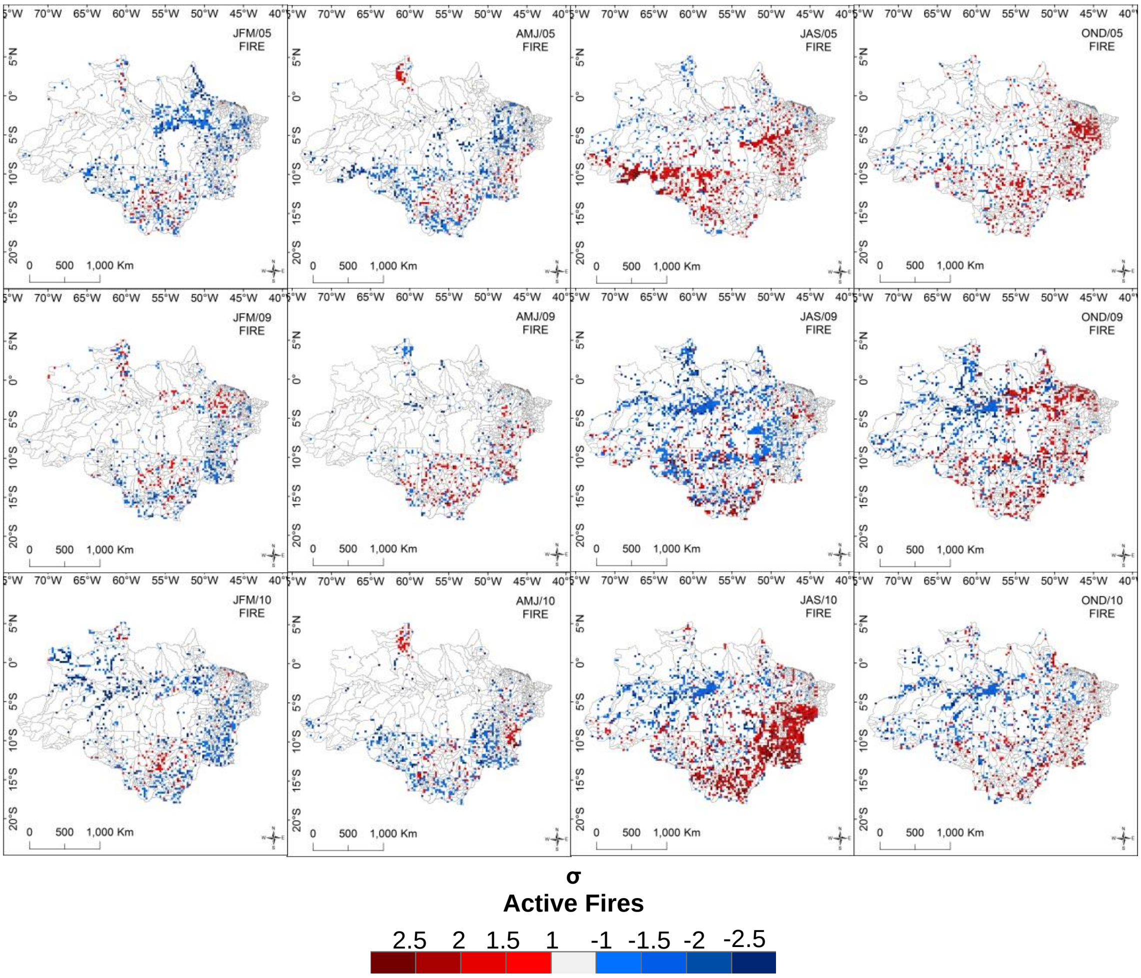
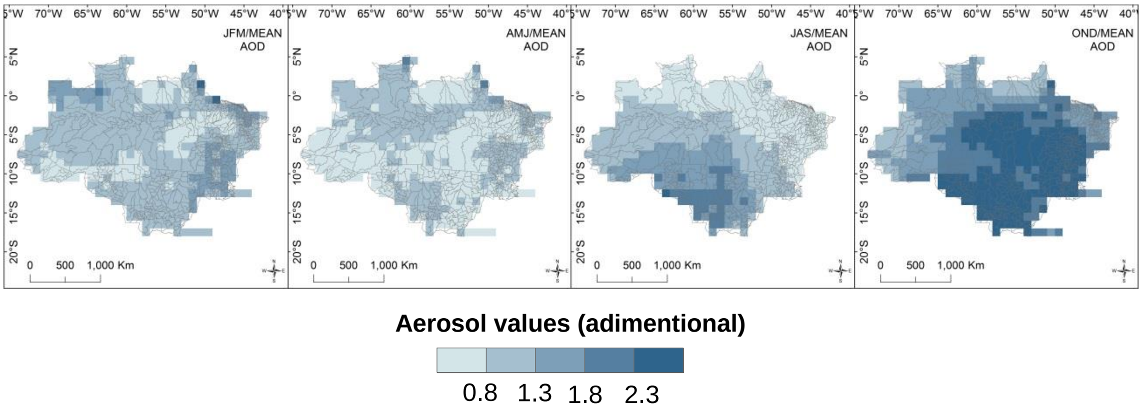


Figure 5.4| Standardised anomalies as a departure from the 2001 - 2010 mean. a) mean fire count (2001 – 2010), b) standardised fire anomalies.

a) Mean aerosol values



b) AOD Anomalies

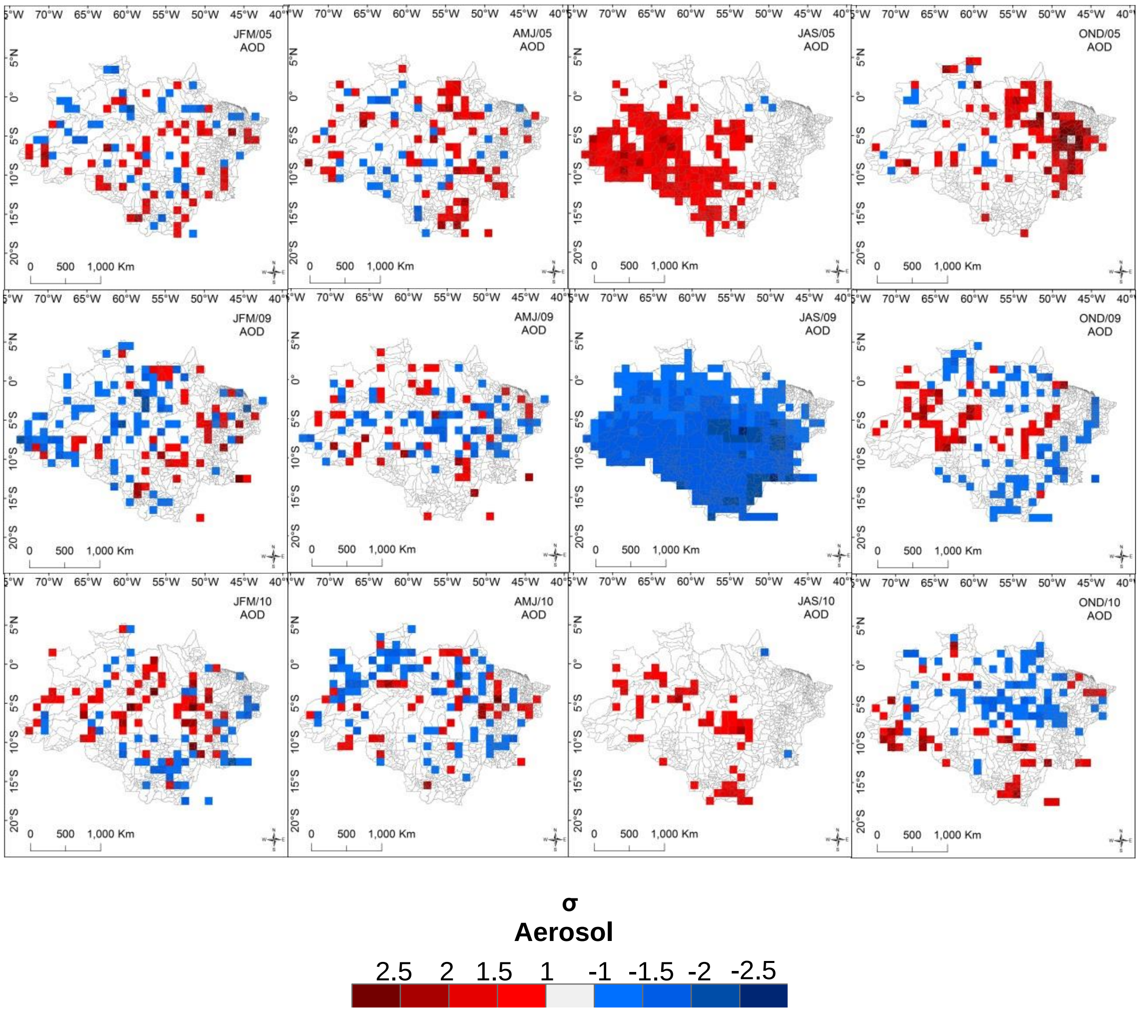


Figure 5.5| Standardised anomalies as a departure from the 2001 - 2010 mean. **a**) mean fire count (2001 – 2010), **b**) standardised fire anomalies.

Examining health data, the States of Mato Grosso and Rondônia are the primary locations for hotspots at the beginning of the time series. Moving through the time series, hotspots shift slightly inwards to southern and eastern Pará State (Figure 5.6). Some municipalities in these states had hospitalisation rates for children under five approaching 27,610/100,000 in Rondônia, 34,128/100,000 in Mato Grosso, and 24,159/100,000 in Pará. A smaller number of cold spots are observed compared to hotspots, which suggests that there are fewer areas within the Legal Amazon which have concentrations of significantly low respiratory diseases. Although the hotspot analysis highlights areas of higher respiratory disease incidence rates, it should be noted that the general distribution forms a patchwork pattern; data containing just incidence rates alone can be seen in Appendix C. This varied distribution of respiratory diseases could be explained by the geographical, cultural and developmental differences that are present within the Legal Amazon.

The cumulative monthly distribution of hospitalisations during the ten year study period found that hospitalisation rates peaked at the end of the wet season and the interim period between the seasons (Figure 5.7). The highest rate for respiratory diseases in under fives was experienced in March in Tocantins, showing 546 per 100,000. Peaks for hospitalisations during March occur in states on the eastern and southern part of the Legal Amazon with a Cerrado vegetation type, while peaks in May occur mainly in tropical rainforest type vegetation states, with the exception of Roraima, which peaked in July. In some states, small secondary peaks occur in October compared with months either side. Mean values across the Legal Amazon show peaks occurring in May with 348 per 100,000, followed by 319 per 100,000 in March, and 242 per 100,000 in October.

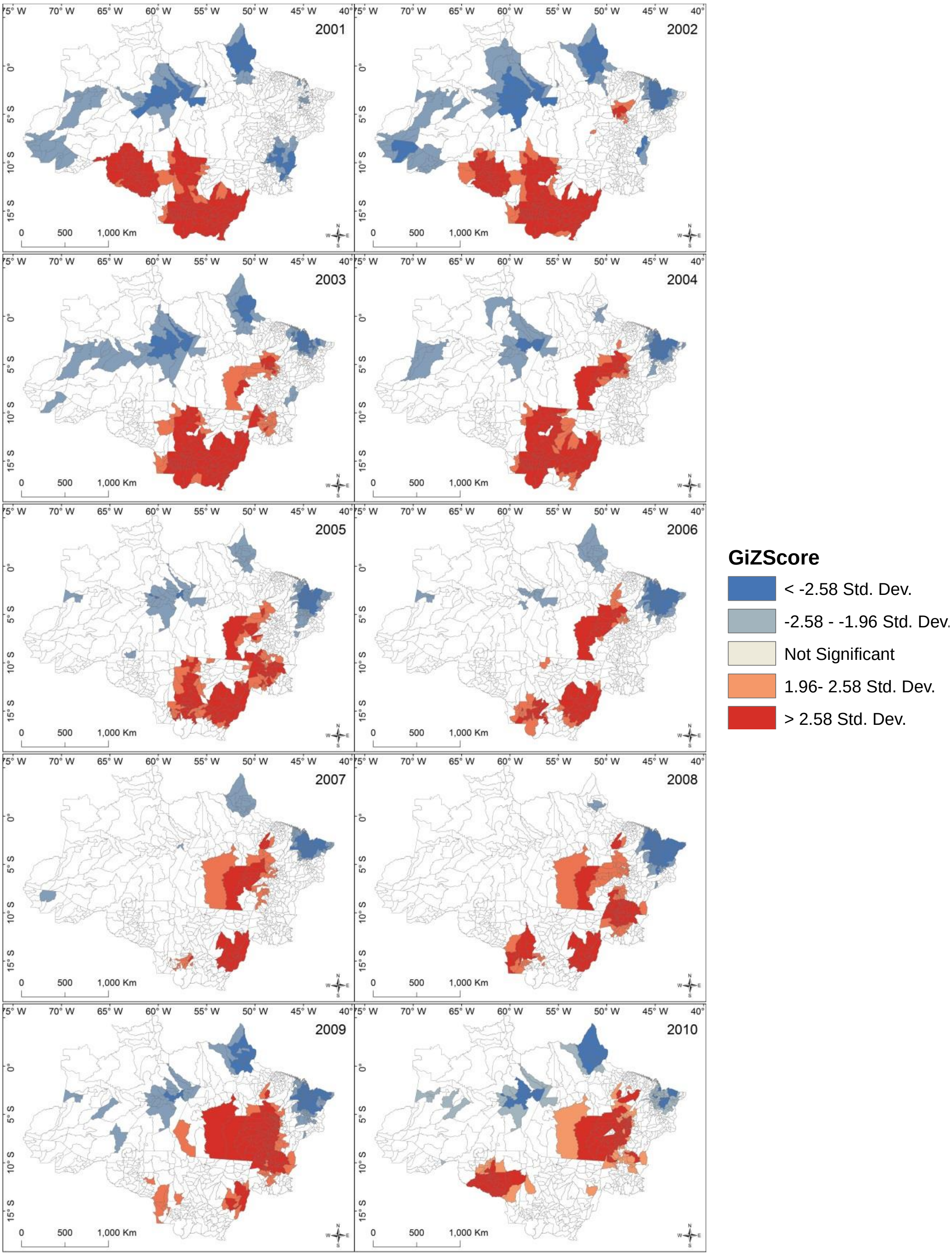


Figure 5.6| Significant clusters with a confidence level greater than 95% for respiratory diseases in children under-five at municipality level.

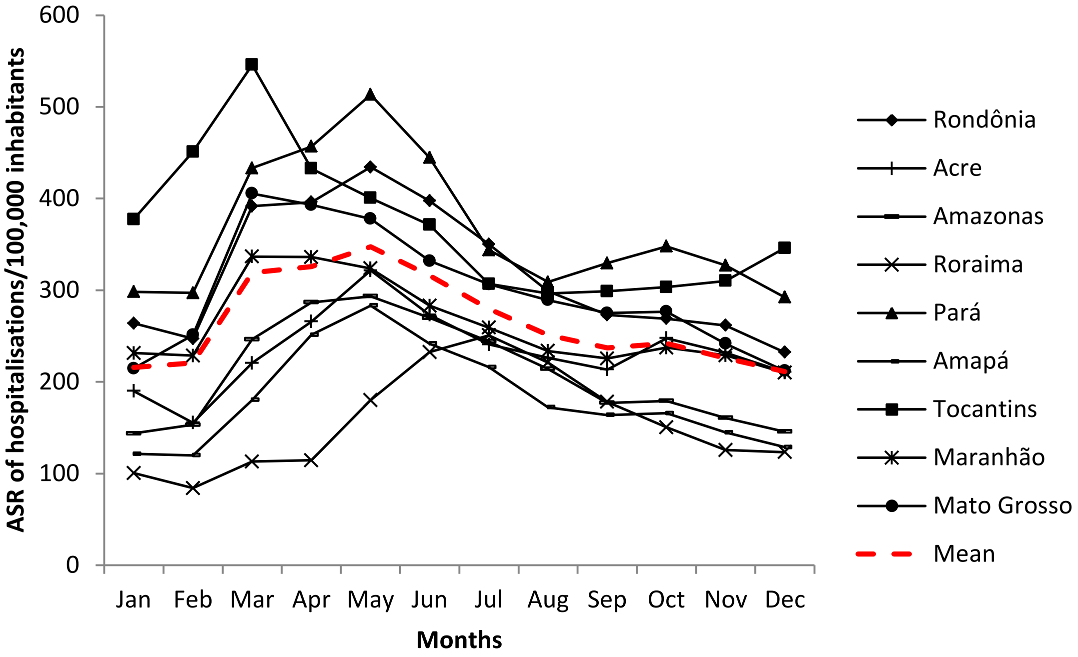


Figure 5.7| Distribution of cumulative monthly ASR of hospitalisations for respiratory diseases in children under-five.

When examining cumulative data for the wet and dry season rather than individual monthly data, it can be seen that respiratory diseases in children under five are more pronounced in the dry season (March - October), with the exception of Tocantins (Table 5.1). Roraima and Amapá also show higher proportions of hospitalisations during these months; however, this is their wet season, accounting for 46% and 24% more hospitalisations than the dry season. On average, children under five had a 6% higher proportion of hospitalisations during the dry season, with statistically significant results ranging from 7% in Mato Grosso to 17% in Amazonas. Of the southern states (south of Equator), only Tocantins experienced a higher number of hospitalisations during the wet season (24%).

Table 5.1| Cumulative seasonal hospitalisations (absolute).

States	Wet n (%)	Dry n (%)	Dry/Wet		
			Ratio	Chi-square	P value
Rondônia (RO)	28074 (46.96)	31705 (53.04)	0.88	219.93	< 0.0001
Acre (AC)	10670 (45.58)	12739 (54.04)	0.84	165.90	< 0.0001
Amazonas (AM)	45093 (45.23)	54610 (54.77)	0.83	898.84	< 0.0001
Roraima (RR)	3372 (35.31)	6177 (64.69)	0.54	757.60	< 0.0001
Pará (PA)	167880 (47.94)	182306 (52.06)	0.92	593.25	< 0.0001
Amapá (AP)	7392 (43.21)	9716 (56.79)	0.76	309.24	< 0.0001
Tocantins (TO)	33775 (55.44)	27152 (44.56)	1.24	712.36	< 0.0001
Maranhão (MA)	108650 (50.14)	108037 (49.86)	1.00	1.69	0.1939
Mato Grosso (MT)	57930 (48.23)	62194 (51.77)	0.93	150.20	< 0.0001
Total	462836 (48.34)	494636 (51.66)	0.94	1054.07	< 0.0001
Total ex. RR & AP	452072 (48.57)	478743 (51.43)	0.94	760.63	< 0.0001

5.4 Discussion

This chapter has examined research questions 1 and 2: where within the basin have the three hydrological extremes and associated human disturbances occurred? What was the spatial and temporal distribution of respiratory diseases within the basin between 2001 and 2010?

It has been shown that the seasonal timing of the two drought events were similar, with peaks both occurring in JAS; however, in 2010, negative rainfall anomalies began earlier in the year. Spatial patterns of the droughts were different, mainly due to the magnitude of the 2010 event. Both droughts affected the south-west of the Legal Amazon primarily in Acre but the 2010 drought spread further across the study area. Lewis et al. (2011) estimated 3.0 million km^2 were affected by the 2010 drought compared to 1.9 km^2 in 2005. Although this figure represents the Amazon basin rather than just the Legal Amazon, it highlights the magnitude of the 2010 drought. In contrast, the peak of the 2009 flood occurred slightly earlier in the year than the droughts, during the interim between seasons of AMJ. It affected a larger proportion of the Legal Amazon than either of the droughts (17.2% more compared to 2010) and floods previously recorded, despite some of the other floods having more severe meteorological conditions (Marengo et al., 2010). Similarly to the 2010 drought, however, the onset of the 2009 flood began in the preceding austral summer, and the intensity and spatial extent of the flood characterised it.

Land use change and subsequent activities are one of the main drivers of fires in the Amazon (Uhl and Kauffman, 1990). Data from INPE PRODES has shown that deforestation rates have been generally decreasing throughout the decade of this study, suggesting Brazil is on track to meet the goal to reduce deforestation by 2020. Despite the declining deforestation rates, this study shows that droughts and fire occurrence peak simultaneously; increases of 39% and 36% were observed in 2005 and 2010 in relation to the 2001–2010 mean. This concurs with Cochrane et al. (1999) and Laurance and Williamson (2001), who have shown that drought conditions further the vulnerability of forest to fires due to water stress, leaf litter and drying, and Aragão et al. (2007a), who show that forest flammability increases by around 30% in drought conditions, even when deforestation rates are declining within the Amazon.

It has been shown here that active fires increase with drought periods and, as a result, increases in aerosol levels have been observed. However, here it is shown that the dispersion of smoke can lead to anomalous increases of aerosol loads away from the ignition point. The most relevant studies that show this elsewhere relate to the forest fires of South Asia in 1997, which highlighted the distance that haze from forest fires can travel and affect the health of a population thousands of miles away. As expected, aerosol levels are reduced during periods of heavy rain, resulting in negative anomalies; Pauliquevis et al. (2007) have shown that in the Amazon, there is no air pollution, only some biogenic particles, during the wet season. Moreover, the magnitude of negative anomalies in JAS 2009 may be due to conditions for fire ignition not being suitable, resulting in fewer fires.

The interaction between droughts and forest fires impacts not only the health of the forest but also the population of the region. Before assessing the impacts of these extreme events on the health of the population, it is important to understand baseline information so that any changes during the extremes can be noted.

Spatial distribution of respiratory diseases showed the main hotspots at the beginning of the time series in the States of Rondônia and Mato Grosso which have shown high levels of deforestation, forest fires and air pollution. Emerging areas of hotspots are seen in Pará State, which is experiencing increasing rates of deforestation and fires. These states are located within the 'arc of deforestation', where it is expected that a high number of hospitalisations would occur due to deforestation rates and forest fires, which have been shown to have a significant impact on the air quality; for example, up to 400μg/m^3 of $PM_{2.5}$ per 24 hours (Artaxo et al., 1994) has been recorded during the dry season in some locations along the 'arc of deforestation'.

It is expected that hospitalisations for respiratory diseases peak during the dry season when high levels of air pollution are present due to forest fires occurring (Silva et al., 2009); however, this association was not found in this study since hospitalisations peaked during the interim period between seasons. In this study as well as in other studies, peaks in monthly rates of hospitalisations were recorded in March and May (Rosa et al., 2008b; Silva et al., 2009; Rosa et al., 2008a). Although peaks occur at the end of the wet season, a larger proportion of hospitalisations has been observed during the dry season months (6% across the whole study area). When studying a larger age range (children under 15), Rosa et al. (2008b) also observed a higher proportion (10%) of hospitalisations for respiratory diseases during the dry season in Tangará da Serra, Mato Grosso. Interestingly, however, when examining primary care visits, Rosa et al. (2008a) found the proportion to be lower (21%) in the dry season. The influence of climatic seasonality in this study and others suggests that less severe cases of respiratory diseases occur in the wet season, while more severe cases requiring hospitalisation occur in the dry season. This observation has been found elsewhere in Brazil

(Botelho et al., 2003). In contrast, higher proportions of hospitalisations and primary care visits for children with asthma have been shown to have higher proportions during the wet season (Rosa et al., 2009; Silva et al., 2009). Examining data on adults over 60 years of age, Rodrigues et al. (2009) found that a greater proportion of hospitalisations for asthma occurred during the dry season months of July–October, where in some cases hospitalisation rates were as high as three times more when compared with the wet season.

Secondary peaks have been observed in October, which compares to the findings of other studies carried out in the Legal Amazon. These peaks have been attributed to high relative humidity at the end of September (Rosa et al., 2008b) which provide suitable conditions for growth of funguses and mould in the household and which are known to be significant allergens in the development of respiratory diseases. Differences are observed such as the October peak in this study, which is conspicuous due to adjacent low rates, whereas in the other studies, increases are observed from July, peaking in October. In comparison, low rates of hospitalisations have been observed in wet season months of December, January, and February for most states. These observations agree with previous studies assessing the seasonality of hospitalisations for respiratory diseases (Rosa et al., 2008a). This peak in the wet season is also associated with operational seasonality, but conversely, as the peaks in March and May are associated; this period is when most health professionals are on vacation (Rosa et al., 2008b).

A limitation to the study is the potential for low confidence in the reliability of the main diagnosis for hospitalisations in Brazil ((Mendes et al., 2000), and Chapter 4 for data quality). Another limitation which may affect hotspot detection and hospitalisation rates is the issue of duplication. For example in Nove Nazaré, Mato Grosso, in 2008 168 hospitalisations were recorded for children less than one year of age when the population for that age group was only 79. This issue of data duplication could not be addressed in this study due to the quality of the data not allowing individual cases to be identified; also the creation of a new database of individual cases is not within the scope of this research.

5.5 Summary

This chapter has been concerned with addressing the first two research questions: where within the basin have the three hydrological extremes and associated human disturbances occurred, and what was the spatial and temporal distribution of respiratory diseases in children under five within the basin between 2001 and 2010?

The analysis has focussed on the period 2001–2010 to assess the extent of three extreme events experienced in the Legal Amazon and the trend of respiratory diseases in children under five during the same period. Frequency of extreme events in the Legal Amazon is increasing and affecting large areas. The south-west of the region around the state of Acre was susceptible to both droughts and the flood. Forest fires associated with the drought events are concentrated in drought-affected municipalities; however, human settlement must be present, and hence fewer anomalous hot pixels during the 2010 drought away from the 'arc of deforestation' were observed. A consequence of high numbers of active fires is an increase in air pollution, which has been shown to influence the respiratory health of populations. Hospitalisations of under fives for respiratory diseases peak at the end of the wet season but a higher proportion is observed during the dry season months. The severity of the problem is concentrated in the states that comprise the 'arc of deforestation', particularly on the eastern and southern peripheries comprising a Cerrado vegetation type. The highest rates of hospitalisations were observed in Mato Grosso and Rondônia. Although the spatial distribution of extreme events and hotspots is different, the aim of this chapter was to identify baseline trends. This chapter has shown that where a drought event occurs, increases in fires and aerosol loads are also observed which are known to cause respiratory health problems. The following chapter examines how these and respiratory diseases interact in the Legal Amazon.

Chapter 6

Drought and flood impacts on children's respiratory health in the Legal Amazon

6.1 Introduction

The aim of this chapter is to answer the third research question; to what extent do strong correlations between hydrological extreme periods and respiratory diseases exist?

On average, Amazonia experiences an extreme flood or drought once every ten years (Marengo et al., 2011). In a recent five-year period, however, two mega droughts have struck the Amazon: in 2005 and 2010. The 2005 drought was classified as a one-in-a-hundred year event, but five years later a drought of greater magnitude stuck the region again (Marengo et al., 2011). Environmental and social devastation can be caused through drought events: forest enters into water deficit causing tree mortality (Phillips et al., 2009); social impact can include: lack of food and medical supplies, isolation of communities and health problems (Marengo et al., 2008a).

During droughts, wind erosion in deforested areas causes soil particles and microbes to be blown into the air, creating and exacerbating respiratory problems, such as irritation of the respiratory tract, and triggering allergies (Pimentel et al., 2007). In Amazonia, droughts can lead to an increase of over 30% in fire occurrence (Aragão et al., 2007b; Aragão et al., 2008). Smoke from fires tends to carry into the atmosphere fine particulate matter particles ($PM_{2.5}$) (Hacon et al., 1995). These particles are extremely hazardous to human health since, when inhaled, they may reach deep in the lungs (Nel, 2005), causing irritation of the throat, lungs and eyes (Moreno, 2006). Within the Amazon, the primary location for fires is around the southern and eastern periphery, the arc of deforestation, where around 85% of fires occur (Becker), emitting as much as 300-600μg/m^3 of PM_{10} per 24 hours (Artaxo, 1999) and up to 400μg/m^3 of $PM_{2.5}$ per 24 hours (Artaxo et al., 1994) during the dry season. These particulates represent around 60% of Particulate Matter released during biomass burning (Hacon et al., 1995). Measurements carried out in southern Amazonia demonstrated that exposure to $PM_{2.5}$ has positive associations with children's respiratory health (Ignotti et al., 2010a). Local studies in Rio Branco, Acre State, and Alta Floresta, Mato Grosso State have shown a 5.6% and 2.9% increase in outpatients simultaneously with an increase of 10μg/m^3 $PM_{2.5}$ (Carmo et al., 2013; Carmo et al., 2010).

Global Climate Models (GCMs) predict a higher probability of droughts in the Amazon by the end of the 21st century in response to climate change (Malhi et al., 2008; Christensen, 2007). This potential increase in drought intensity and frequency may transform Amazonia into a fire-prone system (Malhi et al., 2009), with amplified impacts upon ecosystems and humans. Despite recent demonstrations of the impact of droughts and fire on tropical ecosystems (Phillips et al., 2009; Aragão et al., 2007b; Phillips et al., 2010; Lewis et al., 2011; Aragão and Shimabukuro, 2010b; Saatchi et al., 2012), there is still a lack of large-scale and wall-to-wall assessments that include testing how these droughts would affect the tropical population's health. Although GCMs predict drying in the Amazon, recently flooding has also been observed in the region (Marengo et al., 2010). Also it has been shown that health outcomes for respiratory diseases peak at the end of the wet season. With a variety of extremes having been seen in the Amazon and uncertainties in GCMs, the relationships between respiratory health and recent Amazonian hydrological extremes may provide an approximation of the expected responses of health to future climate conditions. Therefore, in this study it was tested whether the incidence of respiratory diseases during two major droughts (2005 and 2010) and one flood (2009) was statistically dependent on drought and flood-related environmental changes and socio-economic factors, by using Geographically Weighted Poisson Regression models (GWPR) for the whole Legal Amazon.

6.2 Materials and Methods

6.2.1 Study Design

This is a retrospective study of the impacts of the 2005, 2009 and 2010 hydrological extremes on hospitalisations for respiratory diseases in children under five years of age in the Legal Amazon for a decade between 2001 and 2010.

