Modelling the Combinatory Impact of Stressors on Mountain Communities

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Abstract

Rural mountain communities in developing and transitioning countries are experiencing a period of rapid social, economic, and environmental change. While change has long been a feature of mountain life, the rate, magnitude, nature, and number of the transformations now taking place is unprecedented. These processes will have profound implications for the sustainability and welfare of mountain communities in the coming years. It is therefore important that their potential effects be understood. Considering stressors in isolation can give a false picture as each stressor alters the context within which the other stressors are operating. Holistic approaches are therefore needed. In this thesis, a method for doing this in a systematic, quantitative fashion is developed. The approach combines ethnographic fieldwork with agent-based modelling and is applied to a specific case study – a rural Nepalese mountain village that is experiencing stressors typical of many other mountain communities. The model that is developed incorporates the main social and ecological systems that were found at the fieldsite and it is populated with virtual villagers that are designed to behave in ways that closely mimic how real villagers behave. Stressor scenarios relating to changing fertility rates, increasing crop yield variability, and the occurrence of natural hazards are concurrently simulated within the model and their impact on household finances and village demographics is observed over a period of fifteen years. The results show that higher fertility rates, increased crop yield variability, and earthquakes all have negative long-term effects on household finances, and that each of these stressors compounds the effect of the other stressors. The results also highlight heterogeneity in the capacity of households to cope with stressors and demonstrate the important role that happenstance can play in exacerbating the effect of stressors and shocks. Substantial seasonal variation in the financial vulnerability of households is also revealed.

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List of Acronyms and Abbreviations

ABM	Agent-based model
Nepal SIM	Nepal Stressor Interaction Model
NPR	Nepalese Rupees
OAT	One-parameter-at-a-time
SA	Sensitivity analysis

Chapter 1: Introduction

Thesis rationale | Aims & objectives | The fieldsite | Definition of terms and concepts | Thesis roadmap

1.1 Thesis rationale

In 2015, the United Nations estimated that thirteen percent of the world's population were residing in mountainous areas (FAO, 2015). The vast majority of these people lived in rural communities in developing or transitioning countries. Today, many of these communities are experiencing a period of rapid social, economic, and environmental change. While change has long been a familiar feature of mountain life, the rate, magnitude, nature, and number of transformations now taking place is unprecedented. Many areas have seen dramatic population growth, increased pressure on land and resources, changes to the climate, large scale emigration of young people, increased inflow of remittances, improved connectivity and service provision, and a growing penetration of capitalism with a consequent reorientation of agricultural economies (Parish, 2002; Körner *et al*., 2005). Alongside these trends, communities must also continue to deal with age-old challenges like pests, diseases, and natural hazards. Together, these factors undoubtedly have profound implications for the sustainability and welfare of mountain communities in the coming years, but at present our understanding of exactly what these implications may be is limited.

The multifarious and parallel nature of the processes – or stressors as they are commonly termed in the literature – poses a particular challenge to researchers. Studying stressors in isolation, as is the typical approach of reductionist methods and disciplinary academia, can give a false picture. Each stressor alters the context within which the other stressors are operating and, moreover, stressors can interact in nonlinear ways, fundamentally changing the nature of the stressors from what they would be when operating alone (O'Brien and Leichenko, 2000; Crain *et al.*, 2008; O'Brien *et al.*, 2009; Olsson *et al.*, 2014). This means that the cumulative effect of multiple stressors is rarely equal to the sum of the parts. For policy formulation, development planning, and local decision making, this has important implications. If stressors are considered independently of one another, erroneous conclusions may be drawn, potentially leading to sub-optimal, redundant, or even conflicting responses and a lack of policy coherence (Schipper and Pelling, 2006). Consequently, there is a clear need for a holistic approach to the study of multiple stressor contexts.

In the last twenty years a nascent body of literature has emerged that explicitly considers the impact of multiple stressors on socio-ecological systems – much of this literature emanating from the climate change, development, vulnerability, and resilience research fields (O'Brien and Leichenko, 2000; Reid and Vogel, 2006; Schipper and Pelling, 2006; Tschakert, 2007; Eriksen and Silva, 2009; Eakin and Wehbe, 2009; Casale et al., 2010; Eakin et al., 2014; Olsson et al., 2014; Martin et al., 2016; Antwi-Agyei et al., 2017). This wide-ranging body of work has produced a number of valuable insights, but it has tended to focus on past and present stressor contexts. The focus of this thesis, in contrast, is on how multiple stressors could affect mountain communities in the long-term – specifically, in the period up to 2030. Having a clear sense of the potential challenges and opportunities ahead is important because it enables stakeholders to more effectively plan for the future and could help them avoid maladaptive steps. The focus on the period up to 2030 is roughly in line with such planning horizons.

Focusing on future stressors requires a somewhat different methodological approach to those that have typically been used in multiple stressor research so far – an approach that can explore the effect of a range of hypothetical stressor scenarios. Agent-based modelling, which is naturally suited to the study of socio-ecological systems, is capable of doing precisely this. Because agent-based models excel at simulating the interaction and co-evolution of multiple components and processes – such as those that make up socio-ecological systems – they can elucidate complex causal pathways and capture the emergent nature of macro-level patterns in a way that few other methods can. In particular, they are ideal for examining inter-scale dynamics which have often been neglected in stressor research (Burnham *et al.*, 2018). They also have the major advantage of being able to account for the heterogeneity of agents and they are able to represent sophisticated behavioural strategies and adaptive capabilities. In socio-ecological systems research, these things are now understood to be extremely important, but they have historically been neglected in models (Miller and Page, 2009; Schlüter *et al*., 2015). A further benefit is that agent-based models can be used as *in silico* labs for controlled experiments. This is something that is rarely available to social scientists who tend to be reliant on real-world data or theory. All of these strengths are exploited in this study.

1.2 Aim and Objectives

The overarching aim of this research is to understand the potential impact of multiple stressors on mountain areas in the period up to 2030. In order to do this, an agent-based model has been designed based on data gathered in a village in Nepal. The model incorporates all of the main social and ecological systems that are found at the project fieldsite and it is populated with artificially intelligent agents designed to behave in ways that, as closely as possible, match how real villagers behave – interacting with their environment and one another, making decisions based on their beliefs and needs, and learning from experience. Within this model I am able to simulate various stressor scenarios representing potential future economic, social, and climatic pathways. The impact of these scenarios on the virtual villagers can then be assessed. These experiments allow the identification of antagonistic, additive, and synergistic processes in stressor interactions, help in locating system vulnerabilities, and provide insights into resilience, coping, and recovery in mountain communities.

The aim discussed above is achieved through a series of objectives which are as follows:

1. To identify the main stressors and drivers of change in mountain areas, both in Nepal and elsewhere around the world. This is necessary in order to understand the stressor landscape that many mountain communities face and to provide context on which the thesis can build.
2. To develop an empirically informed agent-based model of a rural Nepalese mountain village into which various stressor scenarios can be concurrently simulated. This allows the impact of multiple stressors on individuals and households to be examined in a systematic, process-oriented way, ultimately identifying critical vulnerabilities and risk trigger-points that will be useful in guiding the design of adaptation and preparedness strategies.
3. To conduct simulation runs for a number of future stressor scenarios for the period 2015-2030, examining the impacts on village demographics and household finances. In particular, the following questions are addressed:
    a. How do the various stressor scenarios affect the financial trajectory of households and the demographic trajectory of the village?
    b. To what extent does the impact that a stressor has on household finances depend on the context in which it occurs?
    c. What are the main attributes that determine the capacity of households to financially cope with stressors?
4. To critically reflect on the utility of the agent-based modelling approach that is outlined in this thesis as a tool for researchers in the development field.

1.3 The Fieldsite

Nepal was chosen as the location for the study because the country's hills and mountains are an example *par excellence* of an area experiencing multiple stressors and undergoing rapid change. During initial fieldwork in 2014 I sought out a village upon which I could base the model (see *Chapter 4*). The main criteria for selection were that the community was open to helping with the study and that the village was reasonably representative of the country at large and other mountainous regions in respect to the challenges it was facing. After visiting locations in the Mid-Western, Western, and Central Regions of Nepal, a site was settled on that lay several hours north-east of Kathmandu in the mountain district of Dolakha. It is referred to in this thesis by the pseudonym name, Namsa.