6.2.2 Study Area

Spatial analysis has been conducted at micro-region and municipality levels. There are two reasons for this; the first is data related and the other is policy related. Due to some municipalities being very small in size and population, the numbers of observed cases were also small which can cause the small numbers problem and therefore micro-regions were used for analysis as the large size of them reduces the risk of small numbers problem. However, increasing the spatial resolution, it can be argued, results in only producing averages rather than detailed information. For this reason, municipalities have also been included in analysis. The choice of scale is discussed in health studies as it can affect the results produced. The scale should be based on conceptual and theoretical factors rather than purely on administrative boundaries; following discussions with colleagues in Brazil, it has been suggested that using both micro-region and municipality is appropriate because analysis at municipality level is useful for policy makers when it comes to policy making and decision making on how to cope with the impacts of climatic events and, despite averaging of micro-regions, there is usually a main hospital in each which may be a reference point for people.

The micro-regions (107) and municipalities (807) that make up the Legal Amazon are used in this analysis. Since defining flooded municipalities is more difficult and information regarding those that were in a state of emergency was not available at the time of writing, analysis here looks at micro-regions and municipalities with positive rainfall anomalies when assessing the flood rather than defined affected micro-regions and municipalities.

6.2.3 Data Sources

The datasets used for this analysis have been set out in chapter 4. In brief, six dataset have been used in the GWPR analysis. Count data for all children aged under five was used for the number of hospitalisations for respiratory diseases per month and per micro-region and municipality. Monthly rainfall (mm) (NASA, 2011a) (RAIN), deforestation rates (km) (INPE 2011) (DEF), active hot pixels (INPE, 2011) (FIRE), and aerosol optical depth (NASA, 2011b) (AOD) were used as environmental variables. Including social factors, population density (IBGE, 2010) (POP) was used as a variable to suggest urban and rural micro-regions and municipalities, and HDI (Sistema Fijan, 2011) (HDI) was used as an indicator of the level of development of each micro-region and municipality.

6.2.4 Data Analysis

Critical areas of drought conditions within the Legal Amazon have been identified using at least one negative anomalous rainfall pixel and micro-regions/ municipalities exhibiting less than 100 mm monthly rainfall (Figure 6.1). Absolute values of the environmental variables have been aggregated by municipality and micro-region to identify relationships between those experiencing hydrological extremes and associated conditions, and hospitalisations for respiratory diseases. At the time of writing, information on the micro-regions and municipalities in a state of emergency from the 2009 flood were unavailable. Unlike the drought-affected municipalities, 2009 is being examined in terms of positive rainfall anomalies.

The Geographically Weighted Poisson Regression Model

The local model, GWPR, has been used to identify relationships between hydrological extremes and respiratory diseases because it incorporates local level data rather than 'global' data which assumes to represent the situation in every part of the study area. If the study region had little variation, a global model would be acceptable; however, the Legal Amazon is a vast area with varying land use, climate, population structure, and development. Moreover, incorporating the Poisson regression into the analysis (GWPR) provides a more appropriate basis for analysing areal data where observed counts may include low count numbers, which can arise when working with health data (Lovett and Flowerdew, 1989). The details of the model are described elsewhere (Nakaya, 2009) and the general model of GWPR is shown in chapter 4. Details of the model for this analysis are given below with equations 6.1 to 6.4.

$$y_i \sim \mathrm{Poisson}[N_i \exp(\mu_i)]$$

$$\mu_i(\{x_{k,i}\}) = \sum_k \beta_k(u_i, v_i) x_{k,i}$$

(equation 6.1)

where y_i, μ_i, $x_{k,i}$ and N_i are, respectively, dependent variable (the total number of children aged under five who were hospitalised for respiratory diseases), the linear predictor, *k*th independent variable including the constant term and the offset variable corresponding to population size at risk (defined as population aged under-five) at the location *i*; it should be noted that the estimated risk of child hospitalisation for a respiratory disease at location at the location *i* is given by the term of $\exp(\mu_i)$. (u_i, v_i) is the x-y coordinate of the *i*th location, and coefficients $\beta_k(u_i, v_i)$ are assumed to be smoothly varying conditional on the location.

The model has been executed twice for each hydrological extreme: once to assess purely environmental variables (ENV) and a second analysis that incorporated socio-economic variables (SOCIO). In the case of the SOCIO model, which is the better model, the linear predictor can be rewritten with the names of independent variables as:

$$
\begin{gathered}
\mathrm{y_i} \sim Poisson\ [\mathrm{N_i}\exp(\mu_\mathrm{i})\log(\mu_\mathrm{i}) \\
= \beta_0(\mathrm{u_i},\mathrm{v_i}) + \beta_1(\mathrm{u_i},\mathrm{v_i})[\mathrm{Rainfall}]_\mathrm{i} + \beta_2(\mathrm{u_i},\mathrm{v_i})[\mathrm{Deforestation}]_\mathrm{i} \\
+\beta_3(\mathrm{u_i},\mathrm{v_i})[\mathrm{Fire}] + \beta_4(\mathrm{u_i},\mathrm{v_i})[\mathrm{Aerosol}] + \beta_5(\mathrm{u_i},\mathrm{v_i})[\mathrm{Population\ Density}] + \\
\beta_6(\mathrm{u_i},\mathrm{v_i})[\mathrm{HDI}]\ .
\end{gathered}
$$

(equation 6.2)

The estimates of the local coefficients at the location *i* are obtained by fitting a usual Poisson regression model to the data subset around the regression point *i* with a geographical weighting function. The standard errors of estimated local coefficients can be derived by local regression theory. A descriptive measure of goodness-of-fit for Poisson regression is percent of deviance explained:

$$pdev_i = 1 - dev_i \,/\, nulldev_i$$

where $\mathrm{dev_i}$ is the deviance of the fitted model and $\mathrm{nulldev_i}$ is the deviance of the null model having only a constant term. The equivalent measure for the local fitting at each location can be derived by the local weighting of the deviance of fitted and null models. The estimated values of local coefficients and the local goodness-of-fit measures can be mapped to assess the spatial variability of relationships between the dependent and independent variables.

To some degree, overdispersion tends to be present in the vast majority of count data (Hilbe, 2007). This will lead to an underestimation of the standard errors, which will result in overstating the significance of the parameter estimates, resulting in misleading inference. For example, a variable may appear to be statistically significant when in fact it is not. This is the case with hospitalisation count data for children under five in the Legal Amazon. To manage this, standard errors have been adjusted, based on the quasi-likelihood theory to produce adjusted z values (equation 6.3).

$$\text{Adjusted Z value} = \frac{\text{z value}}{\sqrt{\text{phi}}}$$

(equation 6.3)

where phi is the deviance divided by the degrees of freedom.

To identify significant locations, the Bonferroni correction method has been used which identified z-values of ±4.01and ±1.95 for municipalities based on the number of regression points 807 with threshold p-value of 0.05 and ±3.49 and ±1.95 for micro-regions based on the number of regression points 107 with threshold p-value of 0.05. Z values of location specific coefficients:

$$\frac{\hat{\beta}_{ik}}{\text{se } \beta_{ik}}$$

(equation 6.4)

are mapped. The derivation of the standard error (se) of GWPR is described elsewhere (Nakaya et al., 2005), and the terms of equation 6.4 are described in the text detailing equation 6.2.

The GWPR model specifics for this research

An adaptive kernel weighting and golden section search for the optimal bandwidth size by minimising AICc were used. The adaptive kernel was selected to account for the variation in micro-region and municipality size. Better models have lower Akaike Information Criterion correction (AICc) values, with the general rule of a difference of at least three (Fotheringham AS, 2002), Table 6.1 and Table 6.2 show that the local model is performing better than the global model for both micro-regions and municipalities.

Table 6.1| Summary of model results for micro-regions

	Model	AICc	Percent of Deviance explained
2005	Global Environmental	5129.29	0.04
	Local Environmental	2239.36	0.59
	Global Social	4284.70	0.19
	Local Social	1349.54	0.79
2009	Global Environmental	8709.95	0.05
	Local Environmental	3801.85	0.59
	Global Social	6555.86	0.28
	Local Social	2384.61	0.77
2010	Global Environmental	5565.28	0.05
	Local Environmental	2592.01	0.58
	Global Social	4547.91	0.23
	Local Social	1702.02	0.75

Table 6.2| Summary of model results for municipalities

	Model	AICc	Percent of Deviance explained
2005	Global Environmental	14975.33	0.01
	Local Environmental	6899.01	0.56
	Global Social	14248.12	0.06
	Local Social	5300.90	0.68
2009	Global Environmental	17608.25	0.03
	Local Environmental	10476.04	0.43
	Global Social	15993.63	0.12
	Local Social	9030.41	0.51
2010	Global Environmental	12554.14	0.08
	Local Environmental	6725.82	0.52

Global Social	12214.44	0.11
Local Social	5727.31	0.60

In order to analyse the impacts hydrological extremes have on children's respiratory health, an initial analysis investigated the temporal trend of the selected environmental variables and hospitalisations for respiratory diseases in the state of Acre. Acre was selected because in 2005 it was the epicenter of the drought and the whole state was affected, making it easier to assess the impacts. Following this GWPR models were used to assess local spatial associations between municipalities and micro-regions that were classified as being affected by the drought or flood. This begins by looking at the peak of the droughts, then moves on to examine the peak of the flood. Two spatial scales are being investigated; micro-region and municipalities, and GWPR models are run for the environmental variables, named ENV model, and the model including social variables, SOCIO model. Results for each hydrological extreme and the ten year mean are displayed for the different spatial scales and different variables, showing the z-value for each affected municipality or micro-region. The locations illustrating z values vary between the hydrological extremes because they affected different parts of the Legal Amazon.

6.3 Results

During the July, August and September (JAS) period, 246 and 458 out of 807 municipalities were classified as drought affected in this study, during the 2005 and 2010 droughts, respectively based on methodology used by Shuttleworth et al. (1989) and Rocha et al. (2004) (Figure 6.1). During the peak of the 2009 flood in April, May and June (AMJ), 626 out of 807 municipalities were considered flood affected, based on positive rainfall anomalies.

2005 | **2010**

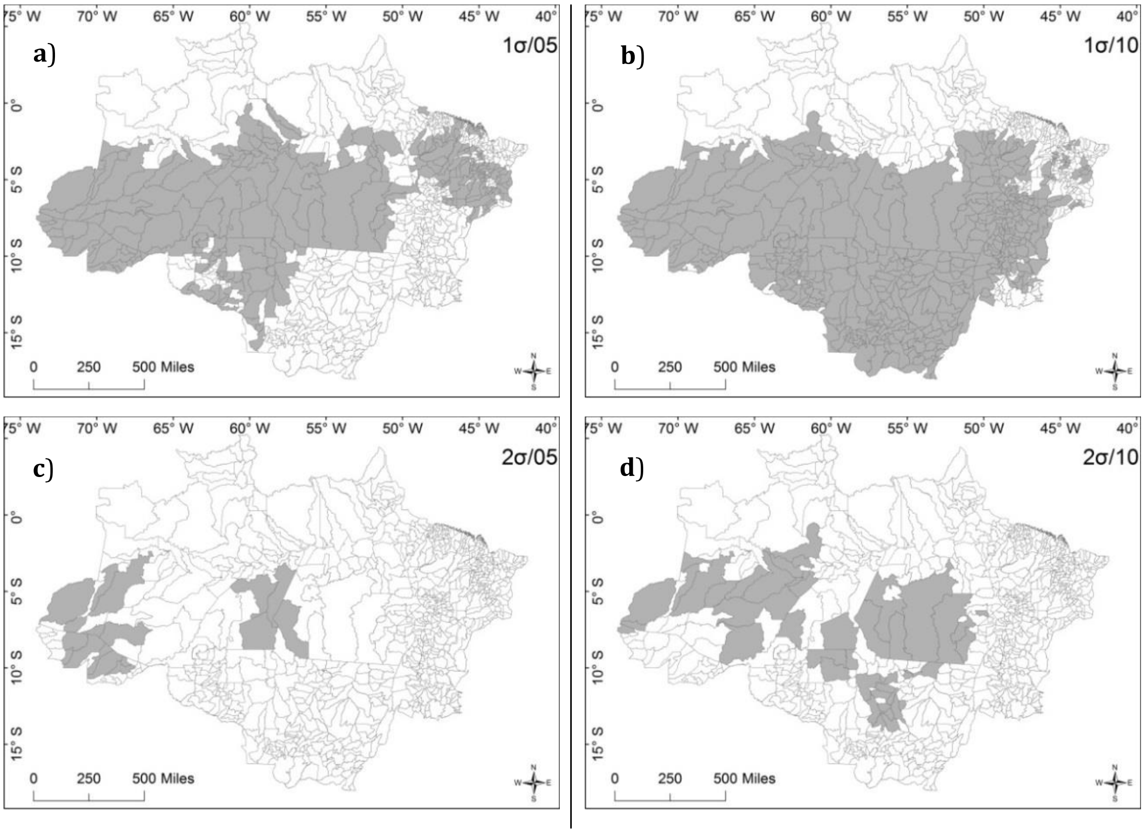


Figure 6.1| Drought affected areas. **a**, 2005 **b**, 2010 **c**, severely hit municipalities in 2005 **d**, severely hit municipalities in 2010. Grey shaded areas illustrate the drought affected municipalities.

For 31.3% (77) of the municipalities affected by the 2005 drought, the total number of hospitalisations increased by between 1.3% and 180.8%, in comparison to the ten-year mean. Capixaba in Acre State was the municipality with the largest increase in hospitalisations during the 2005 drought (180.8%). Similarly, for 43.0% (197) of the municipalities affected by the 2010 drought, the total number of hospitalisations increased by between 1.2% and 267%, in comparison to the ten-year mean. For the 2010 drought, the highest increase in total hospitalisations in relation to the ten-year mean was in Tocantins State, with the municipality of Fátima displaying a 267% increase in hospitalisations. These results confirm the association between increases in emergency room visits and hospitalisations for respiratory diseases and periods of high fire counts previously observed at the local scale (Mott et al., 2005; Marlier et al., 2012). For the 69.5% (627) of the municipalities that were classified as flood areas in this research, increases in the total number of hospitalisations were observed in comparison to the ten-year mean, ranging from 1.0% to 650%.

This analysis also brings to light the fragility of population health in relation to drought-associated impacts. This statement becomes clear when analysing the seasonality of health data in Acre State alone, during the 2005 drought. Acre State is a good example because the 2005 drought was concentrated here, while the other two hydrological extremes were more widespread, making this type of analysis more difficult. The total number of hospitalisations for respiratory diseases increased by 88% compared to the same period in 2004. Moreover, this value was 54% larger than the ten-year mean. Throughout 2005, JAS also accounted for the greatest number of hospitalisations in Acre (Figure 6.2). Chapter 5 demonstrated that peak hospitalisations generally occur at the end of the wet season; however, during the 2005 drought, this peak was displaced and in agreement with the drought and the fire season, indicating a direct effect.

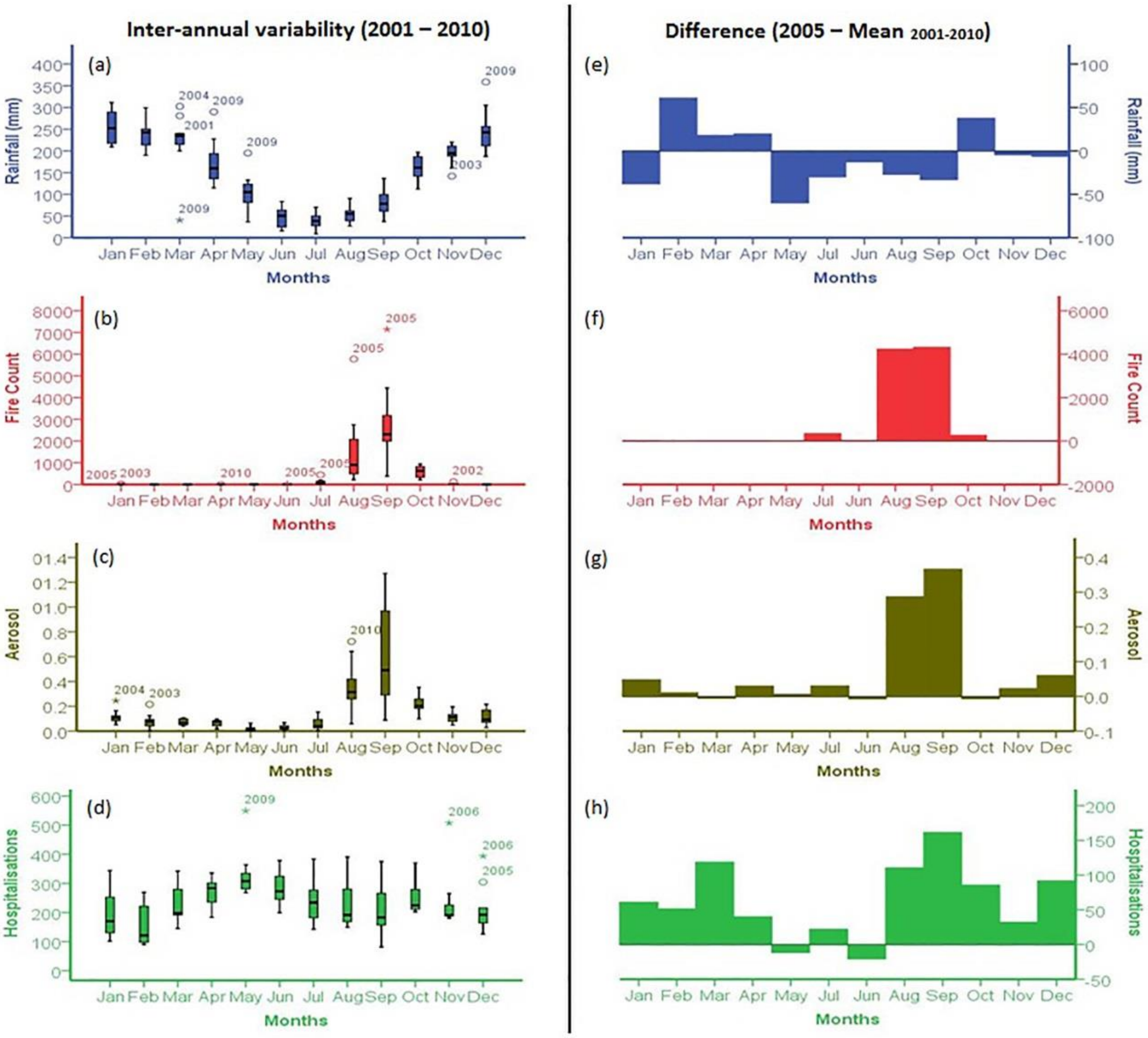


Figure 6.2| Temporal trends in Acre 2005. The right column shows inter-annual variability (2001-2010) for Acre State, while the left column represents the difference between 2005 values for Acre State compared to the mean values. **a** average rainfall, **b** cumulative active fires, **c** average aerosol values, **d** number of hospitalisations, **e** difference in average rainfall, **f** difference in cumulative active fires, **g** difference in average aerosol, **h** difference in the number of hospitalisations.

To examine the spatial relationship between respiratory diseases in children under five and the 2005 and 2010 droughts, and the 2009 flood, a local model, named Geographically Weighted Poisson Regression, was used. As a baseline for comparing the model for hydrological extreme years, the model was first run using the ten-year average values (2001–2010) for each variable associated with drought and flood events (MEAN model). The MEAN and hydrological extreme years have been analysed at micro-region and municipality levels to not only assess the impacts of hydrological extremes but also how they interact with respiratory diseases at different spatial scales. First, the droughts will be discussed before moving on to discuss the flood.

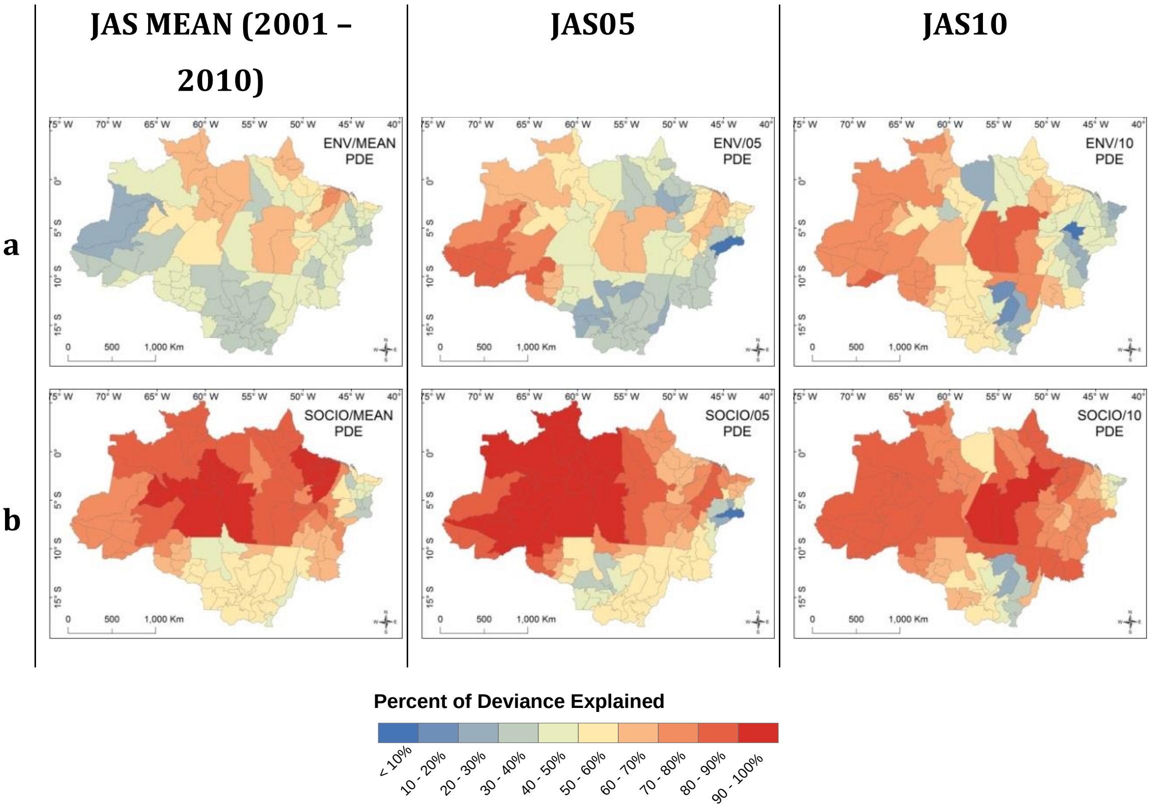
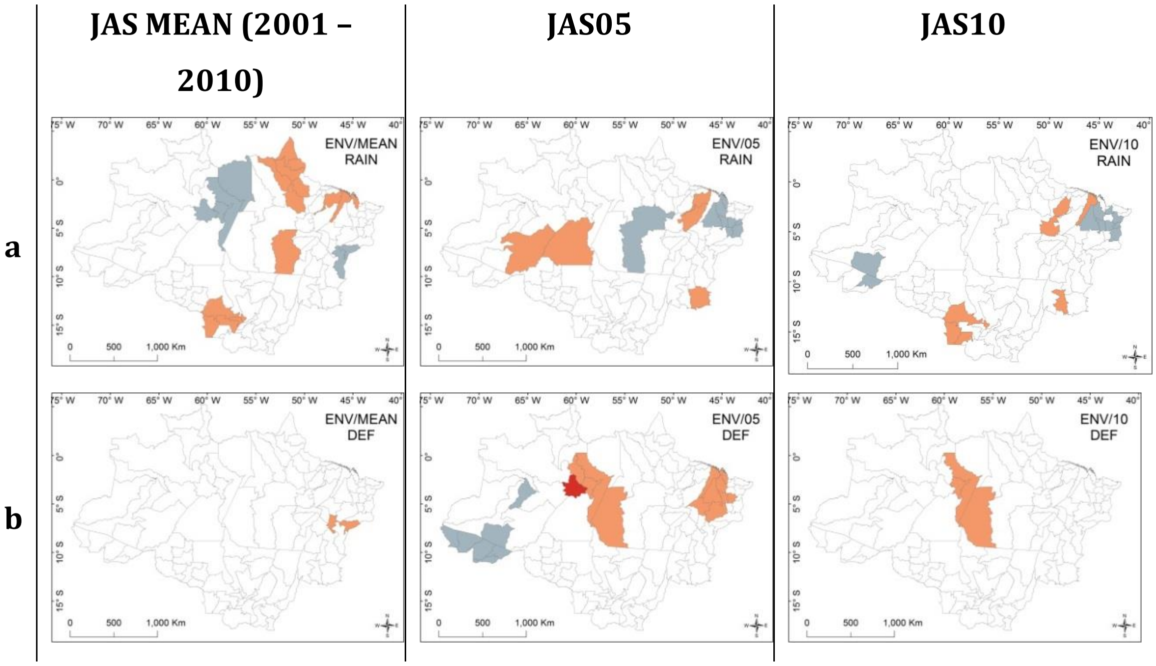


Figure 6.3| Percent of deviance explained for micro-regions in drought years. **a** goodness-of-fit for the ENV micro-region models, **b** goodness-of-fit for the SOCIO micro-region models.

The MEAN model for environment variables only (ENV) in the micro-region model showed a goodness-of-fit, a similar measure of coefficient of determination (percentage of deviance explained, PDE), of 62% increasing to 79% when including Human Development Index (HDI) and population density (SOCIO). PDE was higher in the SOCIO model, particularly around central parts of the Legal Amazon (Figure 6.3). Following this, analysis was carried out for the JAS period of each drought. As with the MEAN models, goodness-of-fit increased in the SOCIO model for both JAS05 and JAS10. The ENV model had a goodness-of-fit of 59% in JAS05 ENV, and 58% in JAS10 ENV, increasing to 79% and 75% respectively (Figure 6.3). The PDE remained spatially similar in the ENV and SOCIO models for both JAS05 and JAS10, with all models mainly showing higher PDE in central and western parts of the Legal Amazon.

Aerosol and HDI were the primary influences on respiratory diseases during the 2005 and 2010 droughts at micro-region level. Examining how the variables in the ENV model interact with the number of hospitalisations for respiratory diseases, it is observed that deforestation showed a statistically positive association with respiratory diseases in 12.1% of drought affected micro-regions in JAS05 (Figure 6.4). However, the local parameter estimates for deforestation as well as rainfall and active fires for both JAS05 ENV and JAS10 ENV were close to zero, indicating they had very little influence in the statistically positive or negative micro-regions. AOD represents a larger number of statistically significant positive micro-regions in 2005 (8.4%) than in 2010 (4.7%). In JAS05 they are concentrated in the south-west, corresponding with the epicentre of the drought, while in JAS10 they are concentrated on the periphery of Maranhão. Parameter estimates range from 0.3 to 1.6 for AOD in 2005, yet in 2010 these range from 4.3 to 6.8, suggesting a stronger influence of AOD in the ENV model for micro-regions for the 2010 drought.



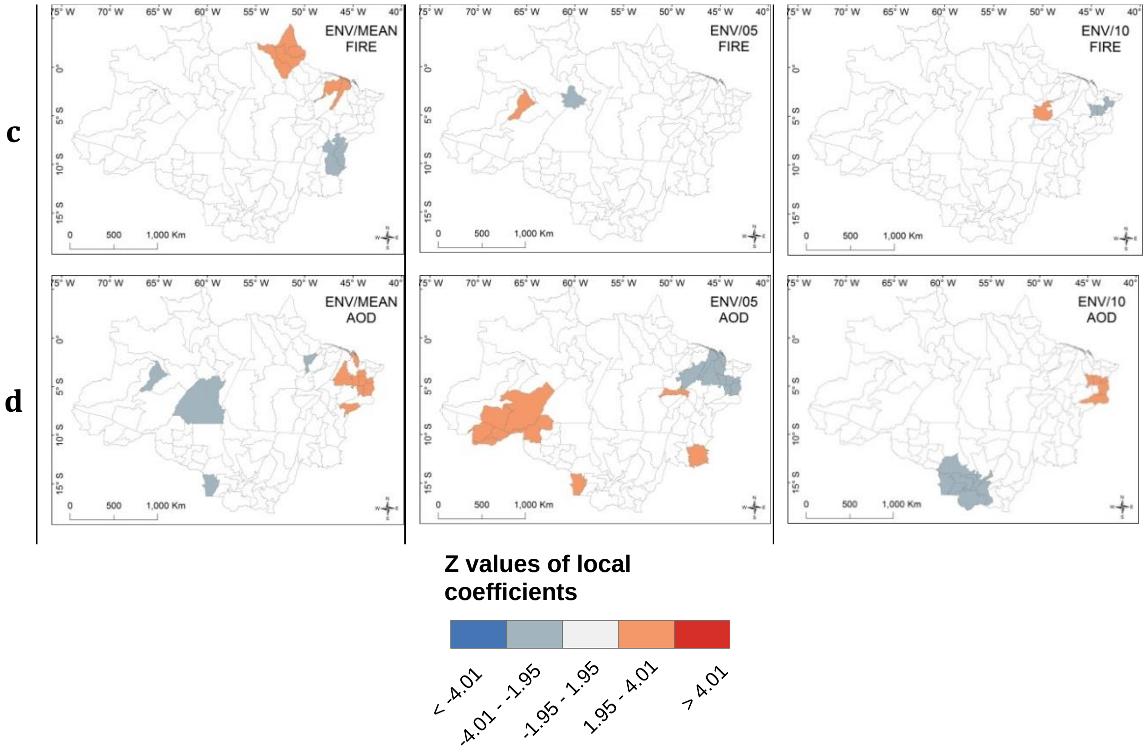


Figure 6.4| Significant values with a confidence level greater than 95% for the ENV model in drought affected micro-regions. Non-significant micro-regions are masked out. **a** rainfall, **b** deforestation, **c** fire, **d** aerosol. Red shades show positive z values of local coefficients, while blue shades show negative z values of local coefficients - the darker the shade the stronger the relationship.

The same is observed in the SOCIO model (Figure 6.5); rain, deforestation, fire, and population have little influence on respiratory health but aerosol remains a key influence on respiratory disease in the SOCIO model. However, the spatial location of aerosol in JAS05 is no longer around the epicentre of the drought. HDI now becomes the primary driver. For both variables, the local parameter estimates are larger in JAS10. The strength of aerosol increases to levels as high as 7.5 in JAS10, while HDI reaches 15 in statistically significant positive micro-regions.

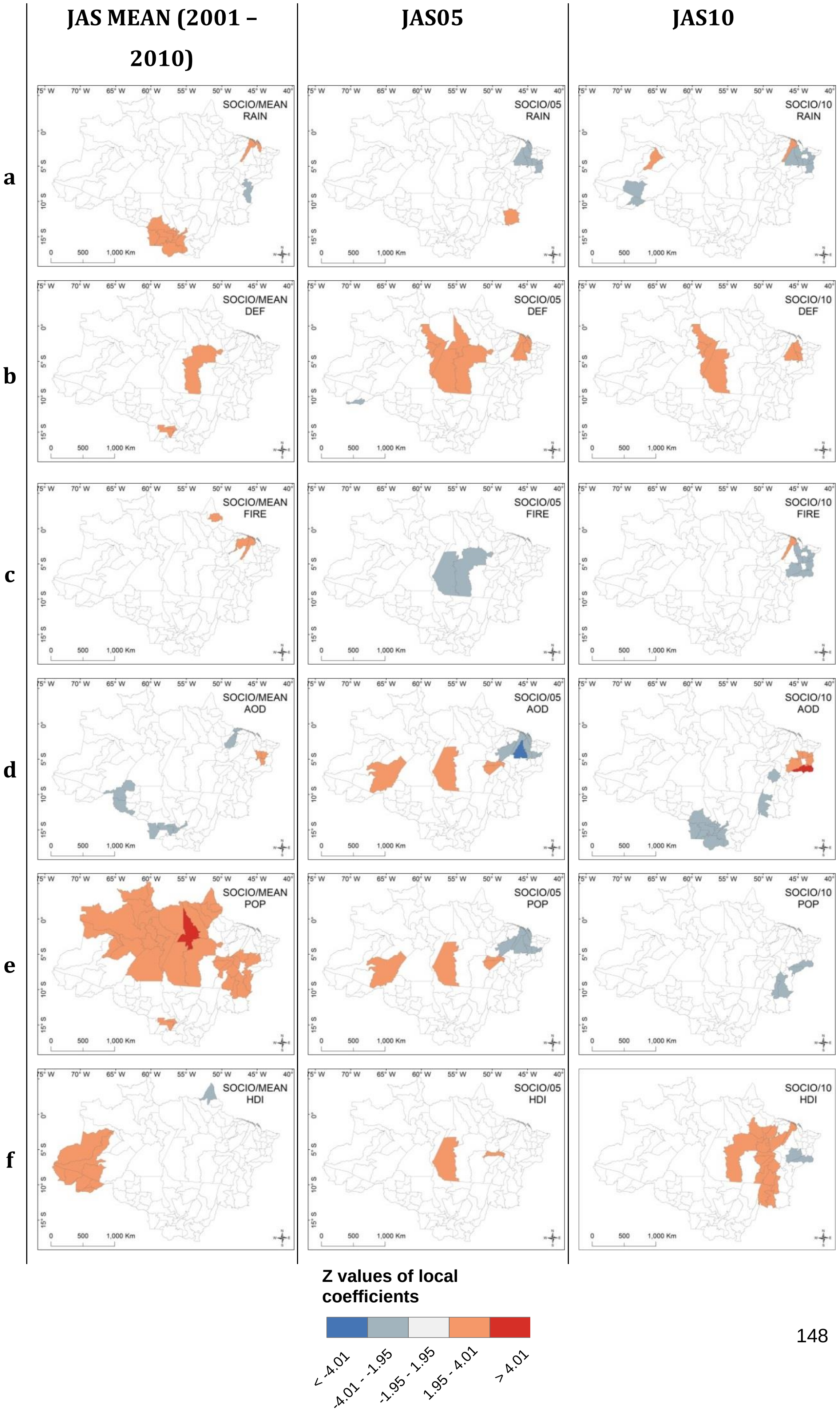

JAS MEAN (2001 – 2010)
JAS05
JAS10
a
b
c
d
e
f
SOCIO/MEAN RAIN
SOCIO/05 RAIN
SOCIO/10 RAIN
SOCIO/MEAN DEF
SOCIO/05 DEF
SOCIO/10 DEF
SOCIO/MEAN FIRE
SOCIO/05 FIRE
SOCIO/10 FIRE
SOCIO/MEAN AOD
SOCIO/05 AOD
SOCIO/10 AOD
SOCIO/MEAN POP
SOCIO/05 POP
SOCIO/10 POP
SOCIO/MEAN HDI
SOCIO/05 HDI
SOCIO/10 HDI
75° W
70° W
65° W
60° W
55° W
50° W
45° W
40°
0°
5° S
10° S
15° S
0
500
1,000 Km
Z values of local coefficients
< -4.01
-4.01 - -1.95
-1.95 - 1.95
1.95 - 4.01
> 4.01

Figure 6.5| Significant values with a confidence level greater than 95% for the SOCIO model in drought affected micro-regions. Non-significant micro-regions are masked out. **a** rainfall, **b** deforestation, **c** fire, **d** aerosol, **e** population density, **f** HDI. Red shades show positive z values of local coefficients, while blue shades show negative z values of local coefficients - the darker the shade, the stronger the relationship.

Increasing the scale to municipality level, the MEAN ENV model showed a goodness-of-fit of 32%, increasing to 67% for the MEAN SOCIO model (Figure 6.6). Subsequent analysis was carried out at municipality level for the peak drought periods of JAS05 and JAS10. The ENV model for municipalities showed a goodness-of-fit of 56% for JAS05, and 52% for JAS10. PDE was higher in south-western Mato Grosso, Acre, and Amazonas States in 2005, south-western Mato Grosso and eastern Rondônia States in JAS10, and south-western Mato Grosso in 2009 (Figure 6.6). In the SOCIO model, the goodness-of-fit increased in the drought affected municipalities. It was observed that 68% of deviance was explained by the SOCIO model in western and central Amazonia for 2005. For 2010, however, the amount of deviance (60%) explained by the SOCIO model remained spatially similar to the ENV model (Figure 6.6).

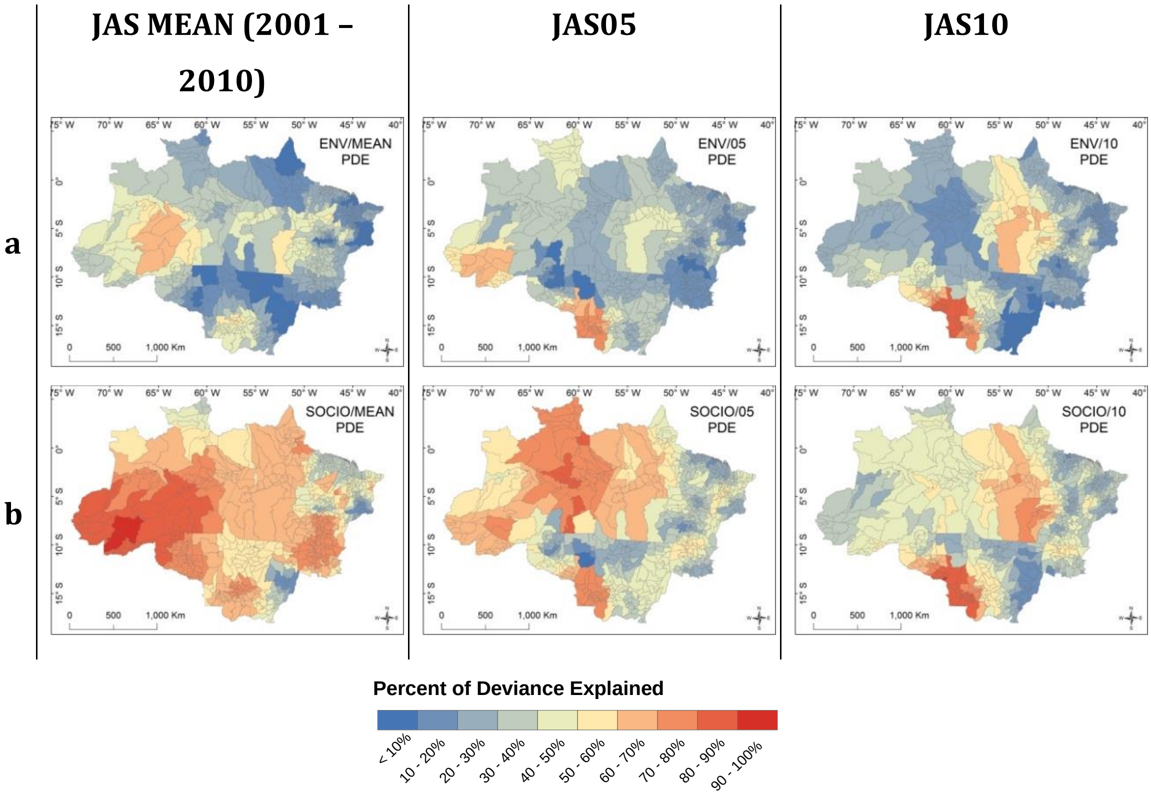
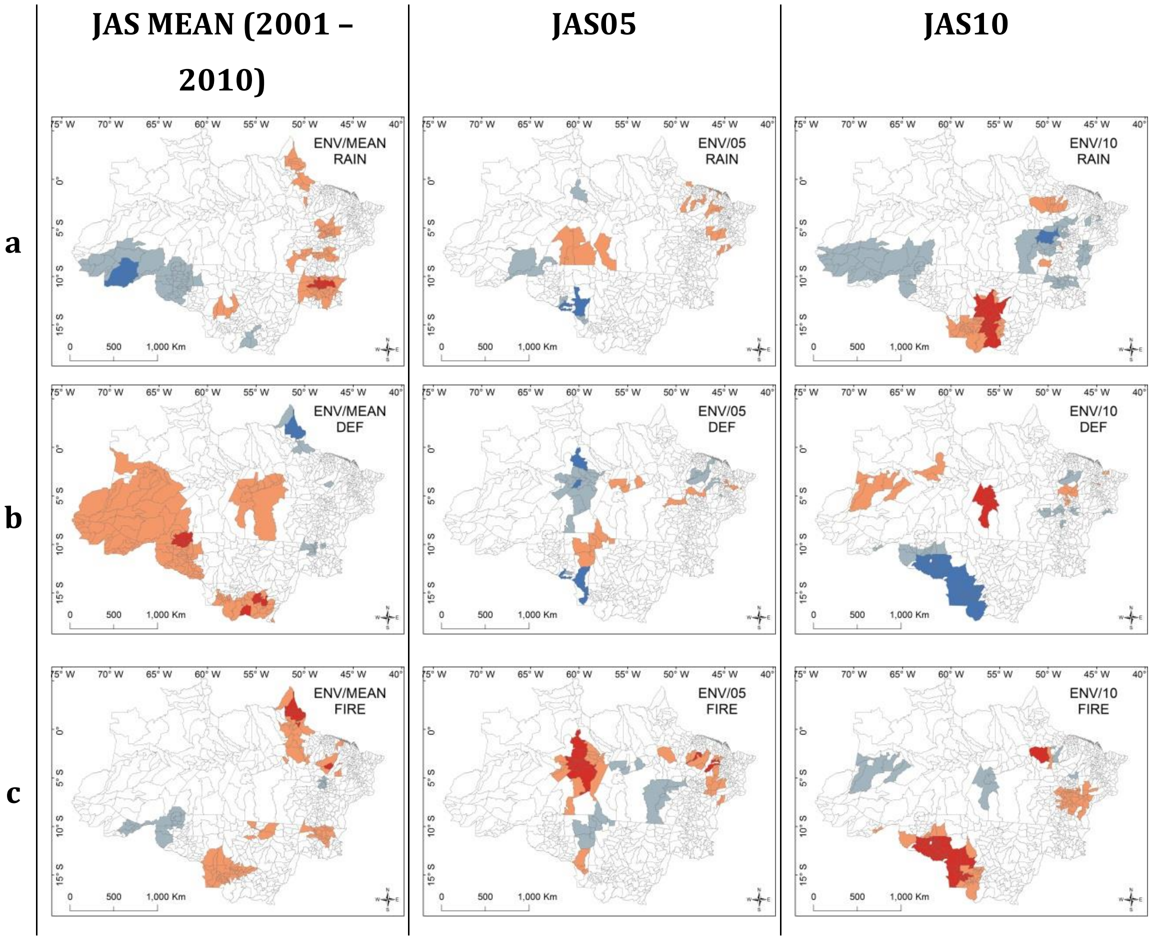


Figure 6.6| Percent of deviance explained for municipalities in drought years. **a** goodness-of-fit for the ENV micro-region models, **b** goodness-of-fit for the SOCIO micro-region models.

In the MEAN ENV model, deforestation exhibits significantly positive z values in most municipalities in the Legal Amazon compared with the other variables. However, the local parameter estimates are close to zero, suggesting deforestation has little impact on respiratory diseases. Aerosol exhibited a large number of micro-regions with negative z values in the JAS MEAN ENV model (Figure 6.7). By including socio-economic variables in the analysis (MEAN SOCIO), HDI becomes the dominant variable affecting hospitalisations for respiratory diseases (Figure 6.8), suggesting development levels are more significant in the development of respiratory health problems than environmental variables in non-drought years.



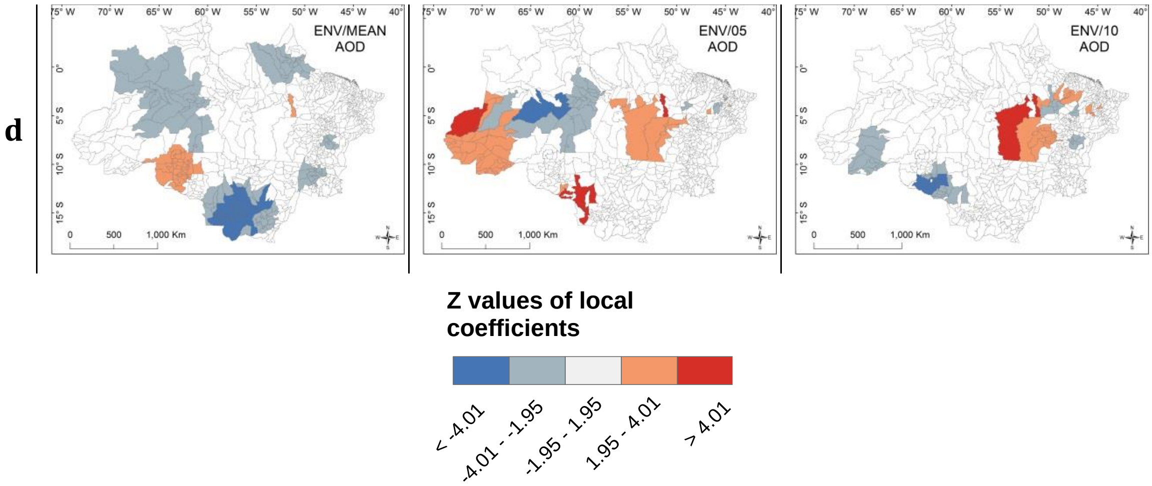
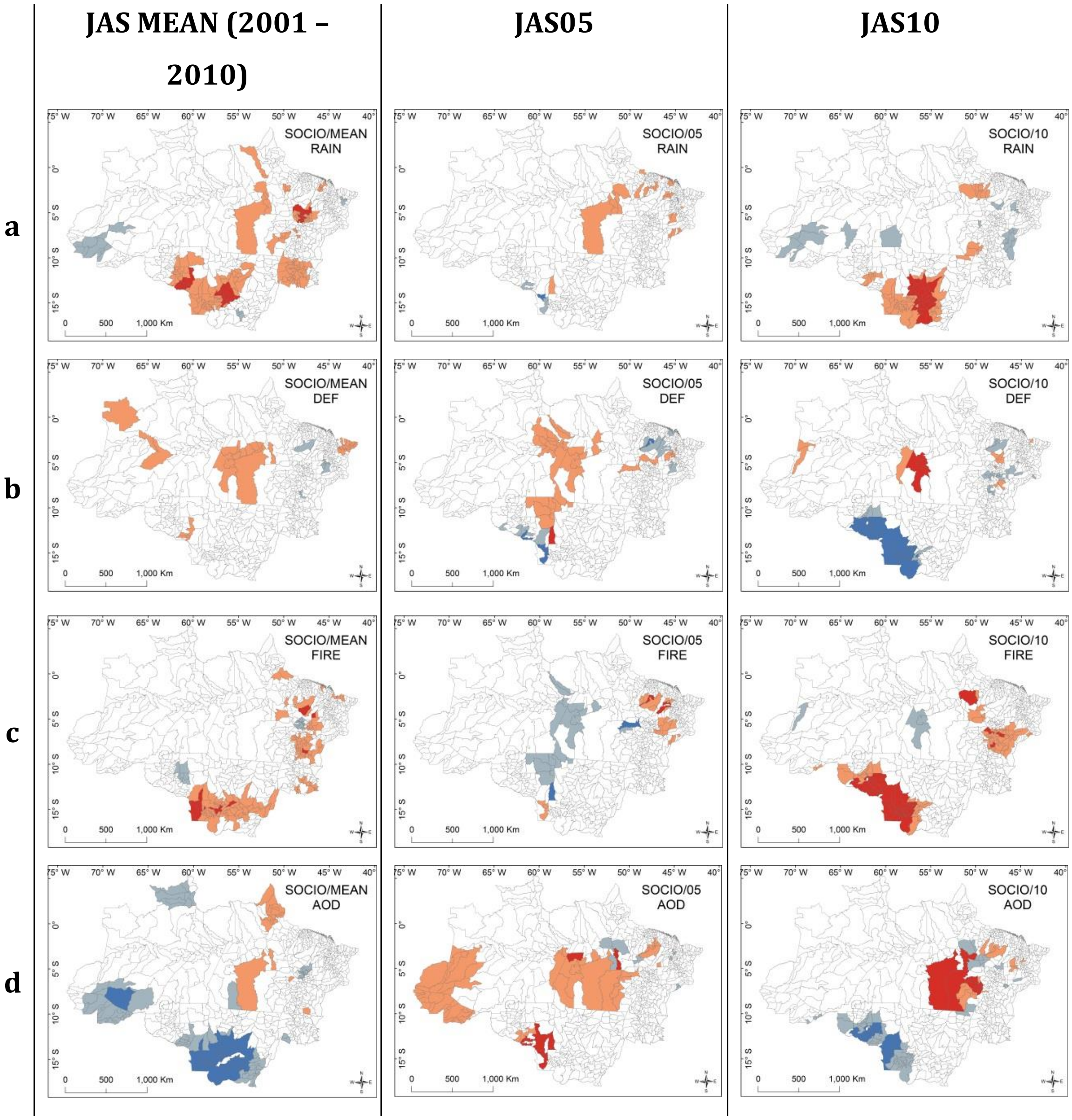


Figure 6.7| Significant values with a confidence level greater than 95% for the ENV model in drought affected municipalities. Non-significant municipalities are masked out. **a** rainfall, **b** deforestation, **c** fire, **d** aerosol. Red shades show positive z values of local coefficients, while blue shades show negative z values of local coefficients **-** the darker the shade the stronger the relationship.

Following this, an analysis was carried out for the peak periods of the droughts for municipalities. Aerosol exhibited the strongest significant positive relationship in all years. The other local parameter estimates are significant but with much lower magnitude than aerosol. This indicates that aerosol may be the primary force driving increases in respiratory diseases during droughts (Figure 6.7). Moreover, statistically significant positive municipalities for AOD showed a shift from Rondônia in the MEAN ENV model to municipalities that were affected by the droughts, particularly in JAS05.

The local parameter estimates indicated that respiratory diseases in 2005 and 2010 were primarily influenced by aerosol and HDI. In the SOCIO model, aerosol showed a significantly positive association with respiratory diseases in 28% of the drought effected municipalities in JAS05, with local parameter estimates as high as 13.2, while negative associations were observed in 13% of the drought effected municipalities. In JAS10, significantly positive associations were found in 7.6% of drought affected municipalities, with local parameter estimates reaching 11.1, 31% were statistically negative. 40.2% of drought affected municipalities in 2005 showed statistically positive associations with HDI with local parameter estimates observed as high as 10.7, and 8.9% showed statistically negative associations. In 2010, the percentage of affected municipalities was 31.4% (positive) and 6.5% (negative) (Figure 6.8). Local parameter estimates also suggested that aerosol affected a larger proportion of the Legal Amazon (34 more municipalities with statistically positive associations) in 2005 in comparison to 2010, despite the latter being a larger event.



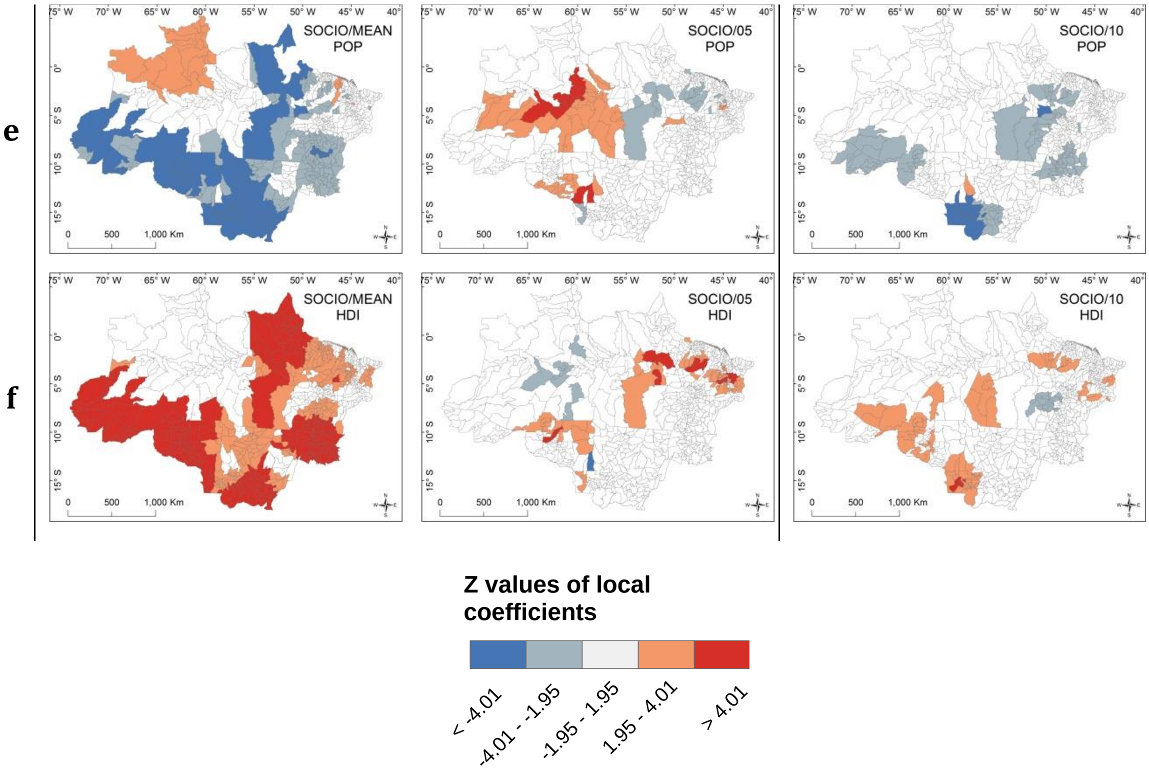
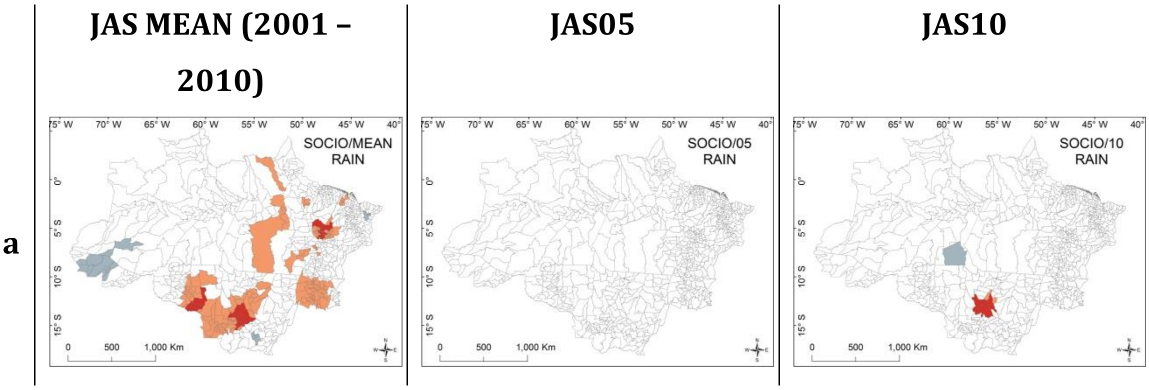


Figure 6.8| Significant values with a confidence level greater than 95% for the SOCIO model in drought affected municipalities. Non-significant municipalities are masked out. **a** rainfall, **b** deforestation, **c** fire, **d** aerosol, **e** population density, **f** HDI. Red shades show positive z values of local coefficients, while blue shades show negative z values of local coefficients **-** the darker the shade the stronger the relationship

Examining only areas that were severely affected by rainfall shortage (anomalous rainfall pixels ≥2 σ and < 300 mm rainfall), aerosol was once again the key variable parameter around Acre State (Figure 6.9). Aerosol was significant in both ENV and SOCIO analyses for both droughts, highlighting the importance of its influence on respiratory diseases



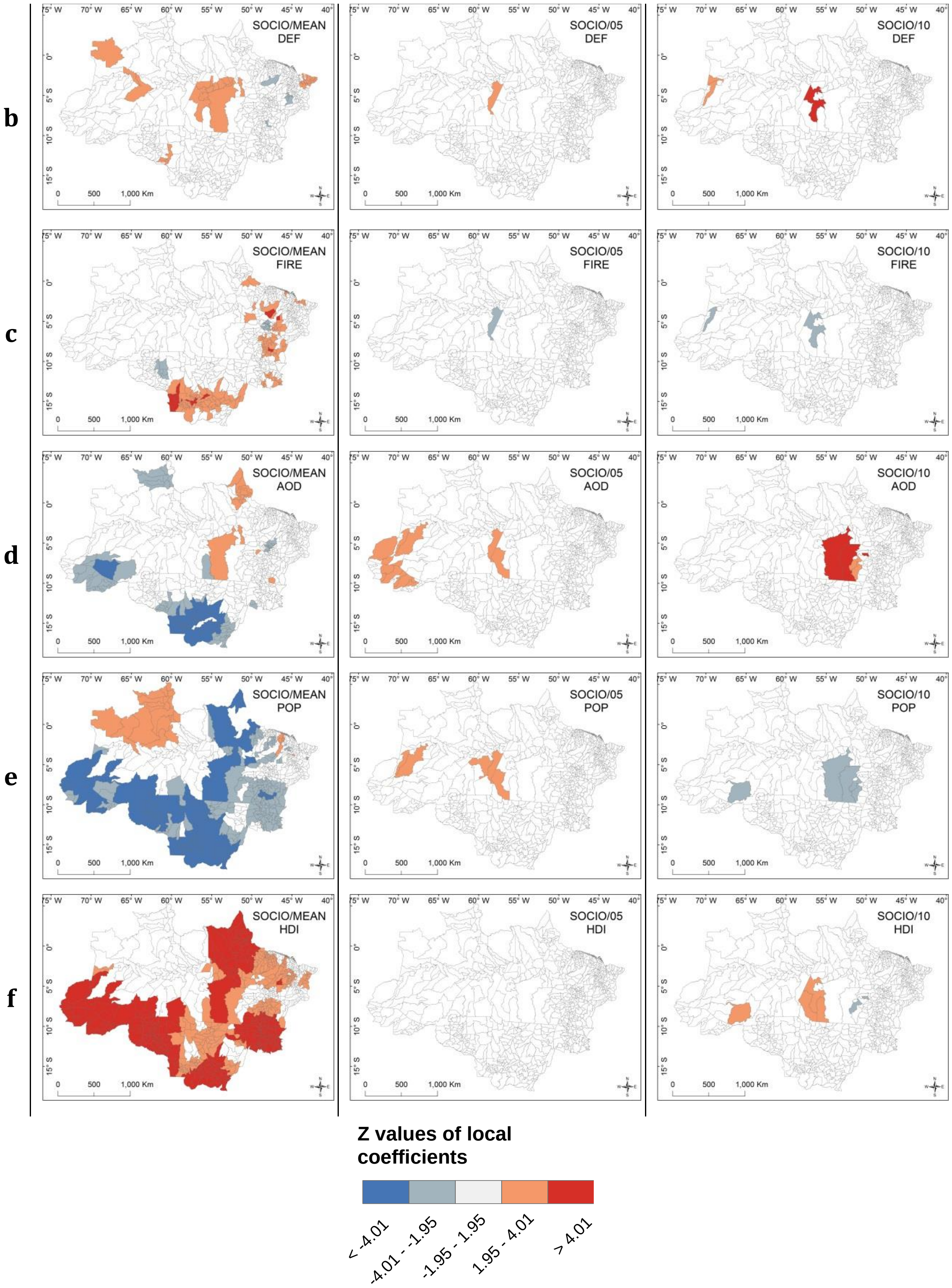
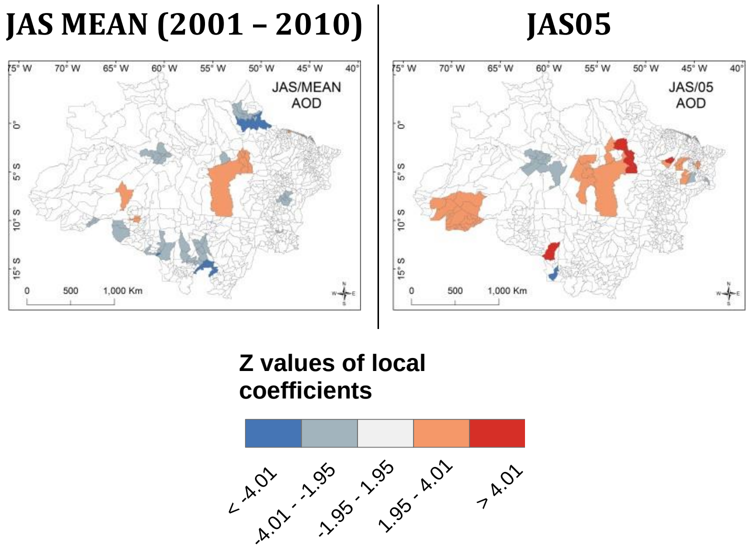


Figure 6.9| Significant values with a confidence level greater than 95% for the SOCIO model in severely affected (100mm rainfall & > 2sd) drought affected municipalities. Non-significant municipalities are masked out. **a** rainfall, **b** deforestation, **c** fire, **d** aerosol, **e** population density, **f** HDI. Red shades show positive z values of local coefficients, while blue shades show negative z values of local coefficients - the darker the shade the stronger the relationship .