Figure 1.1. The chosen fieldsite in Dolakha district pictured in April 2015, shortly before the earthquake. The village encompasses homes in both the foreground and the background as well as homes lower down the slopes (Source: Author).

Livelihoods in the village, as is typical of the region, are primarily based around agro-pastoral activities, with each household owning its own smallholding and producing output for both home consumption and sale. As became apparent during a scoping trip, recent decades have seen a rise in population, the construction of a nearby road, improved access to schools and medical services, and a progressive incorporation into Nepal's monetary economy. This latter trend is manifest in an increase in the amount of off-farm paid labouring that is being done and a steady shift towards the growing of cash, rather than subsistence, crops. More recently, there has been an intensification in cash crop cultivation within certain households, along with a rise in the number of young adults – particularly men – who have sought work elsewhere in the country or in the Gulf where huge numbers of Nepalese are now employed (Pattisson, 2013). There has also been a substantial reduction in the fertility rate with many young people now desiring small families in the hope it will help them maximise their children's life chances (MHP, 2012a). Though not yet strongly pronounced, there has also been a notable change in the local climate, with snow and frosts increasingly infrequent during the winter months despite the village lying at 2,000 meters above sea level (DHM, 2015). Unbeknownst during data collection in early 2015, the village was soon to feel the effects of another powerful force – one that is no stranger to mountain areas, but which was nonetheless unusual in its strength. On the 25 April 2015, the community experienced the 7.8Mw earthquake that struck a large swathe of the country, and over the coming days and weeks they felt the effects of numerous aftershocks (NCEI, 2017). The tremors caused severe damage to the dwellings, razing a number of them. The process of rebuilding is likely to take years, thus the landscape of stressors, shocks, and change the community faces has now taken on a new complexion.

In the model simulations, particular heed is paid to the potential effects of increasing crop variability, declining fertility rates, and the 2015 earthquakes. It is recognised that these stressors are by no means being universally experienced by mountain communities, and that they are not exhaustive of the challenges mountain populations face. Furthermore, it is understood that the particularities of how stressors and transitions play out will differ by context. Nonetheless, many of the insights that the model provides will likely be highly pertinent to other mountain communities. Despite their diversity, mountainous areas and their people often share similar characteristics and adaptive strategies, and the processes and trends they face are often variations on similar themes (Brush, 1976; Parish, 2002).

1.4 Definition of key terms and concepts used in the thesis

A number of terms and concepts are referred to within this thesis, some of which are imbued with different meaning by different authors. For clarity, the meaning of the terms and concepts as they are used in this thesis, are outlined below.

Stressors: Processes and events that cause stress to systems by affecting their structure or functioning (Whittow, 2000). They are distinguished from shocks by having a degree of longevity.

Shocks: Short-term events that cause stress to systems by affecting their structure or functioning, or sudden shifts to new system states potentially catalysed by more gradual changes (Filatova and Polhill, 2012).

Coping capacity: Ability to manage and/or overcome adverse circumstances (Scheuer *et al.*, 2011).

Adaptive capacity: Ability to adjust in order to cope with or exploit changes in circumstance (O'Brien *et al*., 2004; Adger, 2006).

Sensitivity: Degree to which a system or agent will respond to or be affected by a stressor, shock, or change (O'Brien *et al*., 2004).

Exposure: Degree of stress experienced by a particular unit of analysis (O'Brien *et al*., 2004).

Resilience: Capacity of a system or entity to cope with disturbances and adapt to emerging circumstances while preserving essential functions and structure (Carpenter *et al*., 2001; Burkett *et al*., 2014).

Vulnerability: Degree to which a system or entity is susceptible to, and unable to cope with, stressors or shocks (Adger, 2006). The IPCC suggest that this is a function of adaptive capacity, sensitivity, and exposure (Olsson *et al.*, 2014).

1.5 Thesis Roadmap

Chapter 1 has provided a short overview of the background context and focus of the thesis. *Chapter 2* situates the research within its theoretical context, firstly by examining the literature on socio-ecological stressors and shocks, and then by considering past work on multiple stressors. While doing so, the limitations of this past research are discussed. The chapter concludes by outlining the case for using agent-based modelling to assess the potential implications of future stressor scenarios for mountain communities.

Chapter 3 begins by considering the socio-ecological characteristics and geography of mountain systems, with particular reference to Nepal where the study fieldsite is located. Following this, the history of mountain communities and environments as a subject of intellectual enquiry is explored. The main stressors, shocks, and drivers of change that are affecting mountain systems in the developing world are then identified. Once again, particular attention is paid to the Nepalese experience. The goal is to provide background to the particularities of the fieldsite setting, to acknowledge geographical variability, and to give a sense of the different scales at which change is occurring.

Chapter 4 provides details of the fieldsite selection, data collection, and data analysis processes. It begins with an explanation of the fieldsite selection criteria and an overview of the shortlisted locations, before explaining the merits of the chosen village. Next, the various data collection methods are set out along with the rationale for using them. Finally, the approach taken to analysing the data and to dealing with uncertainty, error, positionality, and ethics is discussed.

Chapter 5 provides an ethnography of the fieldsite and provides a descriptive analysis of the data used to inform the design and parameterisation of the model. It covers a wide range of topics including community history, demographics, culture, livelihoods, and decision making. Furthermore, it explores the community's experiences of stressors, shocks, and change.

Chapter 6 presents the agent-based model of the village. Following a recap of its purpose, the entities, state variables, processes, and scheduling are explained. The stressor scenarios that are simulated are also outlined, as is the rationale for their selection and design. The chapter concludes with details of the calibration process, a discussion of the necessary number of simulation runs, details of the validation, and an analysis of the model's sensitivity to key groups of parameters.

Chapter 7 details the outcomes of the scenario simulations. Specifically, it presents data on the impact of the stressor scenarios on the financial and demographic trajectory of individual households and the village as a whole, as well as data showing the role of contextual factors and household attributes in shaping outcomes. This multi-scale approach to studying impacts allows for a more nuanced understanding of how stressors affect communities and helps with identifying heterogeneity in household experiences. The findings and the utility of the agent-based modelling approach that was used are then discussed in *Chapter 8*. In particular, their implications for mountain communities are considered.

The final chapter, *Chapter 9*, offers some concluding remarks on the research as a whole, both in respect to the subject of the research and the agent-based modelling methodology. In doing so, it highlights some of the conceptual and practical contributions the research has made, flags the limitations and uncertainties that remain, and provides a number of suggestions for future research.

1.6 Concluding remarks

To summarise, the thesis seeks to improve our understanding of how multiple stressors could affect mountain areas over the coming years. This is important given the multifarious and powerful nature of the stressors that many mountain communities are currently facing, and the significant uncertainties that currently surround their potential trajectories and interplay. Particular attention is paid to a case study in the Nepalese Himalaya, although many of the findings are likely to be applicable to developing world mountain systems more broadly. The fieldsite in Nepal is recreated in virtual form using data gathered during fieldwork. Into this virtual model, different future stressor scenarios are then simulated, and their impacts observed at high temporal resolution and at multiple scales. This approach is innovative in the context of the multiple stressors literature yet offers a number of valuable and unique insights. Ultimately the knowledge gleaned should be useful to both mountain communities and development practitioners in planning for the future.

Chapter 2: Stressors & Change in Socio-Ecological Systems

The study of socio-ecological stressors & transitions | Multiple stressors | Socio-ecological agent-based modelling

The conceptual focus of this thesis is on the impact of multiple stressors on socio-ecological systems, with mountain systems as a case study. This chapter reviews the literature on socio-ecological systems, discussing the meaning of the term, the relative merits of viewing human-environment relationships through the socio-ecological systems lens, and reflecting on how mountain systems can be conceptualized in that fashion. It also examines the idea of stressors, shocks, and change in socio-ecological systems, and relates this to the literature on adaptation, vulnerability, and resilience. Next, the concept of multiple stressors is examined, along with past research on the topic. The weaknesses and limitations of some of these past studies is flagged and the case for taking an agent-based modelling approach to exploring the potential impact of multiple stressors over the next decade or so is made.