This analysis has highlighted the importance of aerosol during periods of drought, particularly in the 2005 drought. To test the association further, another analysis was carried out for just JAS05, examining only aerosol with respiratory diseases (Figure 10). The results show that the MEAN model did not have many statistically significant municipalities, yet the JAS05 model showed a similar distribution to the JAS05 ENV and SOCIO models. However, the local parameter estimates in JAS05 for the aerosol only model are much higher in some locations, reaching 46.6 in Maranhão.


JAS MEAN (2001 – 2010)

JAS05

Figure 6.10| Significant values with a confidence level greater than 95% for the aerosol only model. Non-significant municipalities are masked out.

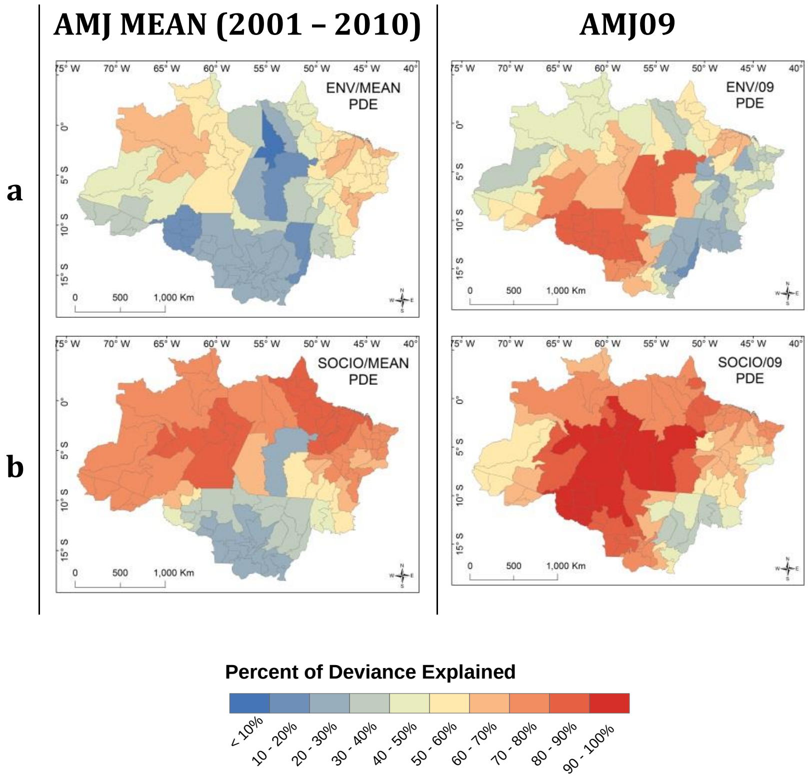


Figure 6.11| Percent of deviance explained for micro-regions in flood years. **a** goodness-of-fit for the ENV micro-region models, **b** goodness-of-fir for the SOCIO micro-region models

Moving on to the flood of 2009 (AMJ09), as with the two droughts, the goodness-of-fit improves in the SOCIO model for both MEAN and AMJ09 models. The MEAN ENV model showed a goodness-of-fit of 56%, increasing to 74% in the MEAN SOCIO model. Analysis of AMJ09 showed the goodness-of-fit in the ENV model was 59%, increasing to 77% in the SOCIO model (Figure 6.11).

Interestingly, the micro-region analysis of AMJ09 shows similar results to those of the droughts. Although only one micro-region in the ENV model shows statistically significant positive association with aerosol in AMJ09 (Figure 6.12), aerosol is the only variable exhibiting a value for the local parameter estimate of 6.4. In the SOCIO model, this increases to 8.4, suggesting a stronger influence in the SOCIO model. HDI and aerosol are the main drivers in the SOCIO model for both AMJ MEAN and AMJ09. The local parameter estimates for AMJ09 are higher than AMJ MEAN for both ENV and SOCIO models. HDI, however, declines in the value of local parameter estimate from AMJ MEAN to AMJ09, yet is a significant variable in a larger proportion of the Legal Amazon (Figure 6.13).

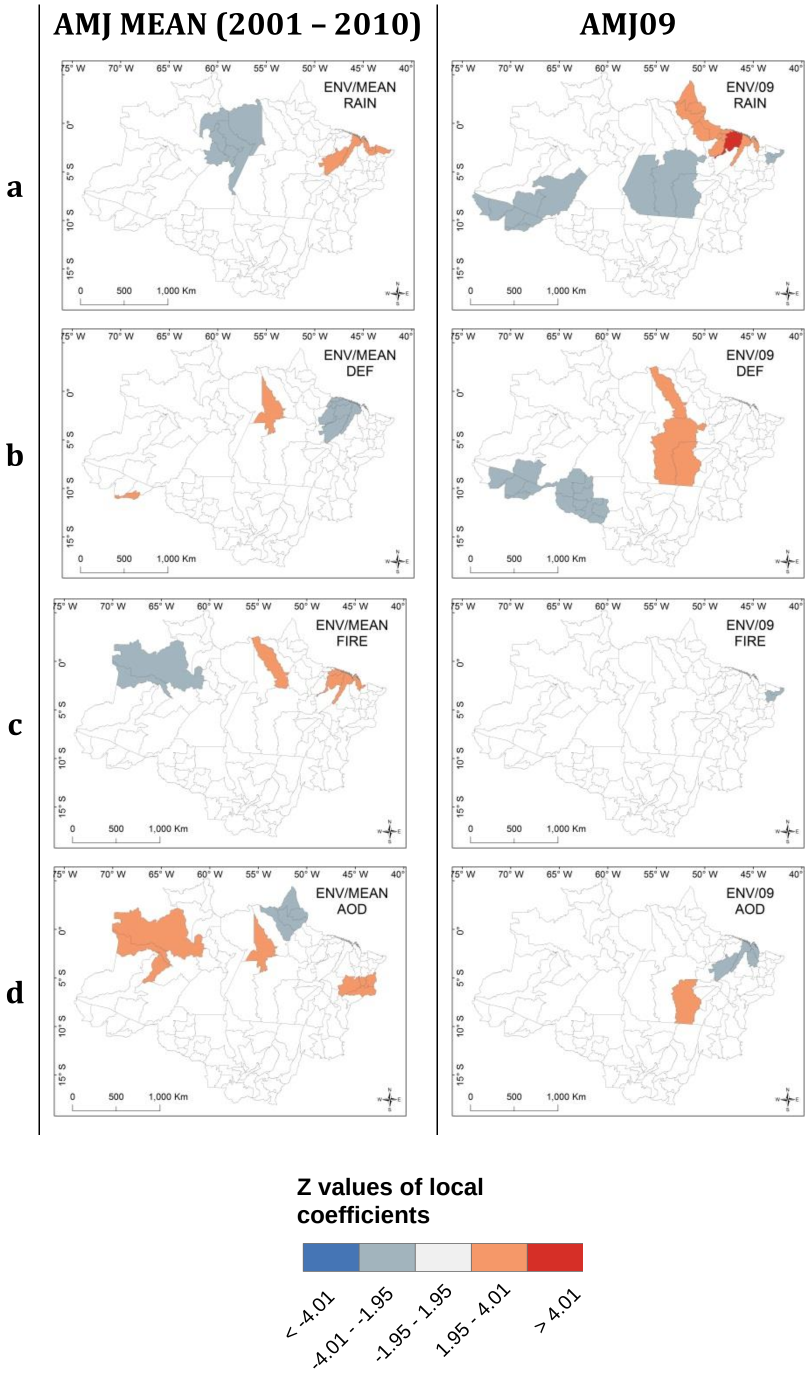


Figure 6.12| Significant values with a confidence level greater than 95% for the ENV model in flood affected micro-regions. Non-significant micro-regions are masked out. **a** rainfall, **b** deforestation, **c** fire, **d** aerosol. Red shades show positive z values of local coefficients, while blue shades show negative z values of local coefficients - the darker the shade the stronger the relationship.

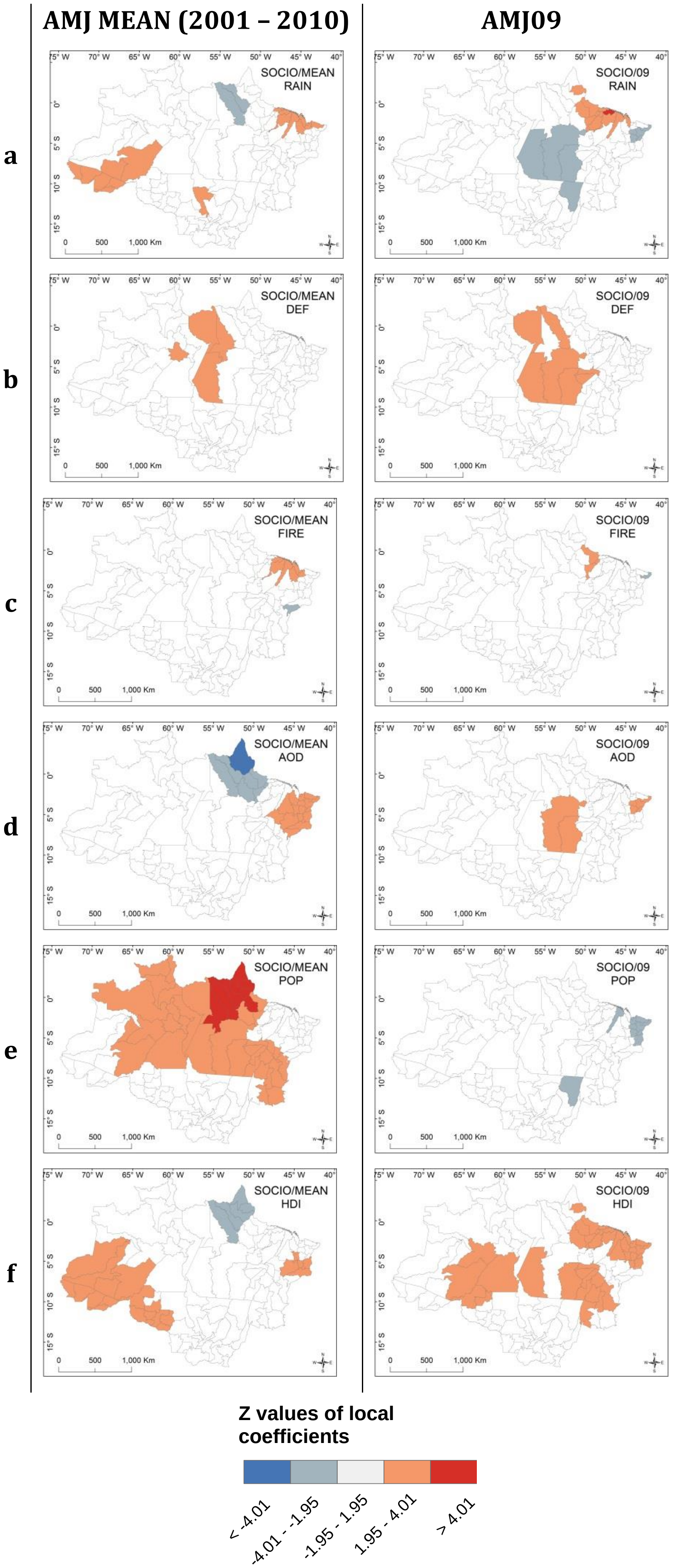

AMJ MEAN (2001 – 2010)
AMJ09
a
SOCIO/MEAN RAIN
SOCIO/09 RAIN
b
SOCIO/MEAN DEF
SOCIO/09 DEF
c
SOCIO/MEAN FIRE
SOCIO/09 FIRE
d
SOCIO/MEAN AOD
SOCIO/09 AOD
e
SOCIO/MEAN POP
SOCIO/09 POP
f
SOCIO/MEAN HDI
SOCIO/09 HDI
75° W
70° W
65° W
60° W
55° W
50° W
45° W
40°
0°
5° S
10° S
15° S
0
500
1,000 Km
N
W
E
S
Z values of local coefficients
< -4.01
-4.01 - -1.95
-1.95 - 1.95
1.95 - 4.01
> 4.01

Figure 6.13| Significant values with a confidence level greater than 95% for the SOCIO model in flood affected micro-regions. Non-significant micro-regions are masked out. **a** rainfall, **b** deforestation, **c** fire, **d** aerosol, **e** population density, **f** HDI. Red shades show positive z values of local coefficients, while blue shades show negative z values of local coefficients **-** the darker the shade the stronger the relationship.

A subsequent analysis examining the flood-respiratory health relationship was conducted at municipality level. Similar spatial distribution of goodness-of-fit is observed between ENV and SOCIO MEAN and AMJ09 models, increasing in the SOCIO model. The MEAN ENV model showed a goodness-of-fit of 36%, increasing to 69% in the MEAN SOCIO model. Analysis of AMJ09 showed the goodness-of-fit in the ENV model was 43%, increasing to 51% in the SOCIO model (Figure 6.14). The MEAN SOCIO model tended to affect the western part of the Amazon, while AMJ09 SOCIO shows higher goodness-of-fit in the south.

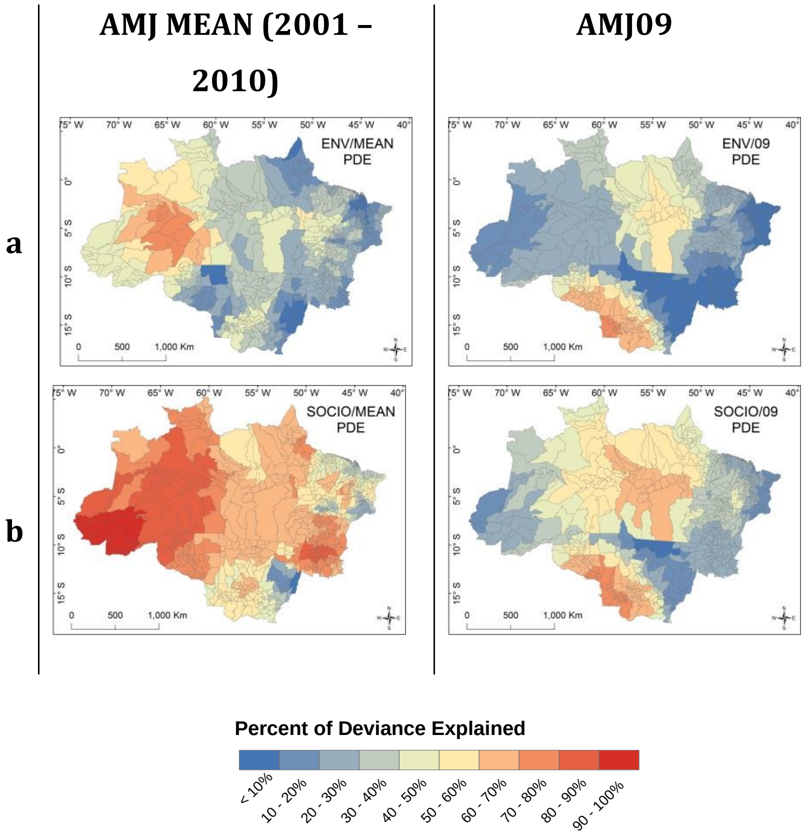
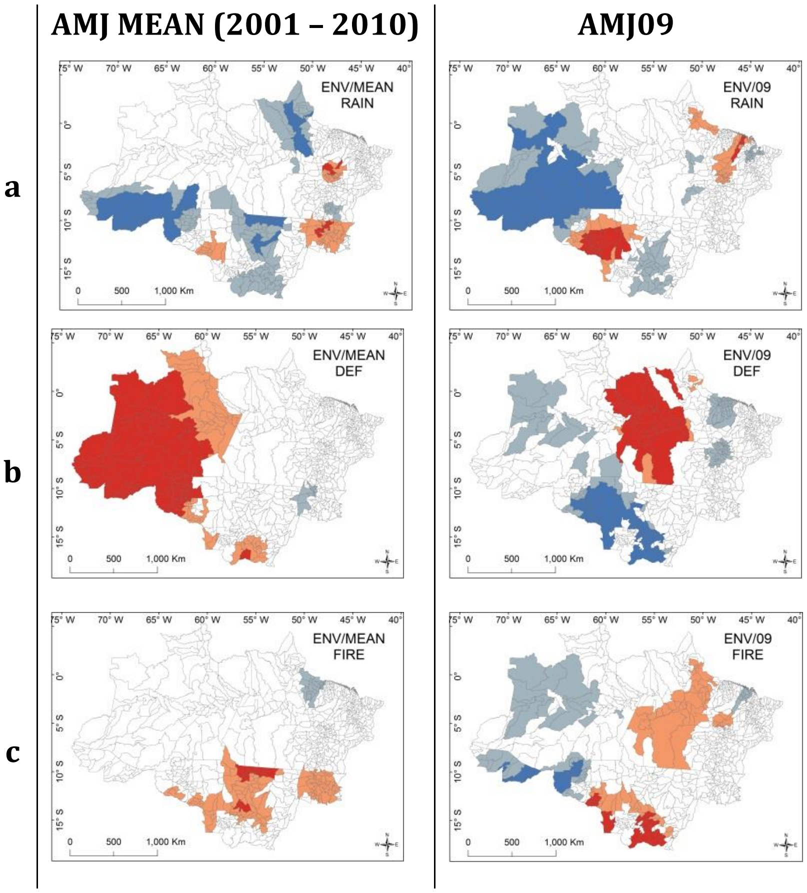


Figure 6.14| Percent of deviance explained municipalities in flood years. **a** goodness-of-fit for the ENV models, **b** goodness-of-fir for the SOCIO models.

As with the micro-region analysis, aerosol was also a dominate variable during AMJ MEAN and AM09 in both the ENV and SOCIO models (Figures 6.15 and 6.16). Although all variables in the AMJ MEAN model exhibited statistically significant positive municipalities, as with the droughts, only aerosol had values above zero for the local parameter estimates. Unlike the micro-region analysis, local parameter estimates (AMJ MEAN = 9.6, AMJ09 = 3.4) and spatial coverage for aerosol were larger in AMJ MEAN, compared with AMJ09. This finding could suggest that the excess rainfall observed in AMJ09 compared to other years cleared the air somewhat. In the SOCIO model, it is observed that spatial coverage is larger for aerosol in AMJ MEAN; however, local parameter estimates are close to zero or exhibiting negative values. HDI, however, becomes the key driver for both AMJ MEAN and AMJ09. Similarly to the micro-region analysis, the local parameter estimate declines from AMJ MEAN to AMJ09 from 20 to 10.2.



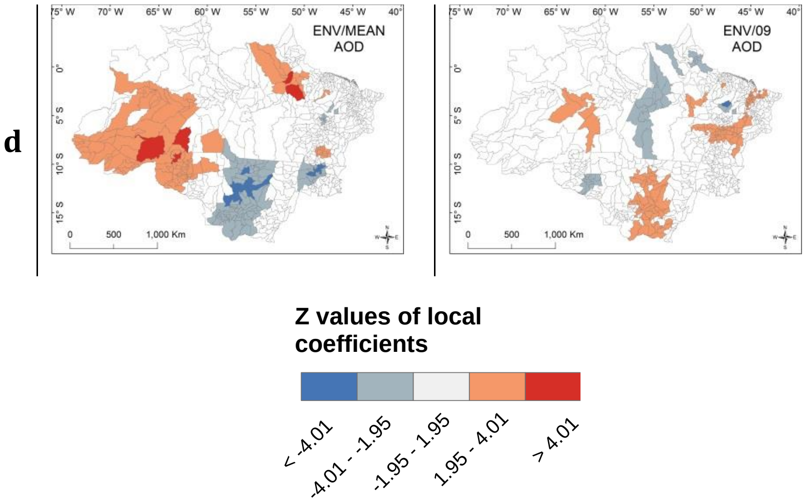
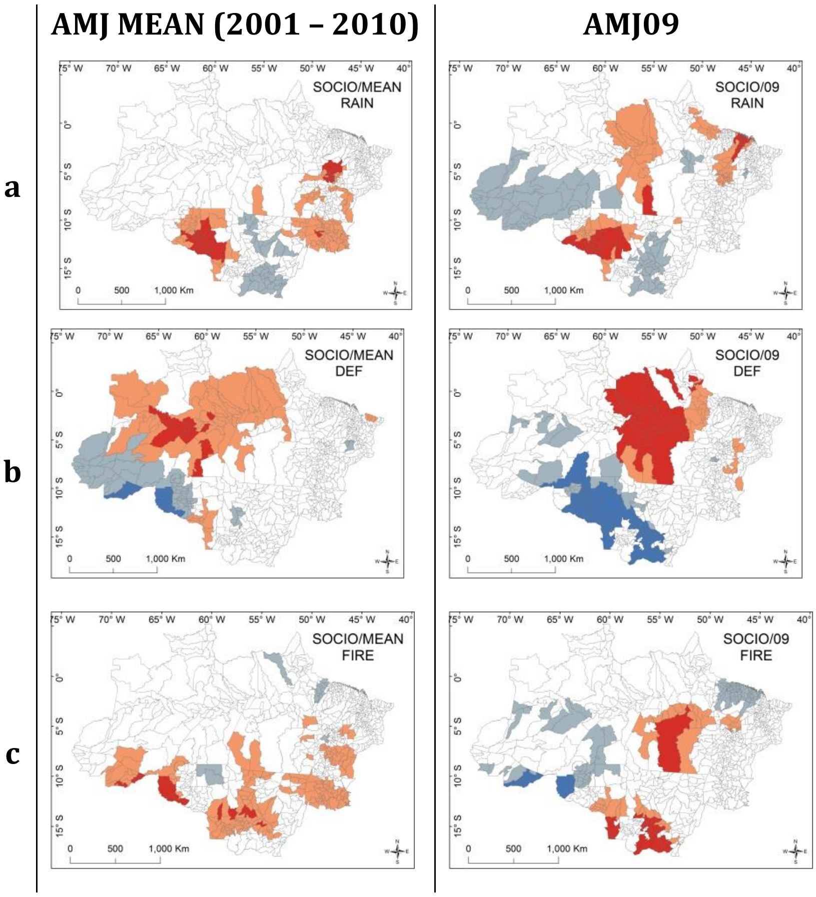


Figure 6.15| Significant values with a confidence level greater than 95% for the ENV model in flood affected municipalities. Non-significant municipalities are masked out. **a** rainfall, **b** deforestation, **c** fire, **d** aerosol. Red shades show positive z values of local coefficients, while blue shades show negative z values of local coefficients **-** the darker the shade the stronger the relationship.



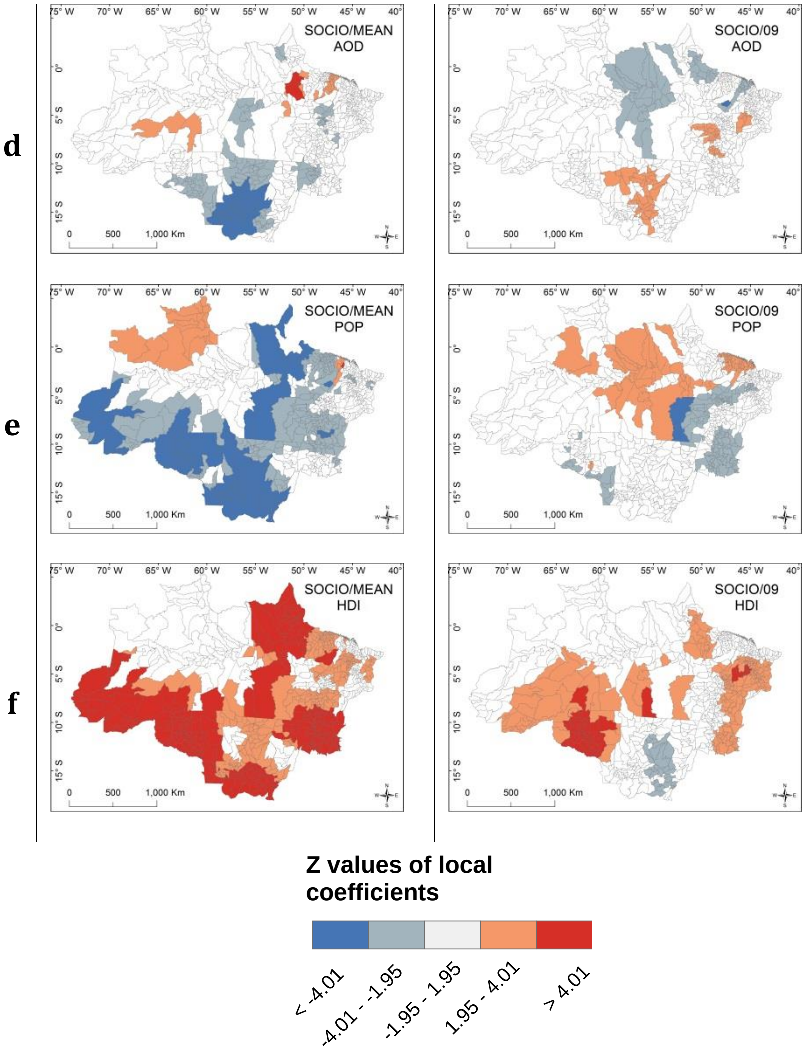


Figure 6.16| Significant values with a confidence level greater than 95% for the SOCIO model in flood affected municipalities. Non-significant municipalities are masked out. **a** rainfall, **b** deforestation, **c** fire, **d** aerosol, **e** population density, **f** HDI. Red shades show positive z values of local coefficients, while blue shades show negative z values of local coefficients - the darker the shade the stronger the relationship.

6.4 Discussion

This analysis has shown that by increasing the spatial scale of analysis, more pronounced associations are shown between hydrological extremes and respiratory diseases. Conducting analysis at municipality level provides greater information which may be useful for policy making as specific measures can be implemented. For this reason, discussion will focus on results from the municipality level analysis.

This data demonstrated that peak hospitalisations in Acre generally occur at the end of the wet season; however, during the 2005 drought, this peak was displaced and in accordance with the fire season, indicating a direct effect. Previous analysis for Mato Grosso State also shows higher monthly hospitalisation rates at the end of the wet season and the interim period between seasons (Rosa et al., 2008b). This is because of higher levels of humidity during the wet season, leading to an increase in funguses and mites that are powerful allergens for the occurrence of respiratory diseases (Croce et al., 1998). Alternatively, this increase could be related to the start of the school term, when children enter into contact with others, increasing the risk of exposure to infection, or it could be aligned with operational factors such as hiring physicians during this time, thus allowing more patients to be treated.

High concentrations of smoke were recorded in Rio Branco during September 2005 (Mascarenhas et al., 2008), which could explain the statistically significant positive z values for aerosol in this region at both micro-region and municipality levels. HDI was significantly positive in drought affected municipalities in Rondônia, western Mato Grosso, Pará, and Maranhão States, but not around the epicentre of the 2005 drought in Acre. Significantly negative areas of HDI are observed in Amazonas. The associations between respiratory diseases and socio-economic status are complex, thus a more detailed investigation into socio-economic status and respiratory diseases is needed to provide possible explanations. However, it could be attributed to the Hygiene Hypothesis that suggests the population in more developed areas may be more susceptible to disease because they are less exposed (Strachan, 1989). Population density was significant in some drought affected municipalities but none around the epicentre of the drought. Moreover, this variable was not significant at the epicentre of the 2005 drought in Acre. Rainfall, active fires and deforestation were not significant in the majority of drought affected municipalities.

Despite the 2010 drought and the 2009 flood being of greater magnitude than the 2005 drought, the impact on respiratory diseases was not as severe. Similarly to the 2005 drought event, HDI had the greatest influence, with larger areas experiencing significantly positive z values of local coefficients. The large coverage of significantly positive HDI in all years could be due to the Hygiene Hypothesis. The strength of HDI in 2010 and 2009 in relation to the environmental variables may be due to the large spatial extent of the drought, which disguised localised environmental impacts, similarly to the MEAN SOCIO, compared to 2005 when the drought was concentrated around Acre State. While the strength of HDI in 2009 could also be due to the fact that the other leading cause in drought years, aerosol, was lower. Aerosol was significantly and positively related to respiratory disease incidence in southern Pará. Elsewhere, significantly negative z values of local coefficients were observed, particularly along the eastern and southern edges of the region, and pockets in Tocantins, highlighting locations where aerosol loads do not increase the number of hospitalisations. This may be because the population living in these locations are accustomed to air pollution exposure as this area sees most fires occurring year on year. Moreover, the 2010 drought and 2009 flood experienced fewer fires and anomalous aerosol loads compared to 2005 (Figure 5.1). The other local parameter estimates were close to zero, suggesting they did not affect respiratory health as greatly (Figure 6.8).

This is the first analysis of the impacts of hydrological extremes on respiratory health of children under five years at the scale of the whole Legal Amazon. Despite the wide trend of respiratory diseases peaking at the end of the wet season, drought conditions exacerbate the incidence of respiratory diseases in children during the dry season. This research suggests that the increase in respiratory diseases during the 2005 drought was driven mainly by aerosol and HDI. Conversely, HDI overcame the impact of aerosol during the drought of 2010, due, probably, to the decrease in aerosol emissions associated with a reduction of 1.9% in fire incidence in 2010 in relation to 2005. The 2009 flood meant there were fewer fires and aerosol loads, which could explain the strength of HDI in the model.