2.1 The study of socio-ecological stressors and change

The concept of socio-ecological systems is based on the idea that humanity and the environment are fundamentally entwined such that any "delineation between social and ecological systems is artificial and arbitrary" (Folke, 2006, pp.261–262). It recognises that many social and environmental dynamics cannot be truly understood without bridging the chimerical domains, the implication being that the linkages and feedbacks that are present between social and ecological systems need to be paid greater heed than they have traditionally been afforded (Stringer *et al.*, 2014). One of the main drivers behind the shift towards socio-ecological systems thinking has been the rise of complex adaptive systems theory – a school of thought that recognises the connected and dynamic nature of the world (Filatova *et al.*, 2013). The traditional reductionist approaches that have been predominant in mainstream science are based on the "methodological presumption that complex phenomena or events can be explained by their reduction to simpler, more fundamental entities" (Barnes, 2009, p.626). In contrast, the complex adaptive systems paradigm is based on the idea that "the system as a whole determines how its parts behave" (Barnes, 2009, p.627). It maintains that system context matters, that interactions between components can give rise to emergent properties, and that not all phenomena are divisible. Given this, complexity scientists would argue that dividing a problem into its most basic constituents' risks divorcing the science from the world it is trying to understand (Waldrop, 1993).

With its emphasis on emergence, connectedness, feedbacks, non-linearities, co-evolution, path dependence, and multiple-equilibria, complex adaptive systems theory helps to highlight the creative, organic, and perpetually novel nature of socio-ecological systems (Waldrop, 1993; Folke, 2006; Filatova *et al.*, 2016). This is important when it comes to thinking about stressors and change because sustainability in the sense of preservation ceases to make sense; transition becomes a problematic concept as equilibria are multiple, short-lasting and rarely attainable; limitations of human understanding, prediction and control become much more apparent; and individual stressors are put in perspective against the multitude of other perturbations that systems face (Brinsmead and Hooker, 2011). Another important aspect of complexity science that is of relevance is the attention it gives to the interaction of individual agents with each other and with their environment. While reductionism has often led to the complexity of human behaviour being reduced to a single fundamental cause – most commonly rational choice – complexity has drawn on behavioural economics and psychology in an effort to more accurately understand its nuances (Barnes, 2009 p.626). Bounded rationality, cognitive biases, competing desires, and learning are given greater prominence which has implications for questions of adaptation in a changing environment. Also valuable, particularly in socio-ecological systems research, is the emphasis placed on understanding interactions and feedbacks across scales (Folke, 2006; Filatova and Polhill, 2012; Stringer *et al*., 2018). As Stringer *et al*. (2018) argue, these interactions and feedbacks can have "important implications for understanding who wins and loses out from different decisions and how social and ecological risks and trade-offs are shared and distributed, temporally and spatially."

Socio-ecological systems thinking has been applied to the study of a wide range of systems, including drylands (e.g. Stringer *et al*., 2017; Dressler *et al*., 2019), tropical areas (e.g. Acosta-Michlik and Espaldon, 2008; Naivinit *et al*., 2010; Gonzalez-Redin *et al*., 2019), and mountains (e.g. Pérez *et al*., 2006; Gardner and Dekens, 2007; Gentle and Maraseni, 2012). Conceptualised as socio-ecological systems, mountains systems – which are the focus of this thesis – are no longer merely defined by their quintessential topographic and ecological characteristics, but also by the people who reside in them, and the human-environment relations that have shaped them over millennia. The influence of people on the environment is emphasised, as is the influence of the environment on people. For example, many mountain communities are recognised as having had to adapt to (or at least cope with) the steep slopes, poor soils, and climatic variability that are often characteristic of upland environments (Dasgupta *et al*., 2014). This has been done through innovative farming practices such as terracing, and through risk management strategies such as engaging in pluri-activity livelihoods and seasonal migration (Funnell and Parish, 2001). At the same time, humans have profoundly influenced mountain environments by changing land-cover, disrupting hydrological systems, re-shaping terrain, bringing in new species of flora and fauna, and altering climatic regimes, to name but a few things (Anderies and Janssen, 2011). Consequently, neither mountain communities, nor contemporary mountain environments can be truly understood without reference to one another. Importantly, mountain systems should not be viewed as separate from the wider world, either. This fact is most clearly exemplified by the global integration of mountain climates, markets, culture, and politics. For example, mountain agriculture and food markets in many places were long ago assimilated into supply chains and markets at national, regional, and international scales (Stringer *et al*., 2018). Globalisation is likely to erode the distinctions between systems ever more in the comings years (Anderies and Janssen, 2011). In *Chapter 3*, I discuss the nature of mountain socio-ecological systems in more depth and I examine the ways in which fuzzification of mountain system boundaries is exposing mountain communities to new and increasingly intense exogenous forces.

In terms of operationalising studies of socio-ecological systems, a number of research approaches and tools have been applied – many of them having their origins outside of the complexity field, and often drawing upon aspects of one another. Among the most prominent are institutional approaches (Ostrom, 2000; Ostrom, 2010), resilience approaches (Folke, 2006), vulnerability approaches (Adger, 2006), and nexus approaches (Bazilian *et al*., 2011). More recently, these have been added to by Stringer *et al*. (2018) who proposed a hybrid of the resilience and nexus approaches in order to address the weaknesses that have been highlighted in both. In this thesis, however, I stick closer to the complexity approach that influenced the initial development of socio-ecological systems thinking. Specifically, I employ agent-based modelling to simulate a smallholder community exposed to multiple stressors. The approach, which is discussed in more depth in section *2.3*, is ideal for examining relationships between entities and processes at multiple scales, and for exploring how future-looking scenarios might play out.

While the existing literature on socio-ecological systems has provided a wide range of useful insights, there are certain weaknesses that merit addressing. Firstly, many studies remain limited in the extent to which they have integrated different sub-systems within their thinking. As a result of how topics are framed, there is a tendency to focus on a subset of processes and entities to the neglect of others. This may be reasonable to do in some instances, but the lack of broader integration can lead to unexpectedly important connections and feedbacks being missed. Nexus studies, for example, typically focus on water, food, and energy (Bazilian *et al*., 2011), while paying only limited attention to topics such as demographics. When demographics are considered, the focus is usually on population growth, yet changes in the likes of population structures can conceivably also have a big influence. Furthermore, the relatively focused nature of the framing can narrow down the kind of stressors, shocks, and change that are considered, again leading to studies potentially having significant blind spots. As discussed later in section *2.3*, agent-based modelling approaches are ideally suited to redressing this as they are capable of integrating a wide range of entities and processes. Indeed, many of the models that are discussed in section *2.3* demonstrate this.

A second issue is the tendency in certain studies to think about socio-ecological systems at a scale and a degree of abstraction that is divorced from people's lived realities. While there is a clear need for high level analyses, translating findings into practical, operable recommendations is often easier to do when the focus is on a more local scale and when studies take a more naturalistic approach. Given the often-limited capacity of governmental actors to pursue policy recommendations, there is a strong case for focusing on potential bottom-up, autonomous actions – something that local level studies are better suited to identifying. Vulnerability and agent-based modelling approaches are particularly strong in this regard as they often focus on individual and household levels (Anderies and Janssen, 2011). The discussion in *Chapter 8* bears witness to this.

A third issue is that overly narrow interpretations of theoretical framings can lead to over-emphasis of certain processes, and under-emphasis of others. Similarly, such interpretations can result in the cherry-picking or unmerited idealisation of case studies. Notable in some of the literature is a surprisingly straightforward adherence of case studies to theories, and a surprising lack of muddy waters. In this project, I have taken a more pragmatic approach – more in line with ethnographic traditions – by letting fieldwork findings and mountain stressors literature largely shape the course of the research and modelling, rather than having it led by pre-prescribed theories. This has certain parallels with the grounded theory approach that is advocated by Glaser and Strauss (2000).

2.1.1 Stressors, shocks and change

In this thesis, I consider the potential impact that stressors, shocks, and long-term trends may have on mountain communities in the period up to 2030. In the context of this thesis, stressors are defined as processes and events that cause stress to systems by affecting their structure or functioning (Whittow, 2000). They are distinguished from shocks by having a degree of longevity. While stressors tend to be thought of as being detrimental in nature, this is not always the case. For starters, what is detrimental to one group of people or entities may not be detrimental to another group (Piggott, 2013). Indeed, O'Brien and Leichenko (2003) note that processes of change often result in both winners and losers – globalisation is a good example of this. Secondly, the impact of a stressor can follow a subsidy-stress gradient (Piggott, 2013). This essentially means that it can be beneficial (or inconsequential) when operating within a certain range, but it can become harmful when this range is exceeded. Viewed this way, a wide range of processes can be thought of as stressors even if the label is not necessarily applied to them in normal circumstances. In this thesis, for example, I simulate the effect of falling fertility rates, viewing it as a potential stressor even though it is not among the standard lexicon of stressors. I also simulate increased crop yield variability – something that might be considered less ambiguous in its stressor credentials.

Shocks, meanwhile, can be defined as either short-term events that cause stress to systems by affecting their structure or functioning, or as sudden shifts to new system states (Filatova and Polhill, 2012). Examples of the former, which are known as shocking events or disturbances, include hazard events such as floods and earthquakes, and socio-economic events like general strikes and commodity price increases. Often systems will recover back to their approximate initial state following such events, but occasionally systems will shift to a new state characterised by a changed structure, function, and properties. In such cases, the event is called a systemic shock (Filatova and Polhill, 2012). While systemic shocks are often triggered by specific events or sequences of events, they can also result from gradual changes in system components, "which prior to the critical point at which the shock occurred had not caused the system state to change" (Filatova and Polhill, 2012, p.2). In this thesis I simulate the effects of the 2015 Nepal earthquake – a classic example of a shock event, and one which had the potential to cause systemic change.

As discussed in *Chapter 3*, mountain communities have always lived with stressors and shocks. As with all human populations, they have had to endure and adapt to a range of perturbations, and they have become well-tuned to certain disturbance regimes (Ostrom, 1990). This is illustrated by the existence of time-honoured coping tactics and risk reduction strategies. The former includes increasing the amount of off-farm labouring that is engaged in during times of need, and decreasing food consumption and non-food expenditures (Porter *et al.*, 2014). The latter include the pursuit of pluri-activity livelihoods. Mountain communities have also modified their ways of life from time to time in order to accommodate new conditions (Fricke, 1993). However, climate change and other contemporary forcings are now exposing communities to disturbances that are unprecedented in nature and number (Fricke, 1993; Anderies and Janssen, 2011). The pace at which socio-ecological systems are now changing is also posing a significant challenge and leading to the emergence of new fragilities (Anderies and Janssen, 2011). The consequences of these stressors, shocks, and processes of change vary from place to place, and from person to person. As Olsson *et al*. (2014) note, "who is affected, how, where, and for how long depends on local contexts." Understanding of impacts also varies by the scale considered. Indeed, there are both spatial and temporal dimensions to how stressors and shocks play out (Olsson *et al.*, 2014). Some have long-term implications, while others are more temporally contained. Some have widespread impacts, while others are localised. Furthermore, impacts can be amplified or weakened at different levels, mediated by cross-level institutions and processes (Thomas *et al.*, 2007). A number of these themes are explored in the coming chapters.

How stressors and shocks are understood in the literature is shaped in large part by the lens through which they are viewed. Adaptation, vulnerability, and resilience are among the most commonly applied concepts. While they have similarities to one another, they emphasise slightly different things and they have their own intellectual histories (Janssen and Ostrom, 2006). Adaptation refers to adjustments in socio-ecological systems in response to actual, perceived, or expected stressors, shocks, and changes (Janssen and Ostrom, 2006). The concept has its scholarly roots in the field of anthropology, but in recent decades it has gained fresh impetus through the complexity and climate change literatures

(Levin, 1998; Adger *et al*., 2005). Common themes within adaptation debates include the efficacy of reactive and planned adaptations, socio-ecological constraints on adaptation options, the agency that different actors have in determining responses, the sufficiency of current adaptations in the context of socio-ecological change, and various other barriers and limits to adaptation (Porter *et al.*, 2014; Dasgupta *et al.*, 2014; Burnham *et al.*, 2018). Importantly, in the context of smallholder communities, adaptation is seen as a continuous process of deliberation and action (Fricke, 1993), and it is recognised that adaptations will not necessarily mitigate the impact of stressors and shocks in full (Porter *et al*., 2014). Nevertheless, the concept emphasises that people are not passive actors in a changing and challenging world – something that is highlighted again and again in the coming chapters.

In contrast to the adaptation concept, vulnerability thinking has its roots in natural hazard and poverty research (Janssen and Ostrom, 2006). It is generally defined as susceptibility to be harmed by stressors, shocks, or changes – something that is seen as a function of exposure, sensitivity, and adaptive capacity (Adger, 2006). Particular emphasis tends to be placed on understanding the attributes that increase or decrease agent vulnerability to particular types of stressors or combinations of stressors (Benson and Clay, 2004). However, a new current of work is also paying heed to the ways in which vulnerability can vary temporally (Olsson *et al.*, 2014; Fawcett *et al.*, 2017). Both of these things are explored in *Chapter 8* of this thesis in relation to the project fieldsite. In the vulnerability literature, it is commonly recognised that smallholders can be especially vulnerable to stressors, shocks, and change because their livelihoods are particularly exposed to climatic and market variability, and to global environmental and economic change (Anderies and Janssen, 2011). Furthermore, smallholder communities are often relatively poor so they have little buffer to face stressors and shocks with (Olsson *et al.*, 2014). This means that even small disturbances can have dramatic social consequences (Folke, 2006). Socio-cultural shifts have also affected smallholder sensitivity and adaptive capacity but in both positive and negative ways. As vulnerability is experienced locally, vulnerability studies have tended to focus on the individual and household level, in contrast to adaptation research which tends to focus on higher levels (Anderies and Janssen, 2011). That said, the causes of vulnerability often have their origins at different geographic and temporal scales (Dasgupta *et al*., 2014).

Resilience refers to the capacity of systems to cope with shocks, stressors, and other forcings while maintaining essential functions, structures, and identities, and while allowing for continued adaptation and learning (Stringer *et al*., 2018). Should present system states not be able to withstand forcings, resilience theories suggest that a transition to a new system state will occur (Holling, 2001). This process may well involve the reconfiguration and renewal of system structures and processes, and the crossing onto new trajectories (Folke, 2006; Sterk *et al*., 2017). Thus, disturbances are seen not merely as destructive, but as having "the potential to create opportunity for doing new things, for innovation and for development" (Folke, 2006, pp.253–254). The resilience concept has its origins in ecology where it was initially used to explain ecosystem dynamics, but it began to be used in the study of human-environment interactions during the 1980s (Janssen and Ostrom, 2006). Since then, resilience perspectives have become commonplace in socio-ecological system discourses (Bamutaze, 2015). In the process, they have provided a wide range of insights, helping to shift thinking from controlling systems to managing them, revealing the processes that lead to episodic change, and highlighting the potential for alternative metastable regimes (Folke, 2006; Anderies and Janssen, 2011). The resilience concept has also been used to understand how communities cope with and adapt to stressors like climate change and the factors that shape smallholder resilience have been explored (Dasgupta *et al*., 2014). The main criticism of resilience approaches is that they tend to focus on a single scale and they are often systems-oriented (Allen *et al*., 2014). This means that they are prone to neglecting cross-scale dynamics and they can overlook the existence of "winners and losers" – something that vulnerability approaches excel at (Stringer *et al*., 2018). As Adger (2006) notes, the points of convergence between the concepts of adaptation, vulnerability, and resilience are more numerous and fundamental than the points of divergence. However, the differences are meaningful. Each approach offers a slightly different perspective on the impact that stressors, shocks, and processes of change have on socio-ecological systems. Studies that consider a problem from only one of these perspectives risk having certain blind spots. Through the agent-based modelling methodology that I use in this thesis, I am able to draw on aspects of all three, exploiting their respective strengths. That said, the thesis draws much more on the vulnerability, complexity, and ethnographic traditions, than it does on adaptation and resilience thinking due to the nature of the research questions.