6.5 Summary

This chapter has answered the third research question: to what extent do strong correlations between hydrological extreme periods and respiratory diseases exist? The analysis assessed the impacts of the peak periods of the 2005 and 2010 droughts, and the 2009 flood on respiratory diseases. It has shown that aerosol is a key environmental factor in the number of hospitalisations for respiratory diseases in children under five. It has also highlighted the importance of socio-economic levels, in the form of HDI, in this case. The decrease in the values of local parameter estimates of HDI in both drought years and an increase in AOD compared to the MEAN model highlighted very well the shift from socio-economic factors influencing health, to environmental factors. In both years, the association was stronger in 2005, however, reinforcing the fact that the smaller spatial scale of the 2005 drought caused more intense conditions. This chapter has shown associations between hydrological extremes and respiratory diseases. The next chapter explores local knowledge of these topics.

Chapter 7

Knowledge & Understanding: Rondônia Case Study

7.1 Introduction

This chapter addresses the fourth research question: what does primary data collection tell us about people's knowledge of respiratory diseases and their link to hydrological extremes? This thesis has already shown that in the Legal Amazon, there is a high prevalence of respiratory diseases and there are associated risks with hydrological extremes and human disturbances. Knowledge and awareness of this information is vital in order to provide mitigation and adaptation methods to protect the Legal Amazon population from what is the second most common cause of hospitalisations: respiratory diseases. However, this thesis has also demonstrated the importance of understanding the population's knowledge about the issue as well as their own social conditions which may be contributing to the high rates of respiratory disease hospitalisations. Literature suggests that mitigation and adaptation measures are more effective when they relate specifically to the population for whom they are being designed. The purpose of this chapter is to give an account of knowledge, attitude and practice towards respiratory diseases within two communities of Porto Velho.

7.2 Methods

7.2.1 Data collection

Two surveys were administered: one household survey and one KAP survey, concerning knowledge, attitude and practice relating to respiratory diseases (Appendix D to G in both languages). Once the surveys had been prepared, they were validated to ensure the questions were comprehensible and relevant, and would prove to be effective in obtaining responses. This was done in two ways. The initial validation process was undertaken with students and staff at FIOCRUZ who had previously worked in the communities. This helped to ensure that questions were worded suitably and in a way that could be understood by the communities who speak their own regional dialect. Further validation took place on the first day of the surveys, when participants' understanding was verified. This verification involved a quality check of respondents' answers to confirm their understanding of the questions. As it was clear that the questions were understood by the participants, no alterations were required.

In each community, surveys were carried out with the aid of local Brazilian nurses who had previously worked in the communities so they knew members of the community well. A consent form outlining the research was given to each participant to sign prior to taking part, or if they were unable to read and write, it was read to the participants and they gave a fingerprint for consent. The consent form can be seen in Appendix A. To ensure consistency and to include those who are unable to read and write, in this instance all surveys were carried out orally and responses recorded in Portuguese and translated once back in the office.

7.2.2 Study Location, and Population

Surveys were carried out in Belmont and Vila Nova de Teotônio, which are both located in the municipality of Porto Velho, Rondônia (Figure 4.1). Belmont is located 10 km north of the city of Porto Velho, where houses are predominantly constructed of wood (Figure 7.1). Vila Nova de Teotônio is located approximately 40 km south of Port Velho, with houses of brick construction (Figure 7.2). Of the 93 houses in Belmont, six are unoccupied. From the remaining 87 houses, 66 participated in the research. Those who did not participate either declined to take part (11) or were absent from their homes for the time the research team spent in Belmont (10). Vila Nova de Teotônio had a higher response rate, with 39 households. Of non-participants, six were absent during the study period and 27 were unoccupied households (still owned by Santo Antônio).

Figure 7.1| Typical houses in Belmont

The survey population for both surveys was broad since its main objective was to sample every household in the village. Other studies that have used KAP surveys may specify the type of participant required, for example, female, person who suffers from the illness being discussed, or unemployed. This was not a prerequisite for this research as the main purpose was to investigate KAP of all households. Results gained would provide an understanding of their overall knowledge and whether different socio-economic levels and distance from an urban area affected knowledge and decisions about respiratory diseases, or whether suffering from the disease provided the participant with a higher level of knowledge and more medically sound explanations for the decisions they made.

Figure 7.2| Typical houses in Vila Nova de Teotônio

7.2.3 Data Analysis

Responses from both surveys were checked for any inconsistences and then the data was coded. Data was entered using SPSS 19, where descriptive statistics were used to present the results from the KAP survey. Results have been presented as percentages, with the exception of Figures 7.4 and 7.5 because multiple responses were given. Odds ratios with confidence intervals at 95% were used to carry out analysis between results from the household survey and the KAP survey.

Many responses were recorded as 'don't know' and those that did answer usually provided short responses. In terms of this research, allowing 'don't know' responses and short responses was deemed appropriate and acceptable because the aim was to understand people's knowledge. The alternative would be to disallow 'don't know' responses and subsequently probe for detail but these responses should be treated with caution. Although there was an opportunity to press for more information through asking follow-up questions or explaining terms to respondents, this would have given false responses. For example, I remember during one survey when asking a participant 'how do you define a respiratory disease?', they asked if I meant diseases like asthma. Although I understood their enquiry, I had to say I could not offer any explanation or confirmation, as their answer had to convey only their thoughts and not those of others or as the result of a prompt.

7.3 Results

The socio-economic data obtained from the household survey is summarised in Table 7.1. The data recorded for marital status shows that over half of the households surveyed are in a married relationship. The data shows that 6.1% of households in Belmont, and 5.1% of households in Vila Nova de Teotônio have at least one member with higher education, while 1.5% and 7.7% of households respectively have at least one person who is illiterate. Average income in the two communities is different, with Belmont on average earning more; Belmont average income is R$ 1304, and Vila Nova de Teotônio average income is R$ 1022. However, there is a difference in the range of income within the communities. The number of households with at least one smoker is quite similar, with over 55% for both communities, whereas the frequency of burning rubbish is higher in Belmont (72.2% of households). An explanation for the higher figure given by participants is that there is no rubbish collection service in the community, whereas participants in Vila Nova de Teotônio said there is a rubbish collection service.

Table 7.1| Summary of household survey data

Socio-economic Variable		**Belmont (N = 66)** **N (%)**	**Vila Nova de Teotônio (N = 39)** **N (%)**
Marital Status	Married	40 (60.6)	28 (71.8)
	Single	20 (30.3)	7 (17.9)
	Divorced	1 (1.5)	2 (5.1)
	Widowed	5 (7.6)	2 (5.1)
Education	Higher	4 (6.1)	2 (5.1)
	Secondary	41 (62.1)	28 (71.8)
	Primary	20 (30.3)	5 (12.8)
	Cannot read/write	1 (1.5)	3 (7.7)
Monthly Income (R$)	Max.	R$ 7000	R$ 3000
	Av.	R$ 1304	R$ 1022
	Min.	R$ 134	R$ 200
Smoker	Yes	39 (59.1)	26 (66.7)
	No	27 (40.9)	13 (33.3)
Burning Rubbish	Yes	47 (72.2)	16 (41.0)
	No	19 (28.8)	23 (59.0)

The distribution of when respiratory diseases are perceived to be worse by those participants where either they or one of their children are sufferers of the diseases is illustrated in Figure 7.3. A greater percentage of participants in Vila Nova de Teotônio perceived that their own or their children's respiratory diseases were worse in May (19%), followed by a smaller peak in July and August (14%). In Belmont, June was recognised as the month when respiratory diseases were perceived to be worse (14%).

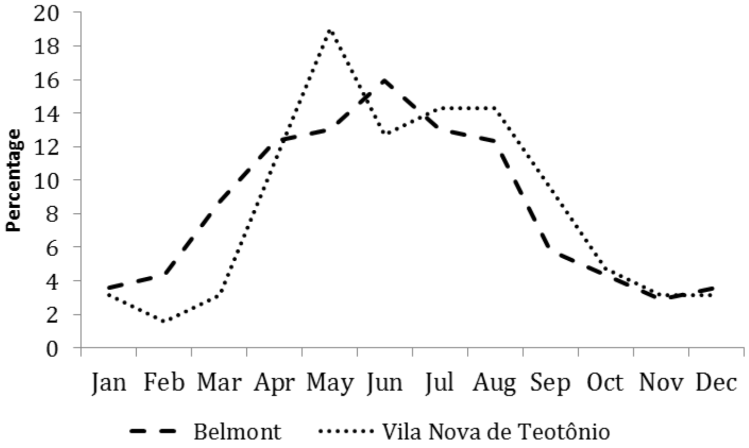


Figure 7.3| Months in which their respiratory symptoms are worse, according to participants.

Knowledge

Knowledge itself has presented itself as a theme from the knowledge aspect of a KAP survey. This because there is such varied knowledge within and between the communities, varying between responses and between people. There is an assumption with KAP surveys that there are low levels of knowledge on the topic, however, some people knew a lot about respiratory diseases – the causes, reducing risk, and definition, while others had a basic understanding but could provide no detail as expected. Finally, there were those who could not answer many of the questions. The communities' knowledge is now discussed.

The definitions of respiratory disease given are detailed in Table 7.2. It was observed that in both communities, the most common response was 'don't know'. For those participants who could provide a definition, a common response was 'disease caused by breathlessness'. On the whole, people in both communities define respiratory diseases differently, with 12 definitions given in Belmont, and 9 given in Vila Nova de Teotônio (excluding those whose response was 'don't know'). There were consistent results across communities where participants responded that they thought the children were the most at risk of developing a respiratory disease, representing 41% in Belmont, and 36% in Vila Nova de Teotônio. In Belmont, 32% of participants said that adults were more prone to developing a respiratory disease, while 24% said that no one in particular is at risk, and 3% were unsure. In comparison, more participants in Vila Nova de Teotônio thought no one in particular was more at risk (36%), with 23% saying adults, and 5% did not know.

Table 7.2| Definitions given for respiratory diseases

Definition Given	Frequency (%)
Belmont	
Disease related to smoke	6.1%
Disease caused by tiredness	3.0%
Disease of coughing	1.5%
Disease affecting the lungs	10.6%
Don't know	25.8%
Disease caused by the climate	3.0%
Disease that attacks the heart	1.5%
Disease of *xxx* (examples)	21.2%
Disease caused by breathlessness	13.6%
Disease that affects tiredness	6.1%
Disease of sensitivity due to allergic bronchospasm	1.5%
Disease caused by air pollution	4.5%
It is a heredity disease	1.5%
Vila Nova de Teotônio Nova Teotônio	
Disease caused by breathlessness	17.9%
Disease affecting the lungs	5.1%
Disease caused by fires	2.6%
Don't know	41.0%
Disease caused by fires and deforestation	2.6%
Disease that interferes with respiration	5.1%
Disease of *xxx* (examples)	15.4%
It is a heredity disease	2.6%
Disease caused by the climate	2.6%
Disease caused by air pollution	5.1%

Multiple responses were given by some participants when asked how someone develops a respiratory disease. Again, 'don't know' was the most common response in Belmont, with 19 participants giving 'don't know' as their response. In contrast, the most common response in Vila Nova de Teotônio was 'through the air' (9 participants). This produced a wide range of responses, ranging from their lifestyle to the climate (Figure 7.4). Although responses were varied, they can be grouped into broad categories of respiration and air, environmental, lifestyle, heredity, and climate.

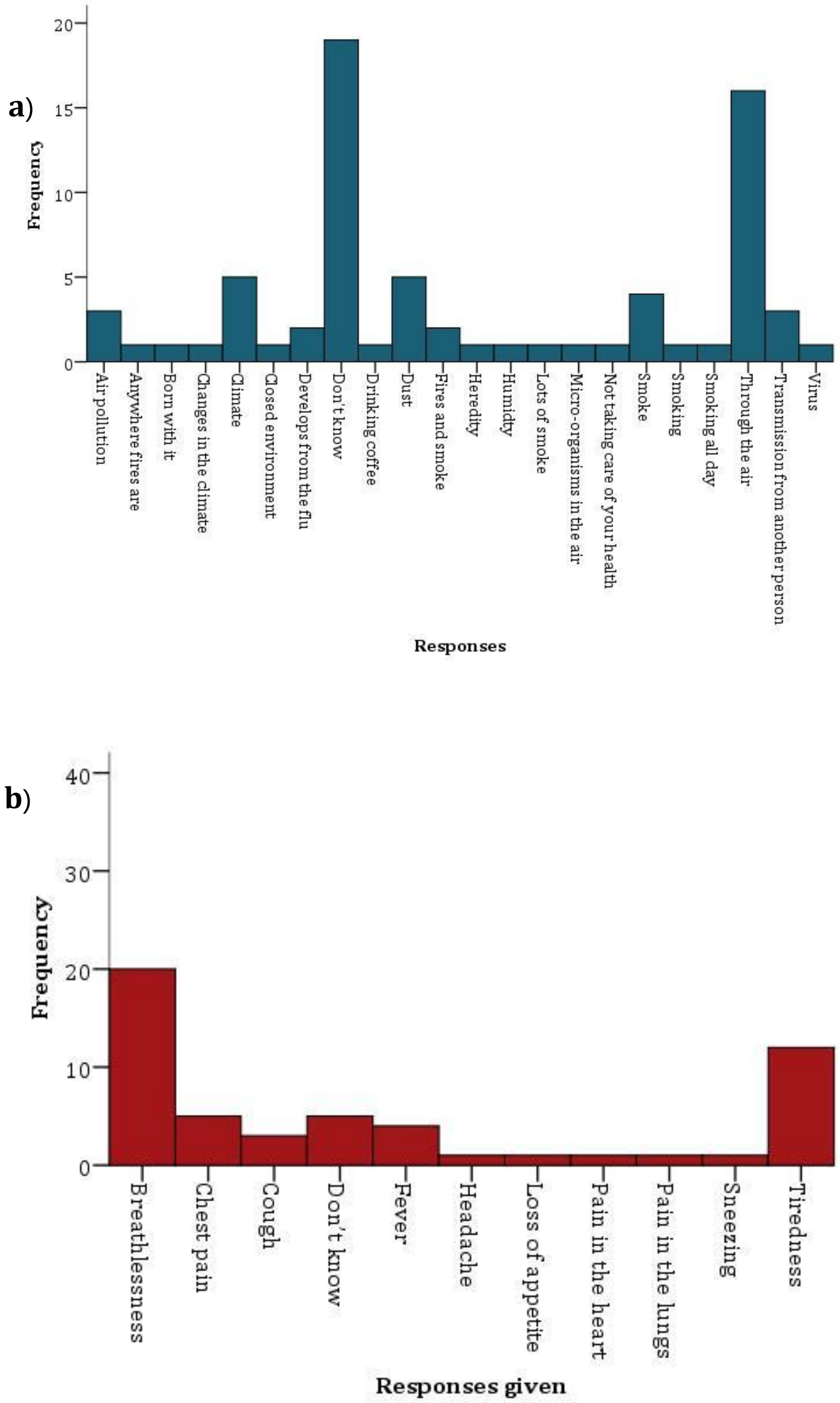


Figure 7.4| Responses for how participants think they can get a respiratory disease. **a**) Belmont, **b**) Vila Nova de Teotônio

Participants in both communities seemed to have better knowledge of the symptoms of respiratory diseases, with only five participants in each community saying they did not know. Breathlessness (36 and 20 participants) followed by tiredness (18 and 12 participants) are the dominant responses in both Belmont and Vila Nova de Teotônio respectively.

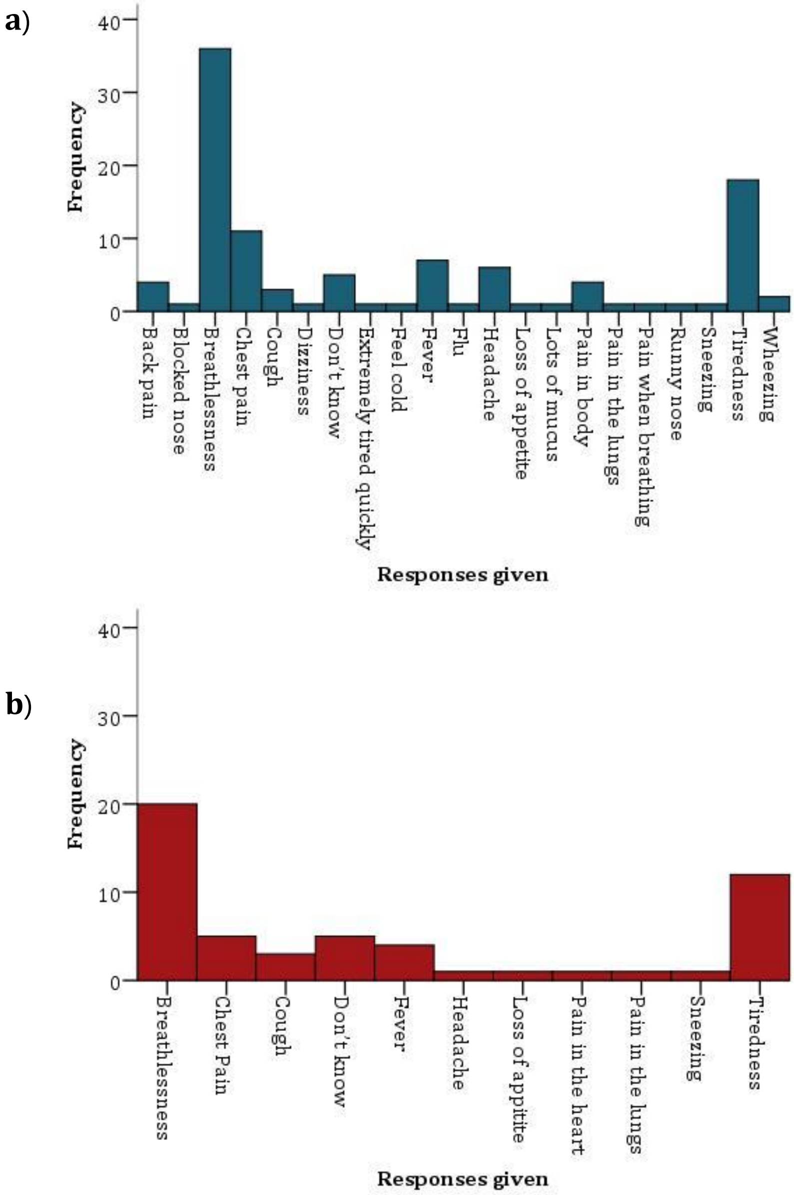


Figure 7.5| Responses participants gave when asked what the symptoms of respiratory diseases were. **a**) Belmont, **b**) Vila Nova de Teotônio

There were a variety of responses regarding how people develop respiratory diseases. In order to assess what the population thought was the principal cause of respiratory diseases, a more direct question was asked: ‘in your opinion, what is the principal cause of respiratory diseases?’ The responses shown in Figure 7.6 once again illustrate the fact that a dominant response is ‘don’t know’. After ‘don’t know’ responses, the three most common responses in both communities were ‘smoke’ (21.2%, 17.9%), ‘dust’ (12.1%, 5.1%), and ‘air pollution’ (10.6%, 5.1%). Smoking was given as a main cause by approximately 10% of the population in Vila Nova de Teotônio, yet only 1.5% named smoking in Belmont.

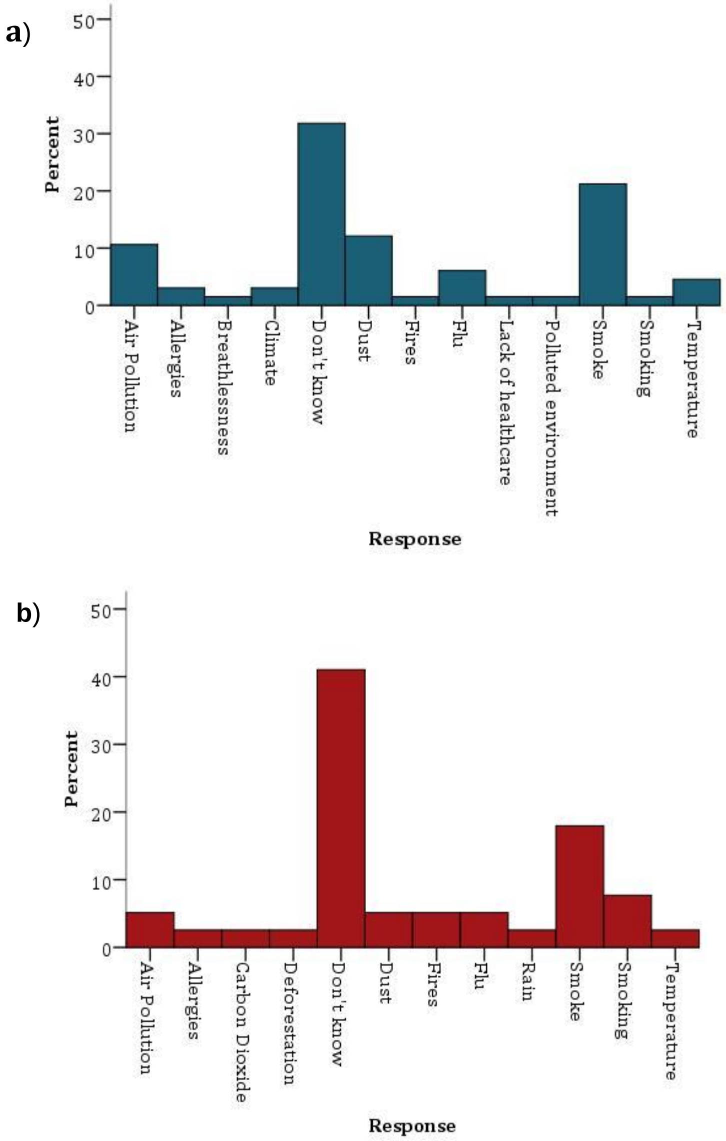
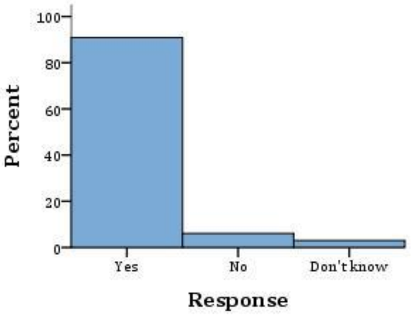
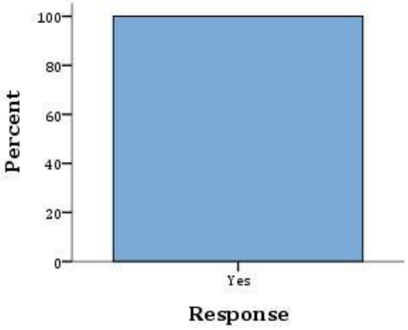
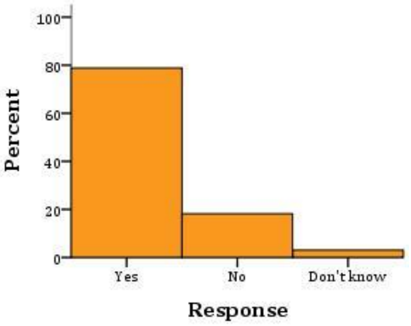
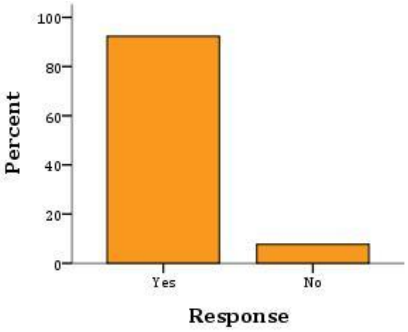
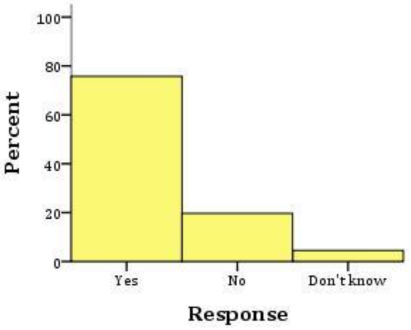
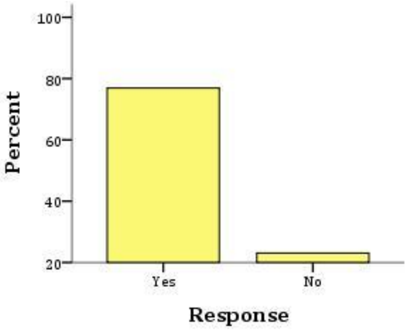


Figure 7.6| Responses given by participants when asked 'What is the principle cause of respiratory diseases?' **a**) Belmont, **b**) Vila Nova de Teotônio

When narrowed down to five factors that could potentially affect the development of respiratory diseases, the results were more consistent (Figure 7.7). Air pollution received the highest percentage of ‘yes’ responses, 91% in Belmont and 100% of participants in Vila Nova de Teotônio. Heredity and lifestyle (for example, smoking and diet) gave the most varied responses.

Factor	**Belmont**	**Vila Nova de Teotônio**
Air Pollution		
House mites		
Climate		

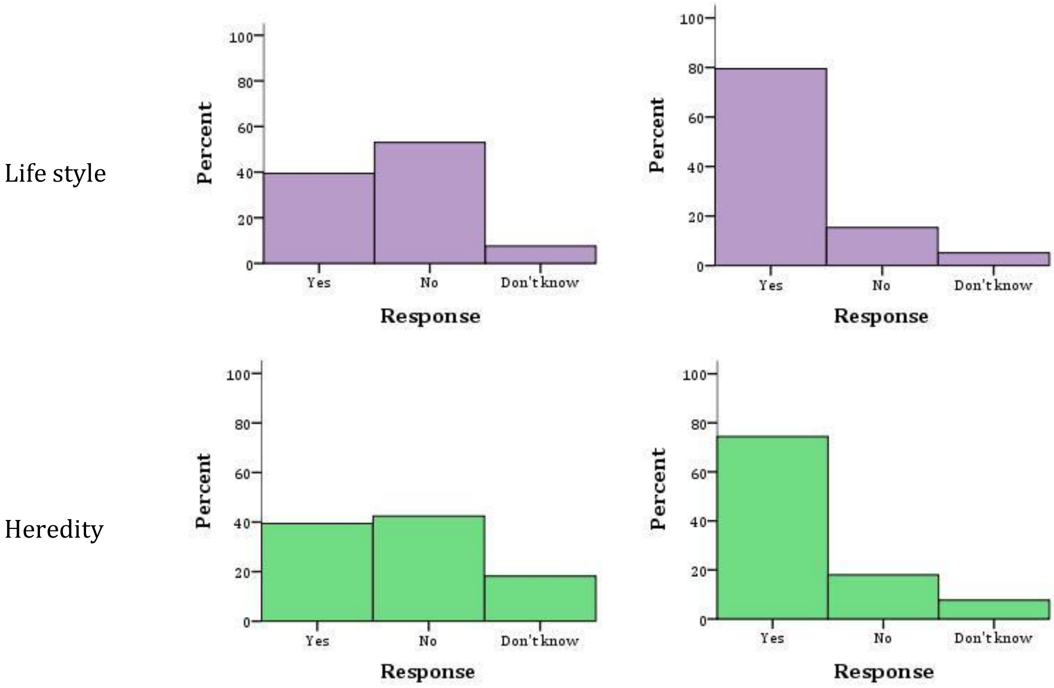


Figure 7.7| Responses given when ask 'do these factors affect the development of respiratory diseases?'

Responses have shown varied knowledge about respiratory diseases, with the primary responses for each question being ‘don’t know’. Although there is some knowledge within the communities, and those that do have knowledge seem to have a good level of it, the majority of participants did not know how to respond, highlighting an issue in overall knowledge. In general, participants have an idea of what respiratory diseases are, but the KAP survey aims to identify the level of their knowledge of treatment by comparison. When asked if respiratory diseases can be cured, the majority of participants in both communities said that they can (71% Belmont, 62% Vila Nova de Teotônio). In Vila Nova de Teotônio, 18% said they cannot be cured, 15% were not sure, and 5% commented that they can be cured depending on what type of disease it is. A wider range of responses was provided in Belmont, with no participant being unsure. Twelve percent did not think respiratory diseases could be cured, while the remaining responses consisted of statements showing knowledge that different respiratory diseases exist:

- '*They can't be cured but can be improved through medication'* (5%)
- '*Some can and some can't'* (2%)
- '*They can with the right medicine'* (3%)

Interestingly, in Belmont, 3% of participants highlighted their religious faith, stating that they can be cured if God wills them to be. This notion of faith was also shown when asking participants if they think there are medicines for respiratory diseases. In both communities, when asked about medicines, approximately 15% of participants responded by referring to home remedies and medicines (15% in Belmont, 13% in Vila Nova de Teotônio). In Vila Nova de Teotônio, 5% said they can be treated through sympathy. Over half of the participants in Belmont (54%) and approximately two-thirds of participants (67%) in Vila Nova de Teotônio know that there is medicine but cannot provide any names or details about them. Where participants could name a medicine, inhalers were the most commonly stated by 12% of respondents in Belmont, and 3% in Vila Nova de Teotônio. 3% of participants in Belmont named amoxicillin, and the same percentage of participants in Vila Nova de Teotônio said antibiotics. In Belmont, 2% said there are medicines for some diseases but not all, 3% did not know, and 6% did not think there are any, while in Vila Nova de Teotônio, 3% said there are none, and 8% were not sure.

The majority of participants in both communities responded 'don't know' to the question of how they could reduce the risk of contracting a respiratory disease. Among the remainder of respondents, the most common responses in both communities were related to fires and smoke, or lifestyle (see Figure 7.8).