2.2 Multiple Stressors

Throughout the academic literature there has long been a tendency for stressors, shocks, and processes of change to be studied in relative isolation from one another (O'Brien *et al.*, 2004; Reid and Vogel, 2006). This compartmentalisation can be troublesome for several reasons. Firstly, it makes it difficult to judge the relative impact and importance of different processes (Nielsen and Reenberg, 2010). Secondly, it can result in certain processes being ignored altogether when they do not fit policy or research agendas. And thirdly, it means that important linkages, feedbacks, and synergies between processes, outcomes, and responses often go un-noticed or under-studied (Leichenko and O'Brien, 2008).

Critiques of compartmentalisation – along with growing recognition of the multifarious nature of the changes and challenges that many communities now face – has led to calls for a more holistic perspective to be taken to the study of stressor dynamics. The result has been the emergence of a sub-field of research that focuses explicitly on how communities are affected by multiple stressors – a concept that refers to instances where two or more stressors or shocks occur simultaneously or in sequence (O'Brien and Leichenko, 2000; O'Brien *et al.*, 2004; McDowell and Hess, 2012; McCubbin *et al.*, 2015). The multiple stressors literature highlights the importance of context for understanding how processes, outcomes, and responses play out. Critically, it also recognises that the processes themselves contribute to the continual transformation of this context (Leichenko and O'Brien, 2008). This two-way feedback between processes and context means that all processes tend to interact to some degree and in doing so they can potentially amplify, mitigate, or transmute the impact of one another (O'Brien *et al.*, 2004; O'Brien *et al.*, 2009).

The origin of the multiple stressors literature can be traced back to a seminal paper by O'Brien and Leichenko (2000) that sought to examine the consequences of "double exposure" to climate change and globalisation. Recognising that the processes are rarely considered together despite operating concurrently, the authors proposed a framework for identifying "double winners," "double losers," and instances where one process offsets the impacts of the other. The framework was subsequently operationalised in O'Brien *et al*. (2004) to identify agricultural areas in India that were jointly vulnerable to the two processes. This was done through the development of sub-national level climate change and globalisation vulnerability metrics which were superimposed onto a map of India so that the areas highly vulnerable to both processes could be identified. Case studies were then performed to ground truth the approach and to give descriptive context to the metrics. Notably, the authors did not attempt to survey the causal linkages between the processes in these papers, but they did provide a foundation upon which the subsequent literature could build.

Many of the multiple stressor papers that have followed O'Brien *et al*. (2004) have also focused on agrarian communities in developing countries. Often, however, the area under consideration has been rather more local in scale. Reid and Vogel (2006), for example, used the sustainable livelihoods framework to assess stressors that communities are vulnerable to in an eastern province of South Africa. In particular, they identified climate change, poor agricultural extension, health problems, and poor governance as important issues. Nielsen and Reenberg (2010), meanwhile, employed human-environmental timelines in an effort to identify how exposure to a variety of stressors has influenced livelihood decision-making in a village in northern Burkina Faso since the 1950s. They argued that the choice of present day livelihood strategies may "be best understood by looking at co-evolution of different driving forces over time" (Nielsen and Reenberg, 2010, p.472). Notably, their analysis demonstrates that factors can change in relative importance with time. It also suggests that climate change and climate variability are not necessarily the lead challenges that the community faces at present, despite climate issues currently dominating the region's stressor literature. A similar point is made in a paper by McCubbin *et al*. (2015) who looked at the vulnerability of a Tuvalu atoll to multiple stressors. The authors found that a number of non-climatic stressors were typically considered more immediately pertinent to respondent's lives than climate change despite Tuvalu now being synonymous with the latter issue. The findings in this thesis point to this being the case in Nepal as well (see *Chapter 8*). Besides this, McCubbin *et al.* (2015, p.53) also note the importance of history in influencing current circumstances, stating that "climate change vulnerability is deeply interwoven in the historical, socioeconomic, and cultural fabric of communities" – something that is in keeping with the arguments of Nielsen and Reenberg (2010). A more recent study by Yiran *et al.* (2017), assessed vulnerability to multiple hazards in savannah ecosystems within Ghana. The authors used a mapping approach similar to that of O'Brien *et al.* (2004), but they incorporated a much wider range of stressors and disaggregated vulnerability by sector. Okpara *et al*. (2017), meanwhile, applied the "double exposure" concept to explore vulnerability in the context of climate change, climate variability, and conflict on the south-eastern shores of Lake Chad. The vulnerability framework that they developed allowed the factors that underlay vulnerability to be unpacked, and it allowed the differential vulnerability of farmers, pastoralists, and fishermen to multiple stressors to be examined. Even more recently, Dressler *et al*. (2019) examined the effect of economic, social, and climatic change on pastoralists in Morocco in an effort to explain the increased financial and resource polarisation witnessed in the region. Using an experimental agent-based modelling approach they found that ecological conditions themselves can trigger polarisation, global change increases the risk of polarisation, and differences in household assets can lead to poverty traps. Importantly, the modelling approach enabled them to gain a mechanistic understanding of these outcomes – the paper is discussed further in section *2.3*.

A final study of particular note is that of McDowell and Hess (2012) which examined the impact of multiple stressors on livelihoods in the Bolivian highlands – a case study choice that is particularly relevant to this thesis. Taking a slightly different direction to the other studies, the authors decided to explore the interaction of multiple stressors and adaptations over time. They found that "stressors and adaptation are intertwined because stressors deplete resources available for adaptation, while adaptation may erode resources available to respond to future stressors" (McDowell and Hess, 2012, p.342). They also noted that trade-offs occasionally need to be made when responding to multiple stressors. In particular, they identify cases in which adjustments to one stressor can increase exposure to other stressors or compromise the ability of households to adjust to, or cope with, other stressors (McDowell and Hess, 2012). O'Brien *et al.* (2004) made a similar point in their study of Indian agriculture when they pointed out that in responding to climate change, communities may inadvertently increase their vulnerability to globalisation and vice versa. This is because there will sometimes be a "mismatch between climate-compatible crops and market-driven demand for those crops" (O'Brien *et al.*, 2004). In recent years, increased attention has been paid to such trade-offs, especially in the context of climate change mitigation and adaptation (Suckall *et al.*, 2014). The risk of maladaptation and lock-in to sub-optimal pathways has been recognised as well (Magnan *et al.*, 2016; Stringer *et al.*, 2016; Antwi-Agyei *et al.*, 2018). Of course, there will also be cases where adaptations and coping strategies are effective in reducing vulnerability to more than one stressor as O'Brien *et al.* (2009) note. In some instances, groups may even be advantaged by social or environmental changes. O'Brien and Leichenko (2003), for example, discuss how globalisation and climate change have led to both winners and losers, with those categorisations not necessarily being binary.

Collectively, these studies offer important insights into the ways in which multiple stressors can affect communities and they provide pointers as to how effective adaptation and coping strategies can be designed. Methodological development, however, is still ongoing, with a diversity of approaches currently evident. The "double exposure" method used in O'Brien *et al.* (2004) to identify areas vulnerable to two or more stressors has the advantage of being readily implementable at scale, but it offers limited insights into *how* the processes interact. Meanwhile, the descriptive approaches used in the other studies (e.g. Nielsen and Reenberg, 2010; McDowell and Hess, 2012; McCubbin *et al.*, 2015) are more difficult to upscale but offer greater process-oriented insight into the dynamics of multiple stressors and vulnerability. In this thesis, I develop an approach that combines scenario analysis, agent-based modelling, and simulation – an approach that has similarities with that used by Dressler *et al.* (2019). By taking this route, I retain the process-oriented focus of many of the previous multiple stressor studies, while being able to draw on methods that are naturally suited to studying a range of hypothetical futures.

Importantly, this modelling approach also offers a means of quantifying the implication of different assumptions, scenarios, and stochastic factors – something that many of the preceding studies have not been able to do. This is important because in the absence of quantification, it is difficult to judge the significance of findings and gauge the importance of particular processes. Modelling furthermore enables the effect of stressors to be analysed at village, household, and individual scales. Again, this is relatively novel within the multiple stressors literature, yet it is important because experience of stressors is mediated across scales, and averaging out outcomes at one level can mask disparities in experience at lower levels. This in turn can lead to important vulnerabilities being missed, and it can result in false conclusions being drawn and maladaptive strategies being implemented. A further benefit of the approach is the ability to simulate a wide range of stressors and shocks concurrently, including both gradual and rapid-onset processes and events. Up to now the multiple stressors literature has, for the most part, narrowed down the number of stressors and shocks considered at any one time to two or three, and few studies have overlaid processes that occur over substantially different temporal and spatial dimensions (Olsson *et al.*, 2014). In this thesis, multiple stressor and shock types are simulated, although the primary focus is on three in particular – increasing crop variability, declining fertility rates, and earthquake events. Notably, these stressors and shocks have very different scale attributes. Additional discussion of the benefits of agent-based modelling approaches is provided in section *2.3*. Meanwhile, details of how I have operationalised the approach in this thesis are provided in *Chapter 6*.

2.3 Socio-Ecological Agent-Based Modelling

The thesis adopts a particular modelling methodology that is increasingly being used to explore issues relating to complex socio-ecological systems: agent-based modelling (ABM). ABMs are comprised of multiple autonomous entities, known as agents, that can interact with one another and with their environment (Malleson, 2010). In socio-ecological ABMs, those agents typically represent individuals or households, and the virtual environment will be a simplified and bounded representation of their actual environment. As models iterate, agents are able to individually assess their situation and make decisions about their future course of action based on a set of rules that are usually intended to represent plausible behavioural rules (Bonabeau, 2002; Malleson, 2010). The environment in the model may also be updated in accordance with an additional set of rules, potentially taking agent behaviour into account. The number of times an ABM iterates is either pre-determined by the modeller or determined by stop-conditions during the simulations (Wilensky and Rand, 2015). Typically, modellers run a number of simulations in order to examine the effect of altering initial conditions or parameters, and to gauge the range of pathways and outcomes that are possible. The latter is important because ABMs often contain multiple stochastic components.

ABM methodologies offer a combination of advantages which set them apart from other approaches that are used in socio-ecological systems research. Firstly, they are valuable for conducting experiments that are not practical or feasible to conduct in real world settings (Oreskes *et al.*, 1994; van der Leeuw, 2004). This includes cases where it is not possible to gain sufficient access to the system of interest, where repeat observations of identical or near-identical systems are necessary, and where the focus is on examining hypothetical "what if" questions or long timeframes (Oreskes *et al.*, 1994; Miller and Page, 2009). They also offer a means of probing system dynamics with a degree of precision and to an extent that is unattainable in the real world (Gleick, 1997; Miller and Page, 2009; Arthur, 2013). Secondly, computer models are useful in that they provide a means to "discipline the dialogue" (Epstein, 2008, para. 1.7). The act of building a model requires researchers to think in detail about how systems function, in a way that goes beyond what is typical (Farmer, 2012). Meanwhile, simulations bound outcomes to plausible ranges (Epstein, 2008). Together, this encourages rigour and helps to "promote a scientific habit of mind," as Epstein puts it (2008, para. 1.9). Thirdly, models allow processes that are traditionally thought of as belonging to different disciplines to be connected through the shared language of mathematics (van der Leeuw, 2004; Schlüter *et al.*, 2015). In this sense, they are particularly useful for socio-ecological systems research, which is inherently inter-disciplinary. Fourthly, ABMs enable a more "natural" description of systems than other modelling approaches because they involve less high-level abstraction – agents, processes, and time can all be explicitly represented (Malleson, 2010, p.42). Among other things, this allows for more sophisticated modelling of individual human cognition and behaviour (Moss and Edmonds, 2005). In the context of stressor and transition research, this is hugely important because it allows the potential for ongoing human learning and adaptive behaviours to be taken into account (Filatova and Polhill, 2012; Porter *et al.*, 2014). Furthermore, as individual agents are simulated, heterogeneity in circumstances, knowledge, and behaviour can also be taken into account. This makes it possible to observe how these factors affect experiences of stressors, shocks, and change (Filatova *et al.*, 2013). A fifth strength of ABM is that it captures the important role that history can play in shaping system and agent evolution because it is simulation based (Waldrop, 1993; Orrell, 2012). Again, this is important in socio-ecological system science as path dependencies and feedbacks often play significant roles, and a common aim of such work is to develop causal understandings (Porter *et al.*, 2014; Filatova *et al.*, 2016). Finally, ABMs provide a means to readily conduct multi-scale research thanks, once again, to the lack of high-level abstraction (Lippe *et al.*, 2019). For example, in the model that is presented in *Chapter 6*, both villagers and households are depicted, with two-way interactions taking place between them. The opportunity to do this is valuable for socio-ecological systems and stressor research because cross-scale dynamics and considerations can be important in shaping outcomes, and understandings of stressor impacts can be influenced by the scale at which they are viewed (Beinhocker, 2006).

The downsides of ABM largely depend on the context in which it is used (Matthews *et al.*, 2007). For example, building detailed, empirically informed socio-ecological ABMs – as is done in this thesis – requires large amounts of data and an in-depth understanding of system processes (Jager and Janssen, 2012). However, such information is often not readily available which means extensive fieldwork is often necessary, as was the case with this project. This can be a time consuming and resource intensive process. Theory-based modelling also has its challenges. Schlüter *et al.* (2017) note, for instance, that decision-making theories often have logical gaps which need filling before they can be used in simulation contexts. Another challenge that has proved pertinent in the context of this thesis is that of model validation. Silverman *et al.* (2006) and Jager and Janssen (2012) have questioned whether true empirical validation is even possible in the case of many ABMs. This is discussed further in *Chapter 6* and *Chapter 8*.

Due to the strengths of ABM methodologies and the relatively manageable nature of the shortcomings, the approach has been applied to a range of topics in socio-ecological systems science. *Figure 2.1* provides a sense of the main research themes, as well as some of the methodological considerations that have been discussed in the literature. Going from the graph, the leading application domain is quite clearly agriculture which is mentioned *literatim* in the title, abstract, or keywords of at least 140 papers and has a degree centrality of 84.[1] This is followed by topics related to decision-making, land-use, ecology, biodiversity, climate change,