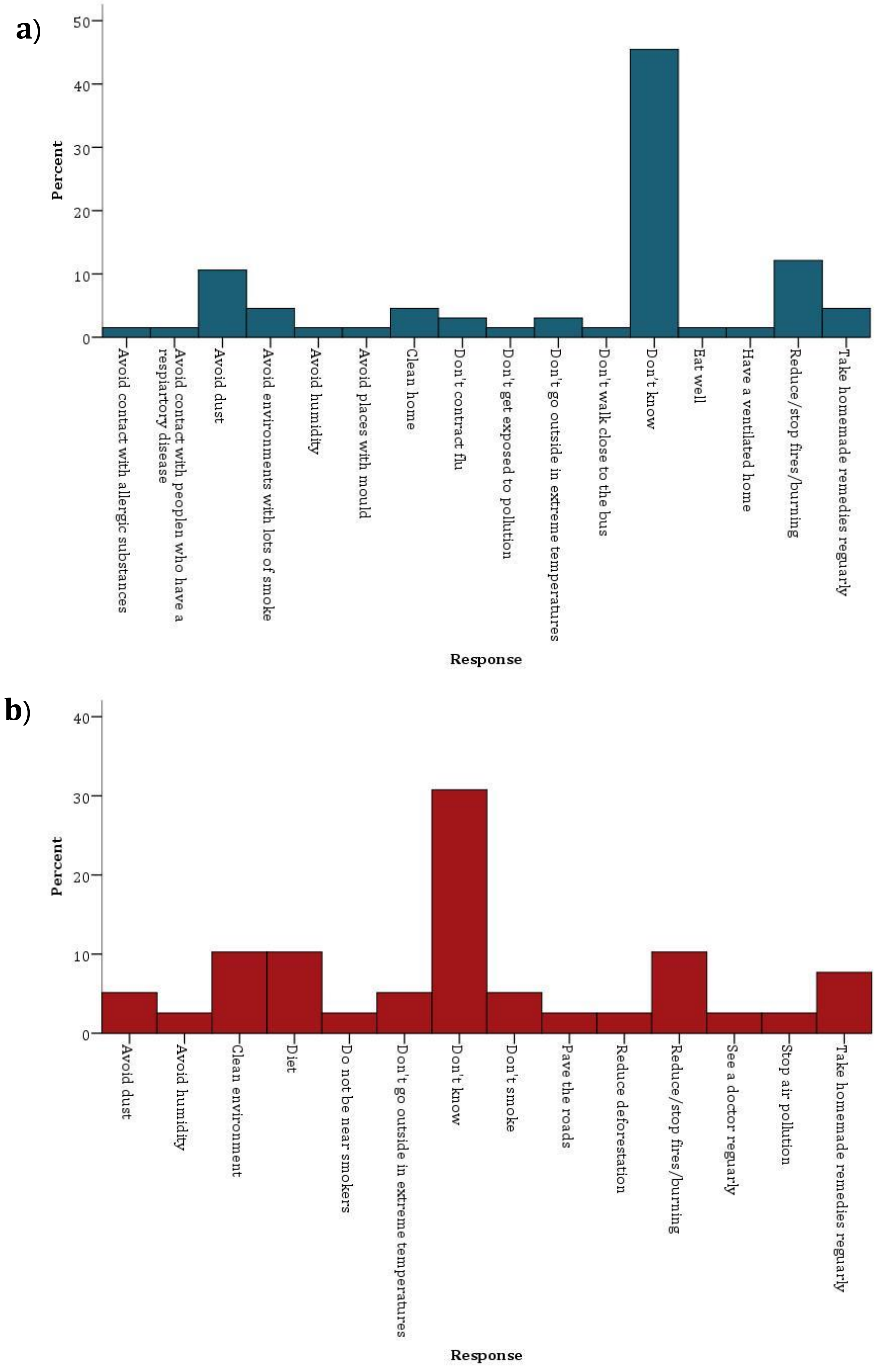


Figure 7.8| Responses to how participants think they can reduce their risk of developing a respiratory disease. **a**) Belmont, **b**) Vila Nova de Teotônio

Attitude

People primarily talked about their concern for those with respiratory diseases and the fact that if they too were diagnosed, they would be concerned and worried. Further inquiry revealed that their concern was due to the fact that they felt that having a respiratory disease would disrupt their family's daily activities, whether this was going to work, household chores, or children going to school.

Table 7.3| Attitudes to respiratory diseases: yes responses

Question	**Belmont**		**Vila Nova de Teotônio**	
	N	%	N	%
Are respiratory diseases a serious type of disease?	54	*81.8*	37	*94.9*
Are respiratory diseases a problem of health in Brazil?	61	*92.4*	36	*92.3*
Are respiratory diseases a problem of health in the Legal Amazon?	31	*46.9*	22	*56.4*
Can you develop a respiratory disease?	32	*48.5*	22	*56.4*

Table 7.3 summarises some of the information collected about people's attitudes about respiratory diseases. Almost all participants in Belmont (81.9%) thought that respiratory diseases are a serious type of disease. Interestingly, 61 participants (92.4%) thought that respiratory diseases were a problem for health services in Brazil, yet a smaller number (46.9%) believed that they were a problem in the Legal Amazon. As with Belmont, almost all participants in Vila Nova de Teotônio (94.9%) judged respiratory diseases to be a serious type of disease, with almost all participants (92.3%) saying they thought it was a problem for health in Brazil, and fewer (56.4%) thought it was a problem in the Legal Amazon.

Overall, it was observed that participants are concerned for the health of their neighbours and want to help them or advise them to go to the doctor. Only one in each community commented about being afraid of someone with a respiratory disease. Twenty-eight percentof participants in Vila Nova de Teotônio, and 21% in Belmont did not know how to respond.

Of the participants in Belmont who do not have a respiratory disease, when asked how they think they would react if told they had one, the most common response was they would look for a doctor and want treatment (48%). On this subject of treatment, one participant mentioned that they would want the *right* treatment. Another participant raised their concern, not about the disease, but the cost of treatment to cure it, and others mentioned they would want home treatment. The other dominant responses recorded were expressions of concern/sadness/being scared. These reactions of concern/sadness/being scared become more apparent when exploring how respondents think their daily activities would be affected. Only 8% of participants said they do not think it would affect them, 14% were unsure, and the remaining 78% said they would not be able to work, they would worry about financial resources, and be too tired to complete activities in the home and at work. Similar responses were given in Vila Nova de Teotônio, with the majority of responses expressing concern and feelings of sadness.

When participants who had a respiratory disease were asked what their reaction was, of the 19 of participants who had a respiratory disease in Belmont, 84.2% commented on thoughts of concern, fear, and sadness when they had been told they had a respiratory disease. Just over 5% mentioned their reaction was about treatment they could receive, and the remaining 10.5% said they reacted normally, as though nothing was wrong. Similar reactions were noted in Vila Nova de Teotônio, with 77.8% of the nine participants with a respiratory disease mentioning sadness and concern. Just over 11% said they reacted normally as though nothing was wrong and 11.1% did not remember how they reacted. A high percentage of participants were concerned when they were told they had a respiratory disease, but the survey sought to discover how these concerns translated into their daily routines. In both Belmont and Vila Nova de Teotônio, the main response to this question was that 'yes, it had affected their daily activities'. Participants said that they were unable to complete their domestic duties, or they found working difficult. In some instances, participants had to work less or stop work altogether. One participant even commented that they now worry about excessive dust when carrying out daily activities. Only one participant in each community said it had not affected them.

Practice

Although it is hard to identify themes in the practice component of KAP, as with the other components, an emerging theme can be noted – sensibleness Participants are sensible in the sense they seek medical care when they believe they need it. Almost all of the participants in both communities who said they had a respiratory problem, past or present, said they would go to the doctor for mild symptoms. Only two participants in each community said they would only go to the doctors when their symptoms prevented them from carrying out their daily activities. However, an interesting finding was that respondents are less sensible in terms of their actions such as burning household rubbish close to the home, particularly in Vila Nova de Teotônio where a rubbish collection service is operational. Although some comment they notice ill health when they burn rubbish, they continue to do it.

Government intervention has resulted in all households in Belmont using gas stoves for their cooking, which means they are no longer using solid fuel. Some houses continue to have a solid fuel method of cooking but this is located outside of the house and tends to be used only occasionally. Figure 7.9 shows the two methods that are being used in Belmont. All houses in Vila Nova de Teotônio have a gas stove, provided by Santo Antonio Electric. Respondents in both communities commented that since having a gas stove it is better as there is no smoke.

Figure 7.9| Cooking methods used: example from Belmont

Figure 7.10| Example of burning outside of a home in Belmont

Just over 71% of households in Belmont burn their household rubbish, while in Vila Nova de Teotônio, fewer households burn their rubbish (41.0%). Although the figure is lower for Vila Nova de Teotônio, 41% still appears quite a large proportion of the population considering the community has a rubbish collection service. Despite some participants (29.8% in Belmont, 37.5% Vila Nova de Teotônio) stating that they find breathing more difficult when burning their household rubbish, households continue to burn rubbish outside their homes. An example of burning outside of the home is illustrated in Figure 7.10.

Figure 7.11 shows the level of symptoms that participants perceive as requiring a need to seek medical attention. Approximately 70% of the participants in both communities said that they would go to the doctor if they experienced mild symptoms they linked with respiratory diseases. Whereas over 10% in Vila Nova de Teotônio said they would only go to the doctor when their symptoms prevented them from carrying out their daily activities, the figure was lower in Belmont (5%). When talking about general health problems, not limited to respiratory disease, an interesting aspect was raised; instead of seeing a doctor, people would seek care and advice from family members or neighbours. This was more common in Vila Nova de Teotônio, representing 53.8% of respondents.

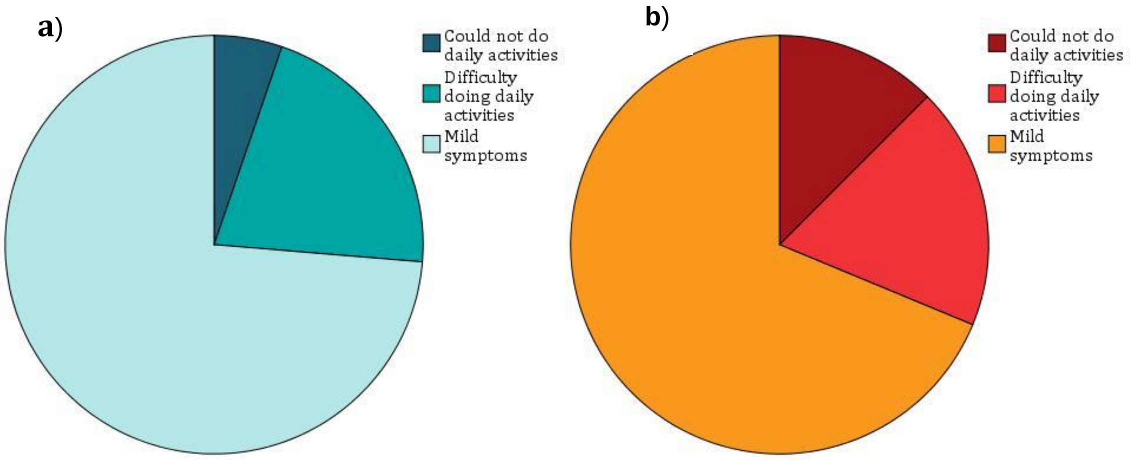


Figure 7.11| When participants go to the doctor for respiratory health problems. **a**) Belmont, **b**) Vila Nova de Teotônio

Finally, the majority of participants in Belmont had confidence in the healthcare service, with just 21% of participants not having confidence in the health service. The reasons for lack of confidence were stated as:

- *'Doctors do not recycle their knowledge to us'*
- *'Delay in treatment'*
- *'Many professionals ignore the symptoms of patients and do not give them appropriate attention'*
- *'There is a lack of trained professionals'*
- *'Too much bureaucracy, difficult to get appointment'*
- *'Public health service is not good enough'*
- *'Prefer home treatment'*
- *'Always a different team'*
- *'Doctor errors'*
- *'Always a different team and no proper monitoring'*
- *'Only prescribe some drugs'*
- *'Do not give adequate assistance'*

A greater number of participants in Vila Nova de Teotônio did not have confidence in the healthcare service, representing 34%. Participants who were not happy with the healthcare service raised the issue that although a health centre is located within the community, there was rarely a doctor there. During my time in Vila Nova de Teotônio, this fact was confirmed by the absence of a doctor for the whole duration. It was also mentioned that there can be a lack of confidence in the staff because they are not doctors, and five people felt that they were not being diagnosed correctly. Another perception which was noted was in relation to medicine, with participants saying there was a lack of medicine, or patients are being given the wrong treatment:

- *'Many doctors don't give the right diagnosis'*
- *'Do not give right diagnosis'*

- *'No confidence in the staff at health post'*
- *'Don't trust the public service'*
- *'The treatment prescribed is sometimes inadequate'*
- *'There is a lack of medication'*
- *'Depends on the disease the person has'*
- *'Negligence in the service in many cases'*
- *'Depends on the doctor, some give attention, others don't'*

Linking respiratory diseases with hydrological extremes

Over half of the participants in both communities could not remember the 2005, 2009, and 2010 hydrological extremes. Considering these events varied from two years from data collection to seven years, it is surprising over half the participants could not remember any of the events, especially as they were such large events causing both environmental and social devastation across the Legal Amazon. Similarly over half of the participants in both communities did not think there were fires or smoke near the community. For those who said they could remember and there were fires/smoke nearby, most ranked their breathing as becoming much worse during these periods. A couple of households said that smoke from fires across the river blows onto them, making it difficult to breathe at times. These households were located on the river side of Belmont.

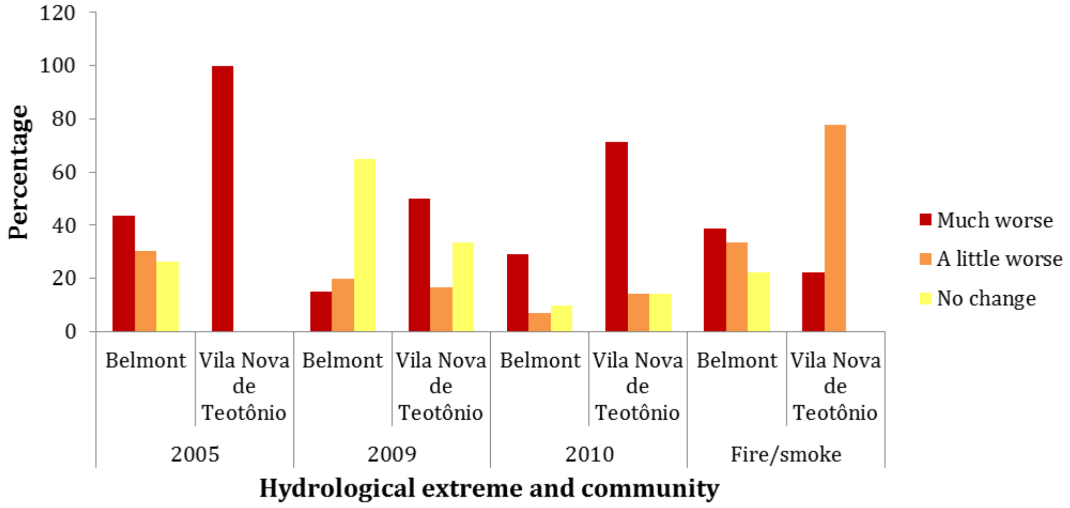


Figure 7.12| How the events affected participants' breathing

Correlations with socio-economic conditions

Table 7.4| Risk of at least one member of the household having a respiratory disease

Variable	Relative Risk (RR)	95% Confidence Interval (CI)	Odds Radio (OR)	95% Confidence Interval (CI)
Belmont				
Burn rubbish	1.15	0.778 – 1.685	1.53	0.49 – 4.72
Smoker in family	0.984	0.713 – 1.358	0.95	0.33 – 2.73
Income below average (R$ 1304)	0.964	0.690 – 1.347	0.89	0.28 – 2.76
Household size below average (< 4)	1.120	0.812 – 1.546	1.46	0.51 – 4.18
Vila Nova de Teotônio				
Burn rubbish	1.438	0.838 – 2.466	2.40	0.63 – 9.14
Smoker in family	1.333	0.688 – 2.583	1.87	0.486 – 7.176
Income below average (R$ 1022)	0.980	0.553 – 1.735	0.96	0.255 - 3.575
Household size below average (< 4)	0.604	0.302 – 1.141	0.33	0.87 – 1.221

The results presented in Table 7.4 show that in both communities, two of the variables cause an increase in the risk of at least one household member having a respiratory disease. In Belmont, the risk of a household having a member with a respiratory disease is 1.5 times greater for households burning their rubbish when compared with households that do not burn their rubbish (OR = 1.53, 95% CI = 0.49-4.72). The same is observed in Vila Nova de Teotônio but with a higher odds ratio observed (OR = 2.40, 95% CI 0.63 – 9.14). A smoker in the household appears to increase the risk of a household having at least one member with a respiratory disease in Vila Nova de Teotônio (OR = 1.87, 95% CI = 0.49 – 7.18), while it decreases the risk in Belmont (RR = 0.984, 95% CI = 0.713 – 1.358). Interestingly, in Belmont, a smaller family size increases the risk of a member having a respiratory disease (OR = 1.12, 95% CI = 0.51 – 4.18), contradicting literature which states that overcrowding can be a factor in the development of respiratory diseases (WHO., 2011).

When exploring the risk between parental genetics and behavioural factors (Table 7.5), it can be seen that children from households in Belmont have a greater risk of having a respiratory disease if their parents smoked when they were pregnant (OR = 2.73, 95% CI = 0.23 – 1.81), while children in Vila Nova de Teotônio have a greater risk if either parent has a respiratory disease (OR = 1.64, 95% CI = 0.37 – 7.33).

Table 7.5|Risk of child having a respiratory disease

Variable	**Relative Risk (RR)**	**95% Confidence Interval (CI)**	**Odds Radio (OR)**	**95% Confidence Interval (CI)**
Belmont				
Parent with RD	0.763	0.397 – 1.469	0.65	0.23 – 1.81
Smoke when pregnant	1.758	0.973 0 3.176	2.73	0.86 – 8.65
Vila Nova de Teotônio				
Parent with RD	1.458	0.460 – 4.625	1.64	0.37 – 7.33
Smoke when pregnant	0.952	0.239 – 3.800	0.94	0.16 – 5.59

Finally, assessment of the links between the existence of a respiratory disease, and education levels, with knowledge of respiratory diseases, is displayed in Table 7.6. The threshold used for the level of knowledge was set, as a participant had to be able to answer at least half of the questions about knowledge. In both communities, knowledge is shown to be higher if someone in the household has a respiratory disease, or the participant has at least secondary education. In Belmont, education showed greater knowledge (OR = 1.375, 95% CI 0.45 – 4.22), while in Vila Nova de Teotônio, higher levels of knowledge were associated with households with a member suffering from a respiratory disease (OR = 2.380, 95% CI 0.59 – 9.54).

Table 7.6| Knowledge and respiratory diseases

Variable	Relative Risk (RR)	95% Confidence Interval (CI)	Odds Radio (OR)	95% Confidence Interval (CI)
Belmont				
Have a respiratory disease	1.025	0.73 – 1.34	1.088	0.34 – 3.44
Secondary education or higher	1.100	0.76 – 1.56	1.375	0.45 – 4.22
Vila Nova de Teotônio				
Have a respiratory disease	1.314	0.83 – 2.07	2.380	0.59 – 9.54
Secondary education or higher	1.320	0.71 – 2.46	2.200	0.47 – 10.30

7.4 Discussion

This chapter has described the knowledge, attitude and practice of two communities in the Legal Amazon, as well as exploring the link between some known factors and the presence of respiratory diseases in the households. The study was motivated by the need for information on a topic that has yet to be explored and can support the previous two results chapters. It is the first known piece of work exploring people's KAP of respiratory diseases in the Legal Amazon.

The overall response rate was almost 76% in Belmont and just over 10% more in Vila Nova de Teotônoio (87%). More respondents in Vila Nova de Teotônio have low levels of education, which could indicate a reason for a greater number of responses that were 'don't know' when asked to define respiratory diseases. According to the geographical location and size of both communities, Belmont is closer to the city and has a larger population, which could explain why more varied responses were given in the Belmont community. Moreover, varied responses in both communities can be attributed to investigating the KAP of all respiratory diseases rather than confining the enquiry to upper or lower respiratory tract diseases. Some participant responses included in the knowledge section would be suitable for either, which suggests that people can recognise the symptoms but are unable to separate the two.

The presence of respiratory diseases according to the survey is higher in Belmont, representing 69.7% of the households having at least one member suffering from one respiratory disease, in comparison to Vila Nova de Teotônio, where the presence of respiratory disease was 56.4%. There is a clear peak in the percentage of people in Vila Nova de Teotônio who said their symptoms are worse at the end of the wet season in May. Albeit on a smaller scale analysis, this finding concurs with data presented in chapter 5 about the temporal trend of respiratory diseases. Belmont, however, shows a peak slightly later in June. Even though respiratory diseases in Brazil, and the Legal Amazon, are a leading cause of hospitalisations, general knowledge of them is limited in Belmont and Vila Nova de Teotônio. An assumption with KAP sirveys is that there is little knowledge on the topic being investigated, so this was expected. Interestingly though at least a third of participants in each community did not know how to answer questions in the KAP survey. Although it was expected that there would be a low level of knowledge on the topic, it wa not expected that such a high number of participants would not be able to provide answers at all. This however could be due to participants preferring to say ‘don’t know’ rather than give a ‘wrong’ answer. All of the symptoms of respiratory diseases which include breathlessness, chest pain, wheezing, and cough (Leach, 2008) were mentioned. The NHS provides a list of other symptoms, depending on whether the infection is an upper respiratory tract or lower respiratory tract infection. In addition to symptoms noted by Leach, these include headache, blocked/runny nose, sore throat, sneezing, muscle aches, build-up of mucus, and tight chest (NHS, 2013). The fact that these responses were given by some participants shows that some members of the communities had a reasonable level of knowledge of the symptoms and therefore they would know when they may need to seek medical care.

The overall attitudes towards respiratory diseases are concern and worry. Participants are generally concerned about the way in which having a respiratory disease would affect their daily activities, with many commenting that they would not be able to complete them, or they would struggle because they would be too tired. Only one participant in each community stated they would be afraid of someone with a respiratory disease; this can be linked to a few participants believing they can develop a respiratory disease through transmission from another person.

It is a positive finding that the majority of participants would go to the doctor if they had a respiratory problem. Where a large percentage state that they would visit the doctor for mild symptoms, it shows that the population are aware and concerned with their health. It may also explain the lack of trust some participants have in the health service. Some participants say that they do not trust the diagnoses doctors give them, which may be due to the fact that misclassification of diagnoses can occur where some symptoms are similar. This issue of misclassification has been suggested in the literature (Farhat et al., 2005). The use of home remedies could be explained by the low number of participants who are unaware of what ‘western’ medicine is available for respiratory diseases, or this could be embedded in faith or cultural beliefs. Faith and cultural beliefs could also be a reason for the consultation of neighbours instead of doctors or this practice could be linked to the lack of confidence in the public health service.

Another positive observation is that households in Belmont have embraced the government intervention of using a gas stove instead of solid fuel. This suggests that they are aware of the potentially negative impacts of cooking with solid fuel. Some participants commented that they found their breathing was better since having a gas stove. A particularly interesting finding from the survey data was the number of household that burn their rubbish and the link between this and the presence of a respiratory disease in the household. The greater number of households burning their rubbish in Belmont could be attributed to the fact that the community has no rubbish collection service. This service exists in Vila Nova de Teotônio so the number of households burning their rubbish is surprising. As is the fact that the relationship between burning rubbish and a person with a respiratory disease in the household was stronger in Vila Nova de Teotônio, which is unexpected as they have a rubbish collection service. Those participants who said that burning rubbish did not affect them related their response either to the distance to the rubbish being burnt (both communities) or the fact that the smoke from burning blows away from them across the river (in Belmont). Participants in Vila Nova de Teotônio commented that they seem to have better health, with fewer health issues being noted, since living in the modern-style houses provided by Santo Antonio Energia. Their old houses were made of wood, similar to the houses in Belmont, and participants noted that they were sometimes damp and house mites used to cause health problems.

More than half of the participants in both communities could not remember the three hydrological extremes being examined in this research. This suggests that there is a need to carry out surveys regarding hydrological extremes closer to the aftermath so that people can remember them. Similar results were found when Brondizio and Moran (2008) asked famers in 2002 about the drought of 1997/8 and 50% could not remember it. The responses from this research of those who did remember signified that they found breathing was much worse, or a little worse. This does not mean that they had a respiratory disease but that they found breathing more difficult during the extreme event.

Assessing socio-economic variables alongside the presence of respiratory diseases in the two communities has shown that households who burn their rubbish are at greater risk of having at least one household member with a respiratory disease. This is unsurprising because most of the households burn their rubbish within 20 metres of their home. Interestingly, however, only 14 of the 47 households that burn their rubbish commented that they find it harder to breathe when burning. Contrasting results between the communities were observed when assessing parent and child respiratory health and levels of knowledge. However, the confidence intervals are broad and span across 1, indicating that the results are not statistically significant and the estimates may be imprecise. This could be due to the small size of both communities. As the odds ratios indicate a link between some of the variables and respiratory health, there is potential value in conducting further work in other Legal Amazon communities.

I concur with other KAP studies (Cleland 1973, Hausmann-Muela et al. 2003) which suggest that caution is needed when interpreting the results of the attitude measurement. There may be localised factors affecting people’s attitudes which were not able to be obtained in the study. Moreover, as Cleland (1973) has stated, it can be difficult for people to judge what their reaction would be for hypothetical situations. Although this is correct, the consistency of these responses about feelings of concern provides reassurance in the results rather than if there was a mix of unexpected responses. It has been suggested that knowledge and behaviour are not directly linked (Launiala, 2009), rather that knowledge is only one aspect of decision making about health treatment. Practices can be based on a range of factors, from socio-cultural to environmental and economic (Launiala and Honkasalo, 2007). This has been shown in the communities of Belmont and Vila Nova de Teotônio, where participants who talked about home remedies and not seeing a doctor were able to provide answers for questions regarding definitions, acquiring a respiratory diseases, and symptoms.

7.5 Summary

This chapter has been concerned with addressing the fourth research question: what does primary data collection tell us about people's knowledge of respiratory diseases and their link to hydrological extremes? The results have shown an overall lack of knowledge about respiratory diseases, a favourable but concerned attitude to respiratory diseases, and contrasting behaviours. The high percentage of participants who do not remember the extreme events is a significant finding in this research. The high number of households burning their rubbish is also a key finding. In order to manage the impacts of hydrological extremes on respiratory diseases, knowledge about perceptions and actions in communities is the first step to achieving suitable management. Following this chapter, a discussion chapter will conclude by drawing together the work and the implications of the research.

Chapter 8

Discussion & Conclusion

8.1 Introduction

By exploring the distribution of three hydrological extreme events in the Legal Amazon and assessing the impacts on children's respiratory health, this thesis has provided original contributions to climate-health research. It goes further to provide policy recommendations based on the spatial data analysis of hydrological extremes and respiratory diseases, and the knowledge of local populations. As discussed in chapters one and three, no research exists on the topic of hydrological extremes and health in the Legal Amazon. Studies assess the impacts on the forest itself or investigate respiratory diseases in relation to air pollution at a smaller scale. This is the first study that preforms spatial analysis of hydrological extremes and respiratory health in the context of the entire Legal Amazon. It is also the first study that explores local populations' knowledge of respiratory diseases.

This concluding chapter will begin by revisiting the research question in relation to Figure 1.1; learning, detection, and anticipation, while bringing the three aspects together. It will then move on to establish policy recommendations to reduce the impact of climate-health interactions in the context of respiratory disease.

Discussion on how this work can be developed further will take place before providing a concluding summary.

8.2 Learning, detecting, and anticipating

Learning:

Where within the basin have the three hydrological extremes and associated human disturbances occurred?

What was the spatial and temporal distribution of respiratory diseases within the basin between 2001 and 2010 in children under five?

The extent of the hydrological extremes has been examined in the context of the Legal Amazon between 2001 and 2010. Previous studies have investigated the spatial and temporal extent of hydrological extremes in relation to the entire Amazon region. Despite this thesis using a similar approach, it has used a different spatial extent for analysis, and shown similar results as to where and when the hydrological extremes occurred. This thesis has shown that the 2010 drought was of greater magnitude than the 2005 drought, affecting 53.2% of municipalities in the Legal Amazon in comparison to 41% in 2005. The 2009 flood, according to positive rainfall anomalies, was shown to affect a larger area (69.5%) of the Legal Amazon than both the 2005 and the 2010 droughts. It was observed that Acre and the south-west part of the Legal Amazon were affected by all three hydrological extremes. Some Global Climate Models projections suggest greater frequency in AMO induced droughts; based on this analysis, the south-west (Acre, Rondônia and western Amazonas) will be the region in the Legal Amazon most vulnerable to extremes in the climate.

In comparison, the region of the 'arc of deforestation' around the east and south is more prone to high rates of hospitalisations for respiratory diseases. Even during years of hydrological extremes, 'hotspots' of hospitalisations did not shift to the corresponding areas of the Legal Amazon.

By answering the first two research questions, this thesis concurs with similar studies on the topic regarding the spatial and temporal distribution of hydrological extremes and respiratory diseases. It has shown differences in where and when hydrological extremes and respiratory diseases primarily occur. Examining them separately has shown different distributions, but do they interact when analysed together?

Detection:

To what extent do strong correlations between hydrological extreme periods and respiratory diseases exist?

Local spatial analysis in the form of Geographically Weighted Poisson Regression has allowed associations to be identified. This thesis has shown that during the hydrological extremes, increases in hospitalisations for respiratory diseases were observed in the affected micro-regions and municipalities. During all three hydrological extremes, aerosol and HDI have been shown to be the primary drivers. The extent of the impact of aerosol was larger during the peak of the droughts than the peak of the flood, and conversely HDI was more important during the peak of the flood. Two main observations have been noted: increasing the spatial scale from micro-regions to municipalities has resulted in more pronounced results and thus associations, and the spatially smaller drought of 2005 had a greater impact than the spatially larger 2010 drought and 2009 flood. Both of these can be equated to the scale – as discussed in chapter 4, aggregating data to larger areas can lead to more generalised results so detail and associations may be hidden.

Exploring localised impacts could be done in the state of Acre in 2005 because it was the epicentre of the drought and the primary location, with almost all of the state being affected. Acre is an excellent example of the impacts drought can have on human health, with results showing that due to reduced rainfall and increases in forest fires, and thus increased aerosol loads, hospitalisations for respiratory diseases peak later in the year corresponding with the peak of the drought, displacing the observed norm of respiratory diseases peaking at the end of the wet season. By creating baseline information, this thesis has been able to see how the hydrological extremes impact on hospitalisations for respiratory diseases and while annually hotspots are located elsewhere from the hydrological extremes, the impact of hydrological extremes can be seen at the local scale.