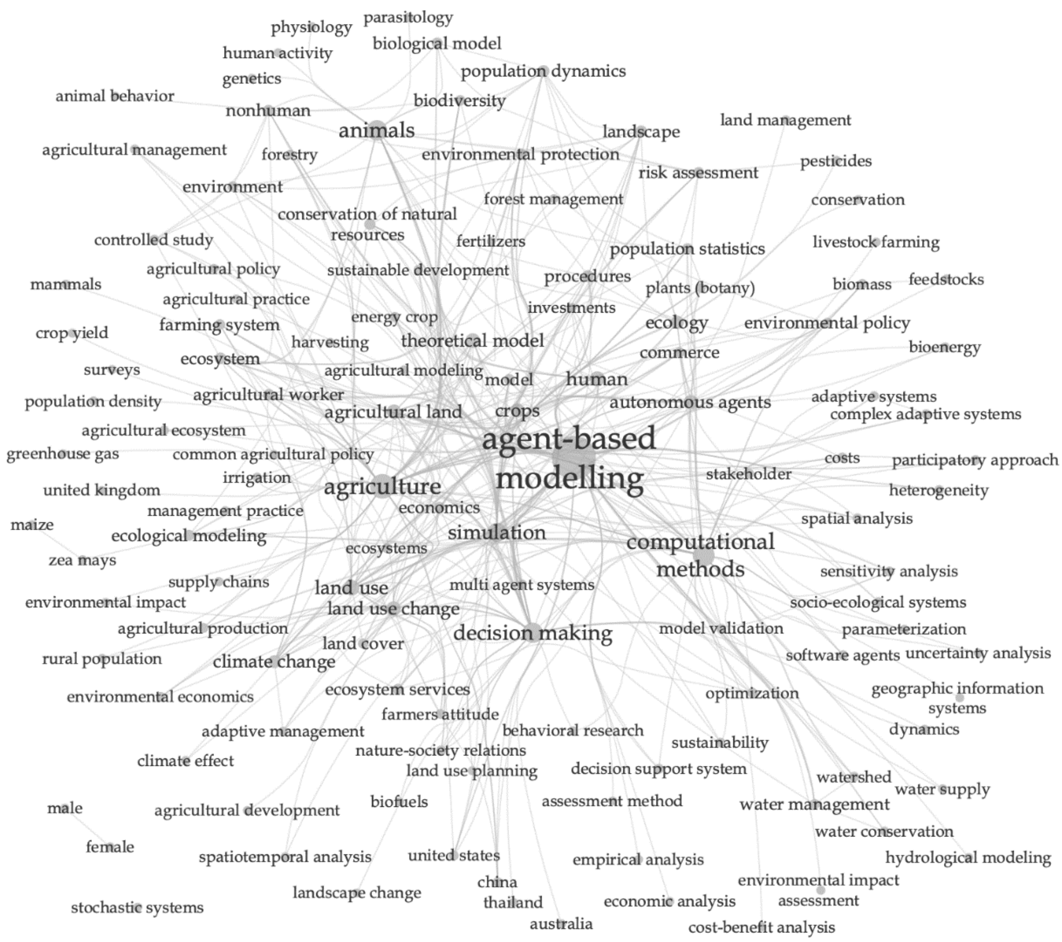

Figure 2.1. Graph of keyword co-occurrence for the 454 papers on Scopus on 3 March 2019 that contained the terms "socio-ecological system" and "agent-based modelling" in their title, abstract, or keywords (variants of these terms are also included). Edges with weights of less than four have been excluded and vertices with a subsequent degree of zero have been dropped (Source: Author).

[1] Degree centrality refers to the number of times a term co-occurs with other terms in the graph. It is a useful, if crude, indicator of a term's importance within a corpus of documents.

natural resource management, ecosystem services, water management, environmental policy, and forestry – to name but a few. The locations that these studies have focused on are also diverse, with 31 countries[2] and 6 continents directly mentioned in the titles, abstracts, or keywords of at least 2 papers. Nepal, where the fieldsite for this study is located, was itself cited in 2 of the papers. In respect to the types of environment considered, there is a similar diversity, with rangelands, farmland, forests, lakes, rivers, and seas all being mentioned in multiple papers. However, mountains as a term is only mentioned in a handful of instances – likewise, specific mountain systems such as the Alps and Andes. That said, many papers do not directly state the type of environment the study focusses on in the title, abstract, or keywords.

There are several examples of ABM being used specifically to study stressors in socio-ecological systems. Among the most relevant to this thesis is a paper by Acosta-Michlik and Espaldon (2008) that sought to assess the vulnerability of farmers in the Philippines to both climate change and food price rises, while also evaluating the efficacy of potential adaptation options. The authors found, perhaps unsurprisingly, that household vulnerability was at its greatest when the stressors were simulated concurrently. The study also concluded that a lack of financial resources and information were the main barriers to adaptation. The previously mentioned paper by Dressler *et al*. (2019) is also pertinent to this thesis, even though its focus was on pastoralists rather than smallholders. It incorporated many of the advances in best practice that have been made since the earlier Philippines ABM study, exploring the effect of stressors in a much more systematic and in-depth fashion. There are several other ABMs that have also examined the impact of stressors and shocks, but most of them have focused primarily on a single process or event type. For example, Naivinit *et al*. (2010) consider the impact of changes in water availability on rice production and labour migration in Thailand, while Naqvi and Rehm (2014) simulate the impact of natural disasters on migratory movements, and on household income and consumption in a low

[2] In order of mentions, these are the United States, China, United Kingdom, Australia, Germany, Vietnam, Thailand, Austria, Denmark, South Africa, Argentina, Brazil, Canada, Italy, Netherlands, Belgium, Burkina Faso, Ecuador, Ghana, Slovenia, Switzerland, Venezuela, India, Malawi, Mexico, Nepal, New Zealand, Nigeria, Senegal, Sweden, and Spain.

income region of rural Pakistan. The latter study is particularly notable because it seeks to understand the distributional effects of shocks. This is similar to what the model in this thesis is designed to do in respect to the 2015 earthquake, although Naqvi and Rehm's (2014) study takes more of a macro-level perspective and is more abstract in its setup. A number of other studies have also examined smallholder socio-ecological system dynamics, but with a less stressor-oriented focus. Saqalli *et al*. (2011), for instance, simulate the impact of two potential development interventions on the populations of three rural villages in Nigeria, taking into account the pluri-activity nature of livelihoods at their fieldsites and the different constraints that villagers are subject to. Notably, the authors model both individuals and households, enabling important cross-scale dynamics to be taken into account. This is something that is also done in the thesis model. Zvoleff and An (2014), meanwhile, created a model of a rural area in lowland Nepal. Their focus was on understanding long-term feedbacks between land use and demographic decision making. The authors' detailed depiction of demographic processes inspired the design of the demographic components of the thesis model.

One of the earliest agent-based models to focus on a mountain population was that of Castella *et al*. (2005). They created a model of rural agrarian communities in the northern mountains of Vietnam in order to explore the factors that were contributing to land use change. Of particular note was their use of companion modelling – an approach proposed by Bousquet *et al*. (1999) for developing models by drawing upon the knowledge and perspectives of the subjects of the modelling efforts and by engaging them closely in the model design process. This heavily participatory approach, contrasts with the theory and data-oriented approaches that have tended to predominate within the modelling community. It is relevant here because the thesis model has also been developed, in part, through the use of participatory methods. More recent agent-based modelling studies of mountain communities include Becu *et al*.'s (2014) work on the dynamics of shifting cultivation systems in North-Cameroon, and Clark and Crabtree's (2015) analysis of adaption of Mongolian pastoralists to climatic variability.

A weakness of many past models is the use of relatively large time-steps. Several of the studies mentioned above advance by a year at a time (e.g. Castella *et al*., 2005; Acosta-Michlik and Espaldon, 2008; Dressler *et al*., 2019), while others have weekly or monthly timesteps (e.g. Saqalli *et al*., 2011; Zvoleff and An, 2014). This can limit the scope for studying fine-grained temporal dynamics and seasonality, both of which are of potential importance when considering the impact of stressors and shocks on smallholders, as the findings in *Chapter 7* show. In this thesis, daily timesteps are used, in keeping with the approach of Naivinit *et al*. (2010), among others. Another issue is the level of detail that modellers have used in their depiction of socio-ecological systems. All models are simplified representation of reality and necessarily so (Castle and Crooks, 2006). As Brian Arthur once said, if you were to build a perfect model of the universe which captured all of its processes and parameters, it would be just about as hard to understand as the real universe (Waldrop, 1993). Therefore, the art of modelling is to make "the most parsimonious representation that still captures key characteristics and behaviours of a real system" (Railsback and Grimm, 2012, p.227). However, modellers have different perspectives on what the balance should be. It is true that there are no hard and fast rules about what constitutes the right level of detail. As Edmonds and Moss (2004, p.143) say, "the trade-off between the practicality of our models and their descriptive adequacy is a complex and context-dependent one." Some past models, though, have arguably erred on the overly simplistic side, neglecting potentially important processes in doing so. The model in this thesis is relatively descriptive because it was clear from the fieldwork that a wide variety of factors played a role in shaping the impact of stressors on households and individuals. Furthermore, my desire to understand the heterogeneous impact of stressors, shocks, and happenstance across the population, and to do so at a high temporal resolution, meant that many more state variables and processes were included than might otherwise have been necessary.