The thesis has provided evidence of positive associations between micro-regions and municipalities affected by hydrological extremes and respiratory diseases, particularly in 2005. Modelling the data has shown that there is a health risk during hydrological extremes, but how does this translate to populations having to cope with this?

Anticipate:

What does primary data collection tell us about people's knowledge of respiratory diseases and their link to hydrological extremes?

Conducting household surveys and KAP surveys in Belmont and Vila Nova de Teotônio has provided an invaluable insight into the knowledge that communities have about an extremely significant matter. It also supports the content of the more quantitative chapters. It has been shown that there is limited understanding about respiratory diseases and the links with social and environmental conditions. A key message taken from this work is that not only do people need educating about the risks of the climate variability and change, but education is also needed regarding the associated health impacts.

8.3 Implications of research

The findings from this thesis have policy implications which could enhance the health protection of the Legal Amazon population during periods of hydrological extremes. In light of the findings in this thesis, consideration could be given to implementing greater fire control enforcement. The National Climate Change Plan is geared to reducing deforestation rates, which is worthy; however, forest fires are also an important component of interactions in the Legal Amazon. Here it has been shown that even when deforestation rates are declining, active fires are not responding in the same way, particularly during drought periods. It has also been shown in that in all three spatial data analyses carried out in this research, aerosol is the primary (environmental) driver influencing respiratory diseases. Although it is difficult to monitor and enforce fire control, particularly when some fires are the result of accidental forest fire spread, the importance of enforcing fire control is considered vital not only to protecting the forest itself, but the health of the Legal Amazon population.

Further work could be done in terms of providing early warning alerts for hydrological extremes. These need to be in place for large-scale events as well as localised events. The warning systems should not only be accessible to National policy makers, but also for local decision makers. Outputs should be presented to the public where possible. At a conference I attended, a presenter from Senegal discussed a system in place which could be applied: mobile phone numbers are government registered and when a possible climate threat is projected, SMS are sent to people in the area. This may be costly, but it is an example of a possible way to notify people. Moreover, a link between these environmental warning systems and health authorities could be useful so hospitals in key municipalities or micro-regions can be prepared for possible increases in demand of services during hydrological extremes. There may also be a need for establishing hospitals in critical areas to deal with the increase in demand.

Considering the high loads of air pollution recorded in the Legal Amazon during the dry season, and with the growing number of studies showing the impact poor air quality in the Legal Amazon has on human health, it seems appropriate that

CONAMA consider producing air pollution standards for biomass burning. Although Brazil can use the threshold set by the Oregon State Department, it seems sensible Brazil have their own biomass burning air pollution standard because it is such a large problem and the thresholds may be different in Brazil due to different vegetation being burnt.

This thesis has highlighted how climatic and environmental changes can impact on the health of the population in the Legal Amazon. It has shown the severity that droughts in the region can have in the context of respiratory diseases. Yet still there are few studies regarding the health impacts of hydrological extremes, and general climate-health studies. Thus, it is suggested that there is greater interaction between environmental researcher and health researchers as it will provide greater understanding of climate-health interactions which in turn will assist in creating suitable measures to cope with potential impacts. This is in agreement with the Brazilian National Climate Plan’s key commitments to increase inter-sector research.

In order to adapt to climate change, it is important to understand the affected population’s knowledge of the topic so suitable measures can be implemented. Also gaining knowledge about how they cope with climatic stresses can assist in writing approaches that have been ‘tried and tested’ by populations being affected. This research has brought to light the difficulty in obtaining this knowledge from populations due to their limited memory of the events happening in the past, in the case of this research between two and seven years previously. Therefore, it is proposed that any future research of a similar nature to this thesis should conduct primary data collection as soon as possible after the event being investigated.

The KAP and household surveys conducted in this thesis have provided invaluable data regarding people’s behaviour that may contribute to the development of respiratory diseases. It has also highlighted a lack of recall of the hydrological extremes, suggesting research regarding people’s responses to extreme events need to carried out closer to the event. Moreover, a standardised approach for validating the findings from the KAP survey would be useful so comparisons can be carried out. between communities or countries in regard to the same topic, based on a standard that is being used everywhere.

8.4 Developing the research

This thesis has improved our understanding of how hydrological extremes in the Legal Amazon impact on children's respiratory health. It has also provided data which can be used as a baseline for future studies about local populations' knowledge regarding respiratory diseases. As this research was solely interested in the direct effects of hydrological extremes, the influence of other environmental variables that are known to affect respiratory health have been excluded. Their potentially important role in the development of respiratory diseases could be included in other studies, as well as more detailed socio-economic variables, to further understand the complex relationships between climate and health.

No other studies exist on how hydrological extremes impact on respiratory health in the Legal Amazon. Thus there is a need to analyse more recent hydrological extremes in the Legal Amazon, such as the 2011 and 2012 events, to see if similar results are found, so that a more comprehensive understanding can be created. Developing a more comprehensive understanding of the interactions of hydrological extremes and respiratory health will allow for future predictions to be made. Incorporating data from Global Climate Models will assist in creating a vulnerability index based on projected data. The vulnerability index can be enhanced through discussions with more communities in contrasting environments and will lead to different levels of knowledge and perception, as well as increasing sample size so statistically significant findings can be produced.

8.5 Summary

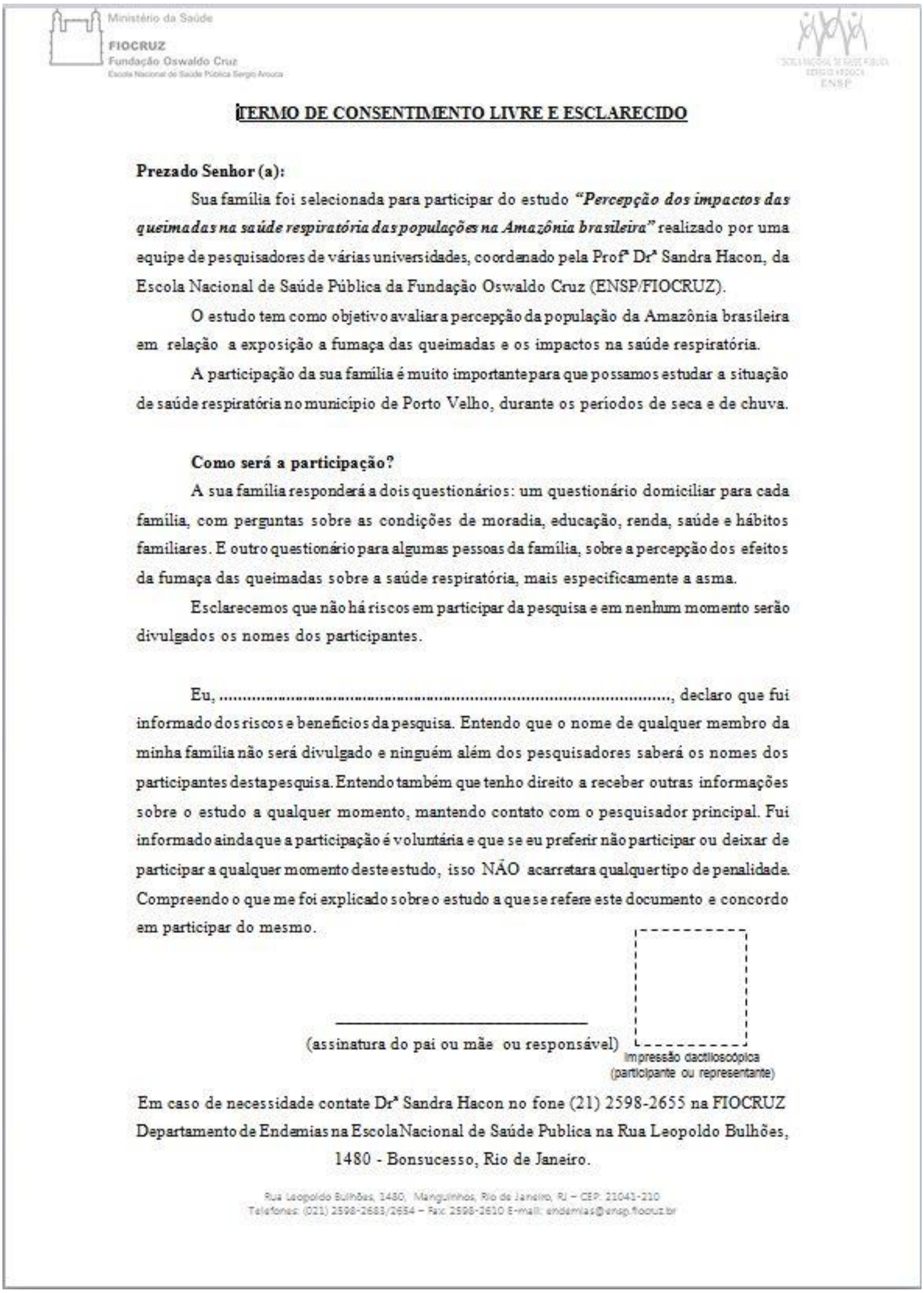
This thesis has highlighted the potential impact drought events can have on respiratory diseases. Despite the 2010 drought and 2009 flood being of larger magnitude, respiratory health was impacted upon more by the 2005 drought. This has been attributed to its smaller spatial scale and thus more concentrated conditions. Although respiratory diseases tend to have a temporal trend of peaking at the end of the wet season, the 2009 flood did not have as large an impact on respiratory health as either of the drought events. The primary variables affecting respiratory health have been shown to be aerosol and human development levels, highlighting the need for more in-depth research investigating the interactions between these and health.

Despite this research providing evidence that respiratory diseases are a health threat to the population of the Legal Amazon, limited knowledge exists within communities. With Global Climate Models predicting a drier climate for Amazonia, and increased risk of droughts, this research provides a starting point for future work on the impacts of hydrological extremes in the region. Other diseases known to be affected by hydrological extremes (e.g. vector-borne diseases, water-borne diseases) can be incorporated into the GWPR model to assess the impacts on them. Moreover, the GWPR model can be extended to other regions of the world for either independent analysis or comparisons between regions affected by hydrological extremes. In view of this, it is suggested that the approach taken in this research can be applied to a wider range of hydrological extremes and diseases.

In conclusion, in the Legal Amazon, not only forests (Phillips et al., 2009) are threatened by drought (Phillips et al., 2009) and fires (Aragão and Shimabukuro, 2010a), but also human populations exposed to health-hazardous agents. It is encouraging, however, that by efficiently enforcing fire control legislation, policy makers could, with a single action, mitigate fire impacts on ecosystems (Aragão and Shimabukuro, 2010a) and on human health. However, adaptation measurements must be pursued in terms of establishing hospitals in critical areas and planning for greater demand on health services during drought periods. These policies, together, would ensure better life quality for local populations and potentially minimise monetary and life costs in a scenario of increased future drought frequency.

Appendices

Appendix A| Consent form for surveys



Ministério da Saúde
FIOCRUZ
Fundação Oswaldo Cruz
Escola Nacional de Saúde Pública Sergio Arouca

ENSP

TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO

Prezado Senhor (a):

Sua família foi selecionada para participar do estudo ***"Percepção dos impactos das queimadas na saúde respiratória das populações na Amazônia brasileira"*** realizado por uma equipe de pesquisadores de várias universidades, coordenado pela Profª Drª Sandra Hacon, da Escola Nacional de Saúde Pública da Fundação Oswaldo Cruz (ENSP/FIOCRUZ).

O estudo tem como objetivo avaliar a percepção da população da Amazônia brasileira em relação a exposição a fumaça das queimadas e os impactos na saúde respiratória.

A participação da sua família é muito importante para que possamos estudar a situação de saúde respiratória no município de Porto Velho, durante os periodos de seca e de chuva.

Como será a participação?

A sua família responderá a dois questionários: um questionário domiciliar para cada família, com perguntas sobre as condições de moradia, educação, renda, saúde e hábitos familiares. E outro questionário para algumas pessoas da família, sobre a percepção dos efeitos da fumaça das queimadas sobre a saúde respiratória, mais especificamente a asma.

Esclarecemos que não há riscos em participar da pesquisa e em nenhum momento serão divulgados os nomes dos participantes.

Eu, ..., declaro que fui informado dos riscos e benefícios da pesquisa. Entendo que o nome de qualquer membro da minha família não será divulgado e ninguém além dos pesquisadores saberá os nomes dos participantes desta pesquisa. Entendo também que tenho direito a receber outras informações sobre o estudo a qualquer momento, mantendo contato com o pesquisador principal. Fui informado ainda que a participação é voluntária e que se eu preferir não participar ou deixar de participar a qualquer momento deste estudo, isso NÃO acarretara qualquer tipo de penalidade. Compreendo o que me foi explicado sobre o estudo a que se refere este documento e concordo em participar do mesmo.

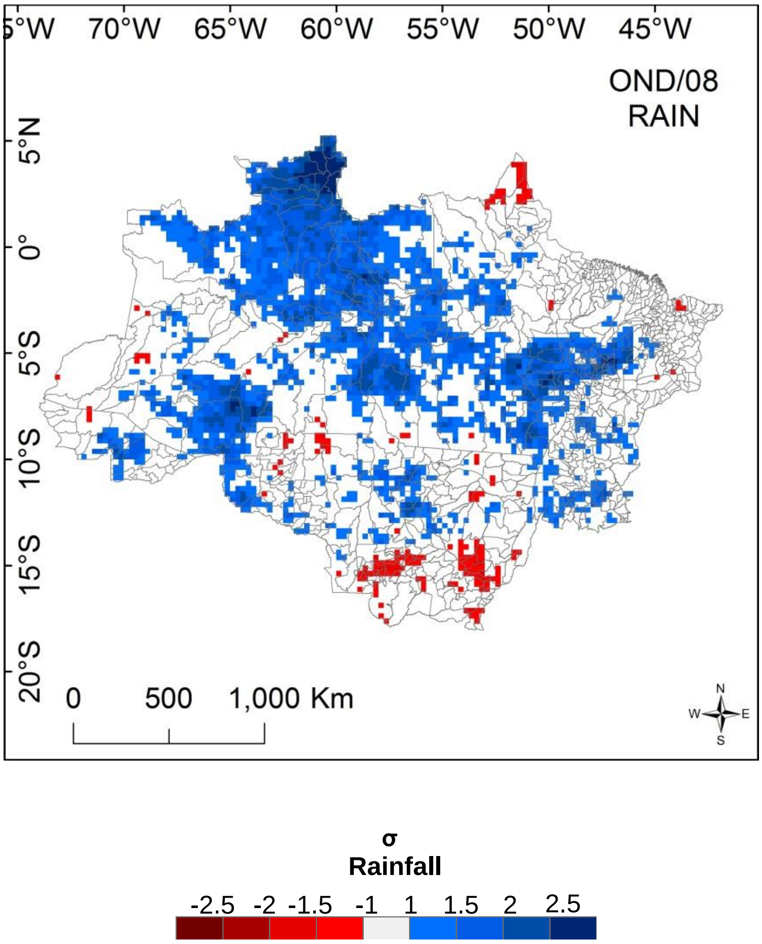
____
(assinatura do pai ou mãe ou responsável)

Impressão dactiloscópica
(participante ou representante)

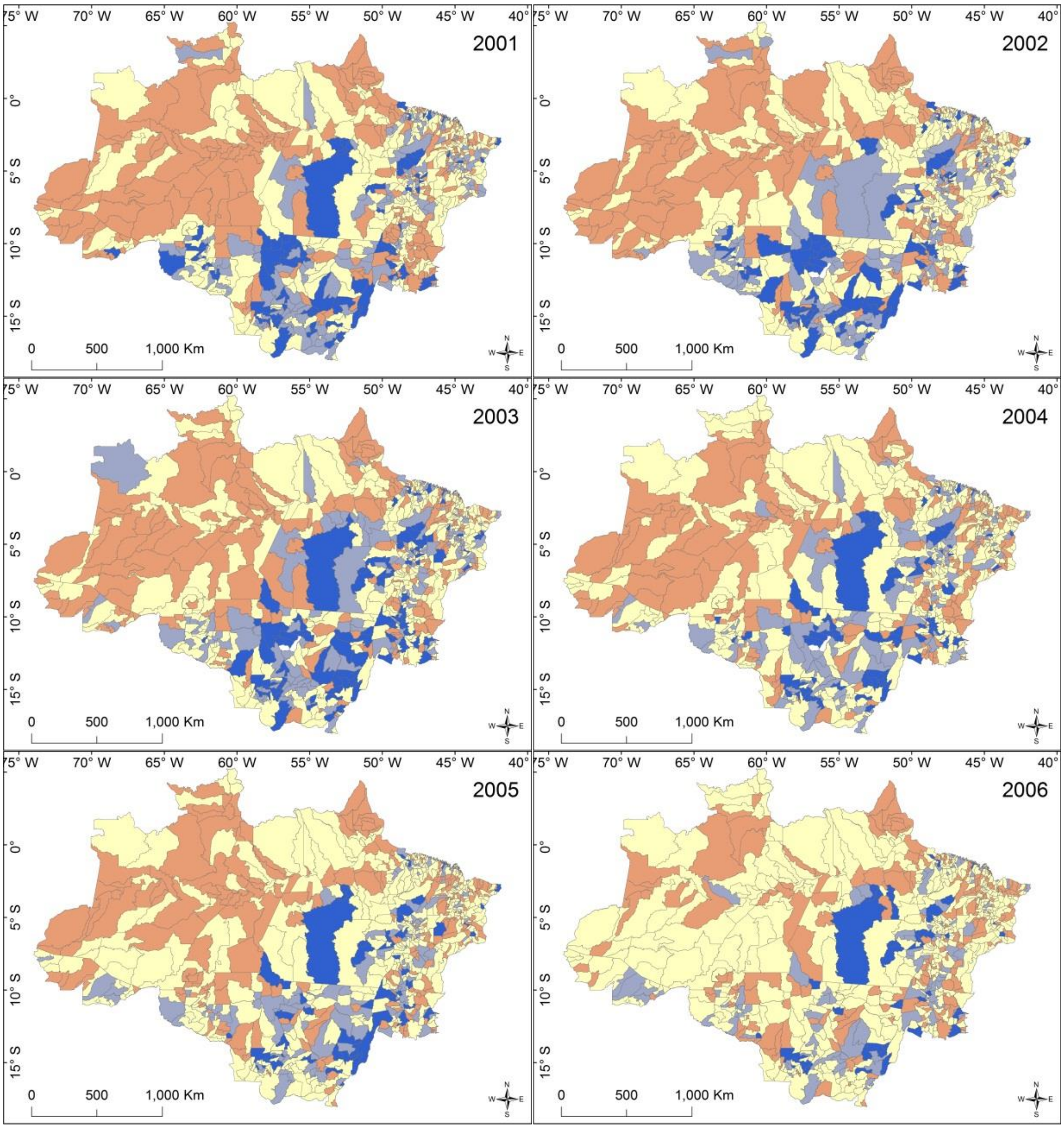
Em caso de necessidade contate Drª Sandra Hacon no fone (21) 2598-2655 na FIOCRUZ Departamento de Endemias na Escola Nacional de Saúde Publica na Rua Leopoldo Bulhões, 1480 - Bonsucesso, Rio de Janeiro.

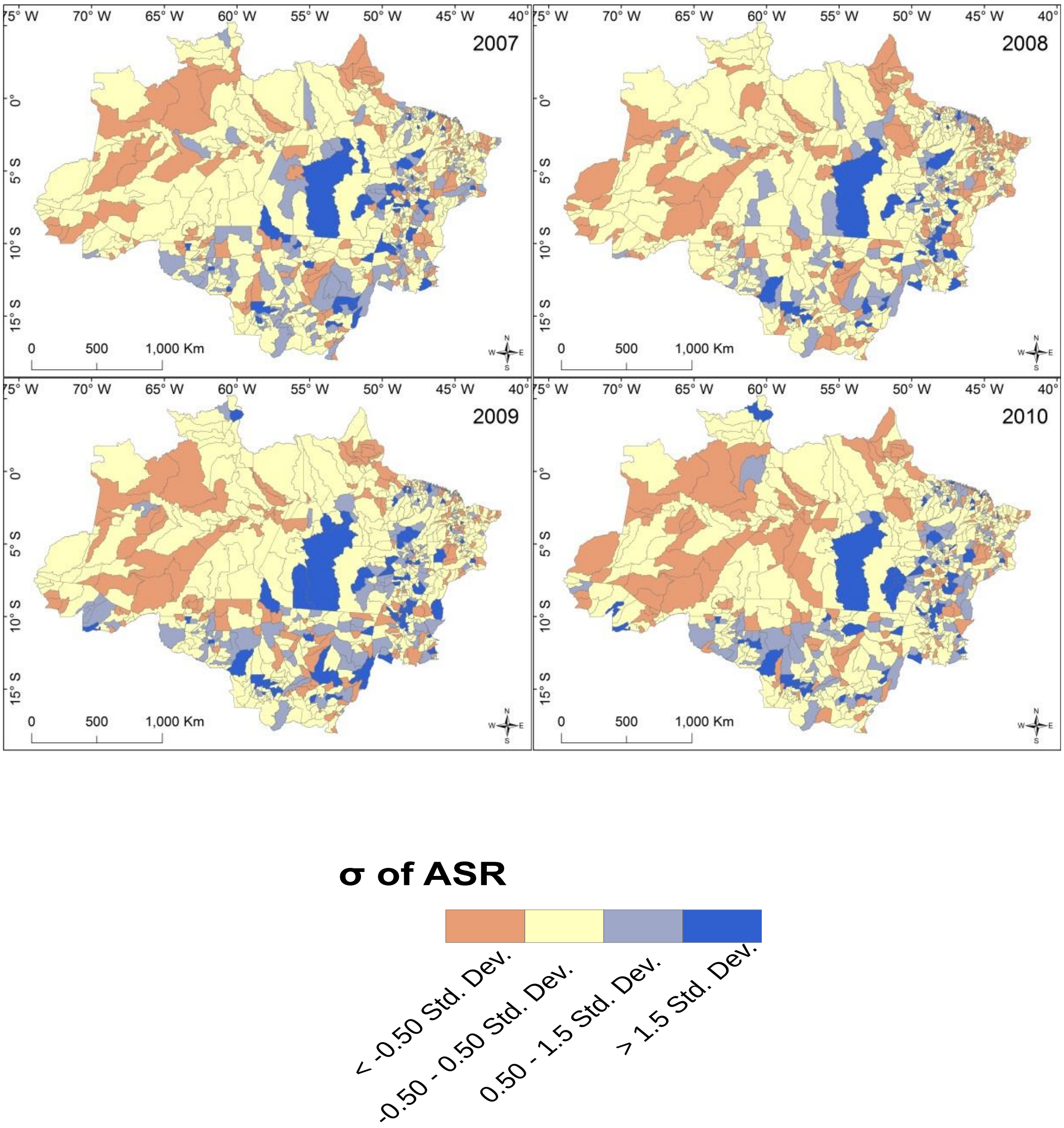
Rua Leopoldo Bulhões, 1480, Manguinhos, Rio de Janeiro, RJ – CEP: 21041-210
Telefones: (021) 2598-2683/2654 – Fax: 2598-2610 E-mail: endemias@ensp.fiocruz.br

Appendix B| OND rainfall data 2008



Appendix C| Incidence Rates




2007
2008
2009
2010
75° W
70° W
65° W
60° W
55° W
50° W
45° W
40°
0°
5° S
10° S
15° S
0
500
1,000 Km
N
W
E
S
σ of ASR
< -0.50 Std. Dev.
-0.50 - 0.50 Std. Dev.
0.50 - 1.5 Std. Dev.
> 1.5 Std. Dev.

Appendix D| Household survey (English)

HOUSEHOLD SURVEY

GPS - Lat: **Long:**

Code of household:

1. GENERAL INFORMATION Date of interview: ____/___/______

1. 1	**Name of community:** _______________________
1. 2	**Nome completo do entrevistado:**______________________________________
1. 3	**Sex:** M ☐ 1 F ☐ 2
1. 4	**Date of birth:** ____/___/_____
1. 5	**Marital status:** Married ☐ 1 Single ☐ 2 Divorced ☐ 3 Widowed ☐ 4
1. 6	**Members of the household. Only those who live with you.**

Name	**Relationship**	**Sex**	**Date of b**

Number of people in the household

1 -2	1
3 - 4	2
5 – 6	3
7 – 8	4
9 +	5

Children under 5

S ☐	1
N ☐	2

Aults 65+

S ☐	1
N ☐	2

2. HOUSEHOLD INFORMATION

2.1 The home is:

Owned ☐	1
Rented☐	2
Borrowed from a friend of family ☐	3
Other ☐____________	4

2.2 Type of material your home is made?

Wood ☐	1
Brick ☐	2
Both ☐	3
Other ☐_______________	4

2.3 How many rooms does your house have? 1 2 3 4 5 6 7 8

2.4 How many rooms are used for sleeping? 1 2 3 4 5

2.5 Do you use a gas stove or wood stove for cooking?

Gas stove ☐	1
Wood burning stove ☐	2
Both ☐	3

2.6 What is the location of this stove?

Gas stove –

Indoors ☐	1
Outdoors ☐	2

Wood burning stove -

Inside ☐	1
Outside ☐	2

2.7 How many hours a day do you spend near the wood burning stove. Answer in hours.

Interviewee	Under 1h ☐	1	1-2 ☐	2	3-4 ☐	3	5-6 ☐	4	More than 6 ☐	5
Under five years	Under 1h ☐	1	1-2 ☐	2	3-4 ☐	3	5-6 ☐	4	More than 6 ☐	5

Over five years	Under 1h ☐	1	1-2 ☐	2	3-4 ☐	3	5-6 ☐	4	More than 6 ☐	5
Father (Grandfather)	Under 1h ☐	1	1-2 ☐	2	3-4 ☐	3	5-6 ☐	4	More than 6 ☐	5
Mother (Grandmother)	Under 1h ☐	1	1-2 ☐	2	3-4 ☐	3	5-6 ☐	4	More than 6 ☐	5
Husband/wife	Under 1h ☐	1	1-2 ☐	2	3-4 ☐	3	5-6 ☐	4	More than 6 ☐	5

2.8 **Do you burn your household rubbish?**

S ☐	**1**
N ☐	**2**

If yes, what is the distance from your home?

1 – 5 m ☐	1
6 – 10 m ☐	2
11 – 15 m ☐	3
16 – 20 m ☐	4
20 + m ☐	5

3. EDUCATONAL INFORMATION

3.1. What is your level of education and people who live with you?

Level		**Respondent**	**Husband/wife**	**Dad**	**Mum**	**1st Child**	**2nd Child**	**3rd Child**	**4th Child**
Not schooling	**1**								
Cannot read and/or write	**2**								
Literate/1st year	**3**								
Elementary school	**4**								
Sedondary school	**5**								
High school	**6**								
Graduate	**7**								
Post graduate	**8**								

3.3 **What age do children start school?** ______year

3.4 **What time of the day children attend school?**

Age 6 – 9	Morning ☐	1	Afternoon ☐	2	All day ☐	3
Age 10 – 13	Morning ☐	1	Afternoon ☐	2	All day ☐	3
Ang 14 - 17:	Morning ☐	1	Afternoon ☐	2	All day ☐	3

3.5 **What days of the week do children go to school?**

Monday ☐	Tuesday☐	Wednesday ☐	Thursday ☐	Friday ☐
Saturday ☐	Sunday ☐			

3.6 **In which months of the year are children on school holidays?**

January	**1**
February	**2**
March	**3**
April	**4**
May	**5**
June	**6**

July	7
August	8
September	9
October	10
November	11
December	12

How many weeks?

1 week	1
2 weeks	2
3 weeks	3
4 weeks	4
5 ou mais semanas	5

4. EMPLOYMENT INFORMATION

4.1 **Please list the occupation of the residents, working hours and total monthly family income.**

NAME	OCCUPATION	HOURS OF WORK

4.2 What is your monthly household income? ________

5. HEALTH INFORMATION

5.1 **Do you or someone in your family suffer from any of the diseases listed below? Only those who live with you.**

DISEASE		RESPONDENT	HUSBAND/WIFE	DAD	MUM	1ST Child	2nd Child	3rd Chid	4th Child
Respiratory disease but do not know the name	1								
Asthma	2								
Pneumonia	3								
Chronic obstructive pulmonary disease	4								
Bronchitis	5								
Ohter respiratory disease. What?________________ _	6								
Obesity	7								

5.2 **Which months of the year are your symptoms for respiratory diseases worse?**

Months		RESPONDENT	HUSBAND/WIFE	DAD	MUM	1ST Child	2nd Child	3rd Chid
January	1							
February	2							
March	3							
April	4							
May	5							
June	6							
July	7							
August	8							
September	9							
October	10							
November	11							
December	12							

5.3 **Does anyone in the household use or used tobacco?**

S ☐	1
N ☐	2

Who?	**Cigarette**	**Chew**	**Pipe**	**Cigar**
	How many a day:____ Year began:______ Year quit:_____	How many a day:____ Year began:______ Year quit:_____	How many a day:____ Year began:______ Year quit:_____	How many a day:____ Year began:______ Year quit:_____
	How many a day:____ Year began:______ Year quit:_____	How many a day:____ Year began:______ Year quit:_____	How many a day:____ Year began:______ Year quit:_____	How many a day:____ Year began:______ Year quit:_____
	How many a day:____ Year began:______ Year quit:_____	How many a day:____ Year began:______ Year quit:_____	How many a day:____ Year began:______ Year quit:_____	How many a day:____ Year began:______ Year quit:_____
	How many a day:____ Year began:______ Year quit:_____	How many a day:____ Year began:______ Year quit:_____	How many a day:____ Year began:______ Year quit:_____	How many a day:____ Year began:______ Year quit:_____

5.4 **Did you smoke during pregnancy?**

S ☐	**1**
N ☐	**2**

5.5 **In general, how many times per week do you consume the following foods?**

	Never	Once a fortnight	1 to 3 times a week	More than 3 times a week	Daily
	1	2	3	4	5
Fish					
Beans					
Rice					
Chicken					
Eggs					
Beef or pork					
Cereals (maize, soybeans, wheat)					
Vegetables (potatoes, spinach, lettuce, carrots)					
Fruit					
Cassava					
Milk, butter, yogurt, or cheese					
Brazil nuts					
Canned food **What kind?** ____________					

5.6 Did you breastfeed?

S ☐	**1**
N ☐	**2**

Module about access to health service

5.7 **What health centre or hospital do you go to?**

In the community ☐ **Which________**	**1**
Near the community/along the rive ☐ **Which________**	**2**
In Porto Velho ☐ **Which________**	**3**

5.8 If there is not a health centre near, do you seek medical care from someone who is not a doctor?

Y ☐ **Who________**	1
N ☐	2

5.9 When you suffer any respiratory problem, do you wait for the doctor or look for a service in another region?

Wait for medical staff ☐	
Search for a service in another region ☐ Where? _________	

5.10 **Do you and your family go to the doctor (or seek mendical help) when a respiratory problem worsens?**

Y ☐	1
N ☐	2

If yes, when do you go?

Mild symptoms	☐	1
Difficultly doing daily activities	☐	2
Cannot do daily activities	☐	3

If not, why? ________________________

5.11 **Do you use medicine for your respiratory problem?**

Y ☐ **What ________**	**1**
N ☐	**2**

6. EXTRA INFORMATION

6.1 **Were you affected by the 2005 drought?**

Y ☐ **How** ____	1
N ☐	2

6.2 **Were you affected by the 2009 flood?**

Y ☐ **How** ____	1
N ☐	2

6.3 **Were you affected by the 2010 drought?**

Y ☐ **How** ____	1
N ☐	2

6.4 **If you or someone in your family has a respiratory illness, did you feel any change during these events?**

Y ☐ How much ____	1
N ☐	2

		Respondent	**Husband/wife**	**Dad**	**Mum**	**1st Child**	**2nd Child**	**3rd Child**	**4th Child**
Drought of 2005	**1**	**Much worse ☐**	**Much worse ☐**	**Much worse ☐**	**Much worse ☐**	**Much worse ☐**	**Much worse ☐**	**Much worse ☐**	**Much worse ☐**
	2	**A little worse ☐**	**A little worse ☐**	**A little worse ☐**	**A little worse ☐**	**A little worse ☐**	**A little worse ☐**	**A little worse ☐**	**A little worse ☐**
	3	**No change ☐**	**No change ☐**	**No change ☐**	**No change ☐**	**No change ☐**	**No change ☐**	**No change ☐**	**No change ☐**
	4	**A little better ☐**	**A little better ☐**	**A little better ☐**	**A little better ☐**	**A little better ☐**	**A little better ☐**	**A little better ☐**	**A little better ☐**
	5	**Much better ☐**	**Much better ☐**	**Much better ☐**	**Much better ☐**	**Much better ☐**	**Much better ☐**	**Much better ☐**	**Much better ☐**

Flood of 2009	1	**Much worse ☐**	**Much worse ☐**	**Much worse ☐**	**Much worse ☐**	**Much worse ☐**	**Much worse ☐**	**Much worse ☐**	**Much worse ☐**
	2	**A little worse ☐**	**A little worse ☐**	**A little worse ☐**	**A little worse ☐**	**A little worse ☐**	**A little worse ☐**	**A little worse ☐**	**A little worse ☐**
	3	**No change ☐**	**No change ☐**	**No change ☐**	**No change ☐**	**No change ☐**	**No change ☐**	**No change ☐**	**No change ☐**
	4	**A little better ☐**	**A little better ☐**	**A little better ☐**	**A little better ☐**	**A little better ☐**	**A little better ☐**	**A little better ☐**	**A little better ☐**
	5	**Much better ☐**	**Much better ☐**	**Much better ☐**	**Much better ☐**	**Much better ☐**	**Much better ☐**	**Much better ☐**	**Much better ☐**
Drought of 2010	1	**Much worse ☐**	**Much worse ☐**	**Much worse ☐**	**Much worse ☐**	**Much worse ☐**	**Much worse ☐**	**Much worse ☐**	**Much worse ☐**
	2	**A little worse ☐**	**A little worse ☐**	**A little worse ☐**	**A little worse ☐**	**A little worse ☐**	**A little worse ☐**	**A little worse ☐**	**A little worse ☐**
	3	**No change ☐**	**No change ☐**	**No change ☐**	**No change ☐**	**No change ☐**	**No change ☐**	**No change ☐**	**No change ☐**
	4	**A little better ☐**	**A little better ☐**	**A little better ☐**	**A little better ☐**	**A little better ☐**	**A little better ☐**	**A little better ☐**	**A little better ☐**
	5	**Much better ☐**	**Much better ☐**	**Much better ☐**	**Much better ☐**	**Much better ☐**	**Much better ☐**	**Much better ☐**	**Much better ☐**

Module of exposure

6.5 **Are there fires/smoke near the community?** Y ☐ N☐

If yes, did you find changes in your breathing during periods of fires/smoke?

		Respondent	**Husband/wife**	**Dad**	**Mum**	**1st Child**	**2nd Child**	**3rd Child**	**4th Child**
Change	1	**Much worse ☐**	**Much worse ☐**	**Much worse ☐**	**Much worse ☐**	**Much worse ☐**	**Much worse ☐**	**Much worse ☐**	**Much worse ☐**
	2	**A little worse ☐**	**A little worse ☐**	**A little worse ☐**	**A little worse ☐**	**A little worse ☐**	**A little worse ☐**	**A little worse ☐**	**A little worse ☐**
	3	**No change ☐**	**No change ☐**	**No change ☐**	**No change ☐**	**No change ☐**	**No change ☐**	**No change ☐**	**No change ☐**
	4	**A little better ☐**	**A little better ☐**	**A little better ☐**	**A little better ☐**	**A little better ☐**	**A little better ☐**	**A little better ☐**	**A little better ☐**
	5	**Much better ☐**	**Much better ☐**	**Much better ☐**	**Much better ☐**	**Much better ☐**	**Much better ☐**	**Much better ☐**	**Much better ☐**

6.6 **If you burn your household rubbish, do you notice changes in your breathing?**

Y ☐	1
N ☐	2

If yes, how much?

		Respondent	Husband/wife	Dad	Mum	1st Child	2nd Child	3rd Child	4th Child
Change	1	Much worse ☐	Much worse ☐	Much worse ☐	Much worse ☐	Much worse ☐	Much worse ☐	Much worse ☐	Much worse ☐
	2	A little worse ☐	A little worse ☐	A little worse ☐	A little worse ☐	A little worse ☐	A little worse ☐	A little worse ☐	A little worse ☐
	3	No change ☐	No change ☐	No change ☐	No change ☐	No change ☐	No change ☐	No change ☐	No change ☐
	4	A little better ☐	A little better ☐	A little better ☐	A little better ☐	A little better ☐	A little better ☐	A little better ☐	A little better ☐
	5	Much better ☐	Much better ☐	Much better ☐	Much better ☐	Much better ☐	Much better ☐	Much better ☐	Much better ☐

6.7 **If you or someone in your family has a respiratory disease, in your opinion, do these contribute to the development of it?**

		Respondent	Husband/wife	Dad	Mum	1st Child	2nd Child	3rd Child	4th Child
Air pollution	1	Y ☐	Y ☐	Y ☐	Y ☐	Y ☐	Y ☐	Y ☐	Y ☐
	2	N ☐	N ☐	N ☐	N ☐	N ☐	N ☐	N ☐	N ☐
House mites	1	Y ☐	Y ☐	Y ☐	Y ☐	Y ☐	Y ☐	Y ☐	Y ☐
	2	N ☐	N ☐	N ☐	N ☐	N ☐	N ☐	N ☐	N ☐
Living conditions	1	Y ☐	Y ☐	Y ☐	Y ☐	Y ☐	Y ☐	Y ☐	Y ☐
	2	N ☐	N ☐	N ☐	N ☐	N ☐	N ☐	N ☐	N ☐
Climate	1	Y ☐	Y ☐	Y ☐	Y ☐	Y ☐	Y ☐	Y ☐	Y ☐
	2	N ☐	N ☐	N ☐	N ☐	N ☐	N ☐	N ☐	N ☐
Genetics	1	Y ☐	Y ☐	Y ☐	Y ☐	Y ☐	Y ☐	Y ☐	Y ☐
	2	N ☐	N ☐	N ☐	N ☐	N ☐	N ☐	N ☐	N ☐

Thank you!

Appendix E| Household survey (Portuguese)

INQUÉRITO DOMICILIAR

GPS - Lat: **Long:**

Código do Domicílio:

1. INFORMAÇÕES GERAL **Data da entrevista:**

____/___/_______

1.1	**Nome da comunidade:** ____________________
1.2	**Nome completo do entrevistado:**_________________________________
1.3	**Sexo:** M ☐ 1 F ☐ 2
1.4	**Data de nascimento:** ___/___/_____
1.5	**Estado civil**: Casado ☐ 1 Solteiro ☐ 2 Divorciado ☐ 3 Viúva ☐ 4
1.6	**Membros do domicilio. Apenas aqueles que vivem com você.**

NOME	PARENTESCO	SEXO	DATA De NASCIME

Number of people in the household

1 -2	1
3 - 4	2
5 – 6	3
7 – 8	4
9 +	5

Children under 5

S ☐	1
N ☐	2

Aults 65+

S ☐	1
N ☐	2

2. INFORMAÇÕES DOMICILIAR

2.1 **A sua casa é**:

Própria ☐	1
Alugada☐	2
Emprestada por algum amigo ou membro da família ☐	3
Outro ☐, Qual?____________	4

2.2 **Tipo de material que sua casa é feita?**

Madeira ☐	**1**

Tijolo ☐	2
Os dois ☐	3
Outro ☐, Qual?______________	4

2.3 **Quantos cômodos sua casa possui? 1 2 3 4 5 6 7 8**

2.4 **Quantos cômodos são utilizados para dormir? 1 2 3 4 5**

2.5 **Você usa fogão a gás ou fogão a lenha para cozinha?**

Fogão a gás ☐	1
Fogão a lenha ☐	2
Os dois ☐	3

2.6 **Qual a localização deste fogão?**

Fogão a gás –

Dentro de casa ☐	1
Fora de casa ☐	2

Fogão a lenha -

Dentro de casa ☐	1
Fora de casa ☐	2

2.7 **Quantas horas por dia você fica perto do fogão a lenha? Respostas em horas.**

Entrevistado	Menos que 1h ☐	1	1-2 ☐	2	3-4 ☐	3	5-6 ☐	4	Mais do que 6 ☐	5
Menores de 5 anos	Menos que 1h ☐	1	1-2 ☐	2	3-4 ☐	3	5-6 ☐	4	Mais do que 6 ☐	5
Maiores de 5 anos	Menos que 1h ☐	1	1-2 ☐	2	3-4 ☐	3	5-6 ☐	4	Mais do que 6 ☐	5
Pai (Avô)	Menos que 1h ☐	1	1-2 ☐	2	3-4 ☐	3	5-6 ☐	4	Mais do que 6 ☐	5
Mãe (Avó)	Menos que 1h ☐	1	1-2 ☐	2	3-4 ☐	3	5-6 ☐	4	Mais do que 6 ☐	5
Marido/Esposa	Menos que 1h ☐	1	1-2 ☐	2	3-4 ☐	3	5-6 ☐	4	Mais do que 6 ☐	5

2.8 **Você queima lixo doméstico?**

S ☐	1

N ☐	**2**

Se sim, qual é a distância até sua casa?

1 – 5 m ☐	1
6 – 10 m ☐	2
11 – 15 m ☐	3
16 – 20 m ☐	4
20 + m ☐	5

3. INFORMAÇÃO EDUCACIONAL

3.1. Qual é o seu nível de escolaridade e das pessoas que vivem com você?

NÍVEL		**ENTREVISTADO**	**MARIDO/ESPOSA**	**PAI**	**MÃE**	**1º FILHO**	**2º FILHO**	**3º FILHO**	**4º FILHO**
Não está na escola	**1**								
Não sabe ler e/ou escrever	**2**								
Alfabetização/1º ano	**3**								
Ensino Fundamental I	**4**								
Ensino Fundamental II	**5**								
Ensino Médio	**6**								
Graduação	**7**								
Pós-Graduação	**8**								

3.3 **Com quantos anos eles começaram a frequentar a escola?** ______anos

3.4 **Qual horário que as crianças frequentam a escola?**

Idade 6 – 9	Manhã ☐	1	Tarde ☐	2	Integral ☐	3
Idade 10 – 13	Manhã ☐	1	Tarde ☐	2	Integral ☐	3
Idade 14 - 17:	Manhã ☐	1	Tarde ☐	2	Integral ☐	3

3.5 **Quais os dias da semana que as crianças vão à escola?**

Segunda-feira ☐	Terça-feira☐	Quarta-feira ☐	Quinta-feira☐	Sexta-feira ☐

	Sábado ☐	Domingo ☐			

3.6 **Em quais meses do ano as crianças entram de férias escolar?**

JANEIRO	**1**
FEVEREIRO	**2**
MARÇO	**3**
ABRIL	**4**
MAIO	**5**
JUNHO	**6**
JULHO	**7**
AGOSTO	**8**
SETEMBRO	**9**
OUTUBRO	**10**
NOVEMBRO	**11**
DEZEMBRO	**12**

Quantas semanas?

1 semana	**1**
2 semanas	**2**
3 semanas	**3**
4 semanas	**4**
5 ou mais semanas	**5**

4. Informação Emprego

4.1 **Por favor, listar a ocupação dos moradores, horas de trabalho e rendimento total mensal da família.**

NOME	OCUPAÇÃO	HORAS DE TRABALHO

4.2 Qual é a sua renda familiar mensal? _________

5. INFORMAÇÃO SAÚDE

5.1 **Você ou alguém de sua família sofre com alguma doença listada abaixo? Informe apenas aqueles que vivem com você.**

DOENÇA		ENTREVISTADO	MARIDO/ESPOSA	PAI	MÃE	1º FILHO	2º FILHO	3º FILHO	4º FILHO
Doença respiratória mas não sei o nome	1								
Asma	2								
Pneumonia	3								
Doença pulmonar obstrutiva crônica	4								
Bronquite	5								
Outra doença respiratória. Qual?_______________ ___	6								
Obesidade	7								

5.2 **Em crianças menores de cinco anos, qual é o mês do ano em que os sintomas da asma pioram?**

MESES		1º FILHO	2º FILHO	3º FILHO	4º FILHO
JANEIRO	1				
FEVEREIRO	2				
MARÇO	3				
ABRIL	4				
MAIO	5				
JUNHO	6				
JULHO	7				
AGOSTO	8				
SETEMBRO	9				
OUTUBRO	10				
NOVEMBRO	11				
DEZEMBRO	12				

5.3 **Alguém na casa faz ou fez uso de Tabaco?**

S ☐	1
N ☐	2

QUEM?	**CIGARRO**	**MASTIGAR**	**CACHIMBO**	**CHARUTO**
	Qtos ao dia:____ Ano que começou:______ Ano que parou:_____	Qtos ao dia:____ Ano que começou:______ Ano que parou:_____	Qtos ao dia:____ Ano que começou:______ Ano que parou:_____	Qtos ao dia:____ Ano que começou:______ Ano que parou:_____
	Qtos ao dia:____ Ano que começou:______ Ano que parou:_____	Qtos ao dia:____ Ano que começou:______ Ano que parou:_____	Qtos ao dia:____ Ano que começou:______ Ano que parou:_____	Qtos ao dia:____ Ano que começou:______ Ano que parou:_____
	Qtos ao dia:____ Ano que começou:______ Ano que parou:_____	Qtos ao dia:____ Ano que começou:______ Ano que parou:_____	Qtos ao dia:____ Ano que começou:______ Ano que parou:_____	Qtos ao dia:____ Ano que começou:______ Ano que parou:_____
	Qtos ao dia:____ Ano que começou:______ Ano que parou:_____	Qtos ao dia:____ Ano que começou:______ Ano que parou:_____	Qtos ao dia:____ Ano que começou:______ Ano que parou:_____	Qtos ao dia:____ Ano que começou:______ Ano que parou:_____

5.4 **Você fuma durante a gravidez?**

S ☐	**1**
N ☐	**2**

Módulo de nutrição

5.5 **Em geral, quantas vezes por semana o(a) Sr(a) consome os seguintes alimentos?**

	Nunca	1 vez a cada 15 dias	De 1 a 3 vezes por semana	Mais do que 3 vezes por semana	Diariamente
	1	2	3	4	5
Peixe					
Feijão					
Arroz					
Frango					
Ovos					
Carne de boi ou de porco					
Cereais (milho, soja, trigo)					
Verduras ou legumes (batata, espinafre, alface, cenoura)					
Frutas					
Mandioca					
Leite, manteiga, iogurte ou queijo					
Castanha do Pará					
Enlatados De que tipo? ___________					

5.6 Você amamenta suas crianças?

S ☐	1
N ☐	2

Módulo de acesso aos serviços de saúde

5.7 **Qual o posto de saúde ou hospital que você vai ou leva seu filho quando necessário?**

Na communidade ☐ **Qual________**	1
Perto da comunidade/ao longo do rio ☐ **Qual________**	2
Em Porto Velho ☐ **Qual________**	3

5.8 Se não houver um centro de saúde ou hospital, você procura alguma pessoa que não seja um médico?

S ☐ **Qual________**	1

	N ☐ | 2
5.9	Quando o seu filho está com algum problema respiratório o senhor(a) espera a vinda da equipe médica ou procura um serviço em outra região? Espera a vinda da equipe médica ☐ Procura um serviço em outra região ☐ Onde? ________
5.10	**Você e sua família vão ao médico (ou procuram o posto de saúde) quando seu problema respiratório piora?** S ☐ | 1 N ☐ | 2 **Se sim, quando você vai?** Leve sintoma ☐ | 1 Dificuldade de fazer atividades diária ☐ | 2 Não pode fazer atividades diária ☐ | 3 **Se não, por quê?** ____________________________
5.11	**Você usa remédio para seu problema respiratório?** **S ☐ Qual________** | **1** **N ☐** | **2**

6. INFORMAÇÕES EXTRA

6.1	**Você foi afetado pela seca de 2005?** S ☐ **Como** ______________________________________ | 1 N ☐ | 2
6.2	**Você foi afetado pela inundação de 2009?** S ☐ **Como** ______________________________________ | 1 N ☐ | 2
6.3	**Você foi afetado pela seca de 2010?** S ☐

	Como ____	1
	N ☐	2

6.4 **Se você ou alguém de sua família tem uma doença respiratória, você sentiu alguma mudança durante esses acontecimentos?**

S ☐ Quanto ____	1
N ☐	2

		ENTREVISTADO	**MARIDO/ESPOSA**	**PAI**	**MÃE**	**1º FILHO**	**2º FILHO**	**3º FILHO**	**4º FILHO**
Seca de 2005	**1**	**Muito pior ☐**	**Muito pior ☐**	**Muito pior ☐**	**Muito pior ☐**	**Muito pior ☐**	**Muito pior ☐**	**Muito pior ☐**	**Muito pior ☐**
	2	**Um pouco pior ☐**	**Um pouco pior ☐**	**Um pouco pior ☐**	**Um pouco pior ☐**	**Um pouco pior ☐**	**Um pouco pior ☐**	**Um pouco pior ☐**	**Um pouco pior ☐**
	3	**Nenhuma mudança ☐**	**Nenhuma mudança ☐**	**Nenhuma mudança ☐**	**Nenhuma mudança ☐**	**Nenhuma mudança ☐**	**Nenhuma mudança ☐**	**Nenhuma mudança ☐**	**Nenhuma mudança ☐**
	4	**Um pouco melhor ☐**	**Um pouco melhor ☐**	**Um pouco melhor ☐**	**Um pouco melhor ☐**	**Um pouco melhor ☐**	**Um pouco melhor ☐**	**Um pouco melhor ☐**	**Um pouco melhor ☐**
	5	**Muito melhor ☐**	**Muito melhor ☐**	**Muito melhor ☐**	**Muito melhor ☐**	**Muito melhor ☐**	**Muito melhor ☐**	**Muito melhor ☐**	**Muito melhor ☐**
Inundação de 2009	**1**	**Muito pior ☐**	**Muito pior ☐**	**Muito pior ☐**	**Muito pior ☐**	**Muito pior ☐**	**Muito pior ☐**	**Muito pior ☐**	**Muito pior ☐**
	2	**Um pouco pior ☐**	**Um pouco pior ☐**	**Um pouco pior ☐**	**Um pouco pior ☐**	**Um pouco pior ☐**	**Um pouco pior ☐**	**Um pouco pior ☐**	**Um pouco pior ☐**
	3	**Nenhuma mudança ☐**	**Nenhuma mudança ☐**	**Nenhuma mudança ☐**	**Nenhuma mudança ☐**	**Nenhuma mudança ☐**	**Nenhuma mudança ☐**	**Nenhuma mudança ☐**	**Nenhuma mudança ☐**

	4	Um pouco melhor ☐	Um pouco melhor ☐	Um pouco melhor ☐	Um pouco melhor ☐	Um pouco melhor ☐	Um pouco melhor ☐	Um pouco melhor ☐	Um pouco melhor ☐
	5	Muito melhor ☐	Muito melhor ☐	Muito melhor ☐	Muito melhor ☐	Muito melhor ☐	Muito melhor ☐	Muito melhor ☐	Muito melhor ☐
Seca de 2010	1	Muito pior ☐	Muito pior ☐	Muito pior ☐	Muito pior ☐	Muito pior ☐	Muito pior ☐	Muito pior ☐	Muito pior ☐
	2	Um pouco pior ☐	Um pouco pior ☐	Um pouco pior ☐	Um pouco pior ☐	Um pouco pior ☐	Um pouco pior ☐	Um pouco pior ☐	Um pouco pior ☐
	3	Nenhuma mudança ☐	Nenhuma mudança ☐	Nenhuma mudança ☐	Nenhuma mudança ☐	Nenhuma mudança ☐	Nenhuma mudança ☐	Nenhuma mudança ☐	Nenhuma mudança ☐
	4	Um pouco melhor ☐	Um pouco melhor ☐	Um pouco melhor ☐	Um pouco melhor ☐	Um pouco melhor ☐	Um pouco melhor ☐	Um pouco melhor ☐	Um pouco melhor ☐
	5	Muito melhor ☐	Muito melhor ☐	Muito melhor ☐	Muito melhor ☐	Muito melhor ☐	Muito melhor ☐	Muito melhor ☐	Muito melhor ☐

Módulo de exposição

6.5 **Existem alguma queimada perto da comunidade?** S ☐ N☐

Se sim, você verificou mudanças em sua respiração durante esse acontecimento

		ENTREVISTADO	MARIDO/ESPOSA	PAI	MÃE	1º FILHO	2º FILHO	3º FILHO	4º FILHO
Mudança	1	Muito pior ☐	Muito pior ☐	Muito pior ☐	Muito pior ☐	Muito pior ☐	Muito pior ☐	Muito pior ☐	Muito pior ☐
	2	Um pouco pior ☐	Um pouco pior ☐	Um pouco pior ☐	Um pouco pior ☐	Um pouco pior ☐	Um pouco pior ☐	Um pouco pior ☐	Um pouco pior ☐

	3	Nenhuma mudança ☐	Nenhuma mudança ☐	Nenhuma mudança ☐	Nenhuma mudança ☐	Nenhuma mudança ☐	Nenhuma mudança ☐	Nenhuma mudança ☐	Nenhuma mudança ☐
	4	Um pouco melhor ☐	Um pouco melhor ☐	Um pouco melhor ☐	Um pouco melhor ☐	Um pouco melhor ☐	Um pouco melhor ☐	Um pouco melhor ☐	Um pouco melhor ☐
	5	Muito melhor ☐	Muito melhor ☐	Muito melhor ☐	Muito melhor ☐	Muito melhor ☐	Muito melhor ☐	Muito melhor ☐	Muito melhor ☐

6.6 **Se você queima lixo domestico, você verifica mudanças em sua respiração?**

S ☐	1
N ☐	2

Se sim, quanto?

		ENTREVISTADO	MARIDO/ESPOSA	PAI	MÃE	1º FILHO	2º FILHO	3º FILHO	4º FILHO
Mudança	1	Muito pior ☐	Muito pior ☐	Muito pior ☐	Muito pior ☐	Muito pior ☐	Muito pior ☐	Muito pior ☐	Muito pior ☐
	2	Um pouco pior ☐	Um pouco pior ☐	Um pouco pior ☐	Um pouco pior ☐	Um pouco pior ☐	Um pouco pior ☐	Um pouco pior ☐	Um pouco pior ☐
	3	Nenhuma mudança ☐	Nenhuma mudança ☐	Nenhuma mudança ☐	Nenhuma mudança ☐	Nenhuma mudança ☐	Nenhuma mudança ☐	Nenhuma mudança ☐	Nenhuma mudança ☐
	4	Um pouco melhor ☐	Um pouco melhor ☐	Um pouco melhor ☐	Um pouco melhor ☐	Um pouco melhor ☐	Um pouco melhor ☐	Um pouco melhor ☐	Um pouco melhor ☐
	5	Muito melhor ☐	Muito melhor ☐	Muito melhor ☐	Muito melhor ☐	Muito melhor ☐	Muito melhor ☐	Muito melhor ☐	Muito melhor ☐

6.7 **Se você ou alguém de sua família tem asma, em sua opinião, quais seriam os motivos?**

		ENTREVISTADO	MARIDO/ESPOSA	PAI	MÃE	1º FILHO	2º FILHO	3º FILHO	4º FILHO
Poluição atmosférica	1	S ☐	S ☐	S ☐	S ☐	S ☐	S ☐	S ☐	S ☐
	2	N ☐	N ☐	N ☐	N ☐	N ☐	N ☐	N ☐	N ☐
Ácaro	1	S ☐	S ☐	S ☐	S ☐	S ☐	S ☐	S ☐	S ☐
	2	N ☐	N ☐	N ☐	N ☐	N ☐	N ☐	N ☐	N ☐
Condições	1	S ☐	S ☐	S ☐	S ☐	S ☐	S ☐	S ☐	S ☐

de vida	2	**N** ☐	**N** ☐	**N** ☐	**N** ☐	**N** ☐	**N** ☐	**N** ☐	**N** ☐
Clima	1	**S** ☐	**S** ☐	**S** ☐	**S** ☐	**S** ☐	**S** ☐	**S** ☐	**S** ☐
	2	**N** ☐	**N** ☐	**N** ☐	**N** ☐	**N** ☐	**N** ☐	**N** ☐	**N** ☐
Genético	1	**S** ☐	**S** ☐	**S** ☐	**S** ☐	**S** ☐	**S** ☐	**S** ☐	**S** ☐
	2	**N** ☐	**N** ☐	**N** ☐	**N** ☐	**N** ☐	**N** ☐	**N** ☐	**N** ☐

Obrigada!

Appendix F| KAP survey (English)

KAP

GPS - Lat: **Long:**

Code:

1.1	**Name of community:** ______________________
1.2	**Full name of respondent:**____________________________________
1.3	**Sex:** M☐ F☐
1.4	**Date of birth:** ___/___/_____

1) Have you heard of respiratory diseases?
2) How do you define respiratory diseases?
3) How do you acquire a respiratory disease?
4) What are the signs and symptoms of respiratory diseases?
5) In your family, who is more vulnerable to developing a respiratory disease?
6) In your opinion, what is the principal cause of respiratory diseases?
7) Can respiratory diseases be cured?
8) Does treatment exist for respiratory diseases? If yes, what are they?
9) What can a person do to reduce their risk of developing a respiratory disease?
10) How much does treatment cost?
11) In your opinion, are respiratory diseases a serious type of disease?
12) Do you consider respiratory diseases a serious problem in Brazil? In the Legal Amazon?
13) If you don’t have a respiratory disease, do you think you can develop one?
14) What is your level of concern for respiratory diseases? Score between 0 and 10.
15) What do you think of a person who has a respiratory disease?

16) If you don't have a respiratory disease, if you were told you developed one, how would you react?

17) If you have a respiratory disease, how did you react when you were told?

18) If you develop a respiratory illness, how do you think your daily activities would be affected?

19) If you have a respiratory disease, how does it affect your daily activities?

20) Do you have confidence in the medical staff or health centre to seek treatment for respiratory diseases?

    ☐ Yes

    ☐ No, why?

Appendix G| KAP survey (Portuguese)

CAP

GPS - Lat: **Long:**

Código:

1.1	**Nome da comunidade: ______________________**
1.2	**Nome completo do entrevistado:_____________________________________**
1.3	**Sexo:** M☐ F☐
1.4	**Data de nascimento: ___/___/____**

1) Você já ouviu falar de doenças respiratórias?
2) Como você define as doenças respiratórias?
3) Como você adquire doenças respiratórias?

4) Quais são os sinais e sintomas de doenças respiratórias?

5) Na sua família quem é mais vulnerável a ter doenças respiratórias?

6) Na sua opinião, qual e a principal causa de doenças respiratórias?

7) As doenças respiratórias tem cura?

8) Existem tratamentos para doenças respiratórias? Se sim, quais você conhece?

9) O que uma pessoa pode fazer para reduzir o risco as doenças respiratórias?

10) Quanto você acha que custa o tratamento de doenças respiratórias no Brasil? Na Amazônia?

11) Na sua opinião, a doenças respiratórias é uma doença grave?

12) Você considera as doenças respiratórias um problema sério no Brasil? E na Amazônia?

13) Se você não tem uma doenças respiratórias, você acha que pode ter?

14) Qual é a sua preocupação quanto as doenças respiratórias? De uma nota de 0 a 10.

15) O que você pensa sobre uma pessoa que tem as doenças respiratórias?

16) Se você não tem uma doenças respiratórias, qual seria sua reação se lhe dissessem que você têm asma?

17) Se você tem uma doenças respiratórias, qual foi sua reação quando descobriu?

18) Se você vir a ter uma doenças respiratórias, como você acha que suas atividades diárias seriam afetadas?

19) Se você tem uma doenças respiratórias, quando descobriu? Como as doenças respiratórias poderia afetar suas atividades diárias? Depois de conviver com as doenças respiratórias, como realmente ela afetou suas atividades diárias?

20) Você sente confiança na equipe medica ou centro de saúde para procurar tratamento para doenças respiratórias?

    a. Sim

    b. Não, porque?

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