2.4 Concluding remarks

In this chapter, the socio-ecological systems and stressors literature has been reviewed, research examining multiple stressors has been critiqued, and the use of agent-based modelling for studying socio-ecological system dynamics and stressors has been looked at. In the processes of doing so, the main knowledge gaps in the multiple stressors field have been identified, and the case for using agent-based modelling approaches for studying multiple stressors has been made. In the next chapter, I look specifically at the stressors and shocks that have afflicted mountain systems in the past, as well as those that are set to shape the coming decade or so of mountain life. The chapter picks up on many of the themes that were discussed in section *2.1* and *2.2*.

Chapter 3: Mountain Systems

The nature and geography of mountains | The study of mountain systems | Stressors and change in mountain systems

The focus of this thesis is on how multiple stressors could affect mountain systems in the developing world over the coming decade or so. In this chapter, the core socio-ecological characteristics of these systems are detailed, as are the main stressors, shocks, and processes of change that are set to shape them going forward. The chapter also reflects on how stressors have affected mountain systems in previous decades, and it explores the history of mountain socio-ecological systems as a subject of intellectual enquiry. Throughout, particular attention is paid to the Nepalese case due to the location of the study fieldsite in the country. The purpose of the chapter is to provide context to the study. It contributes towards fulfilling the objective shown below.

> ***Objective 1.*** To identify the main stressors and drivers of change in mountain areas, both in Nepal and elsewhere around the world. This is necessary in order to understand the stressor landscape that many mountain communities face and to provide context on which the thesis can build.

3.1 The Nature and Geography of Mountains

There is no single, universally accepted definition for what constitutes a mountain or a mountainous environment. Their diversity of form both locally and globally makes it difficult to achieve consistency in criteria (Gerrard, 1990; Owens and

Slaymaker, 2004). Most commonly, however, they are thought of as "elevated landforms of high local relief" (Price, 1981, p.5). Many proposed definitions also include ideas of steepness, volume, expanse, ruggedness, and ecological and climatic transitions (Gerrard, 1990). Of course, the debate around attributes is further compounded by questions around what values should be placed on those attributes. Funnell and Parish (2001, p.4) recognise this in saying mountains are as much a socially defined concept as they are one arising from "carefully established and globally accepted criteria." This openness to diversity in definition and the acceptance of a degree of subjectivity is reflected in the academic literature on mountain areas and within global political discourse on the subject. Here I will be similarly open, as within this thesis it is the commonalities in the livelihoods of mountain peoples and the commonalities in the challenges they face that are of importance, not the differences that delineate them from other communities.

Mountain systems – in the broadly defined sense[3] – are present on each of the seven continents. Shown in *Figure 3.1*, they cover around 23% of the Earth's land surface with around a third of this area lying above 1,500 metres and one-fifth above 2,500 metres (Huddleston *et al.*, 2003; Körner *et al.*, 2005). Major ranges include the Andes in South America, the Rocky Mountains and Appalachians in North America, the Kunlun, Himalaya, and Ural Mountains in Asia, the Atlas in

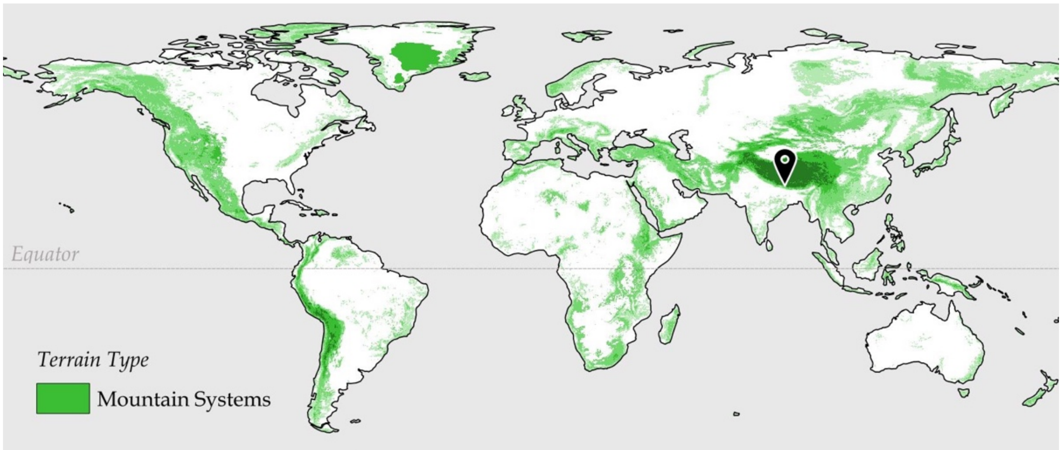

Figure 3.1. Mountain systems and high lands based on the UNEP-WCMC definition. The fieldsite discussed in this thesis is marked by the pin. Darker shades represent higher elevation (Data: Millennium Ecosystem Assessment, 2005).

[3] *Figure 3.1* uses the UNEP-WCMC definition of mountain systems. This definition includes areas of (1) elevation 1000-1500 metres and slope >= 5 degrees; (2) elevation 1500-2500 metres and slope >= 2 degrees; (3) elevation 2500+ metres; (4) elevation 100+ metres and local elevation range > 300 metres (see: Huddleston *et al.*, 2003).

North Africa, and the Alps in Europe. Dozens of smaller yet nonetheless notable systems are scattered elsewhere over the continental landmasses and are also central to many island territories such as Japan, New Guinea, and New Zealand. It is, though, Asia – where the project fieldsite is located – which plays home to the greatest extent of mountainous area with approximately a quarter of the global total, followed at some distance by South America and the Near East (Huddleston *et al*., 2003).

As of 2015, the number of people living in the world's mountains and high-lands was estimated to be 950 million, or 13% of the then global population (FAO, 2015). Around 90% of these people lived in developing countries and 70% lived in rural areas (FAO, 2015). The research that is outlined in this thesis on the impact of stressors on mountain communities is therefore pertinent to a substantial portion of the world's population, even though particulars may differ from location to location.

3.1.1 Socio-ecological characteristics of mountain systems

Mountain environments can be highly diverse at global, regional, and even local scales, yet a number of commonalities are evident across systems (Gerrard, 1990; Körner *et al*., 2005). For starters, this is apparent in the geomorphological processes that shape mountain landscapes. The high relief and steep slopes that characterise mountain systems provide huge potential energy for erosion and sediment transport, whether through soil creep, landslides, avalanches, or fluvial and glacial processes (Barsch and Caine, 1984). This can lead to high rates of denudation, often exacerbated by intense precipitation, temperature fluctuations, periods of snow and glacial melt, seismic activity, and other local factors such as reduced vegetation cover at altitude (Gerrard, 1990). Consequently, mountain landscapes tend to be complex and ephemeral in nature. For example, in Nepal, the Mid-Hills region alone encompass elevations that range from 500 meters to 3,000 meters, with elevation, relief, and aspect often varying dramatically from one place to the next (see *Figure 3.2*).

These topographic and geomorphological characteristics have a number of implications for mountain communities. Firstly, they make agriculture challenging as ground is often steep, local conditions can be highly varied, and soils tend to be shallow, low in nutrients, and prone to erosion (Gerrard, 1990; Körner *et al.*, 2005) – topics that are discussed further in section *3.3*. Secondly, they contribute to the fragmented and isolated nature of many settlements[4] by hindering connectivity and by making the construction of infrastructure both difficult and costly (Funnell and Parish, 2001). This has historically led to many mountain communities developing high degrees of self-sufficiency and resourcefulness, but it can also increase their vulnerability to stressors as will again be discussed in section *3.3*.

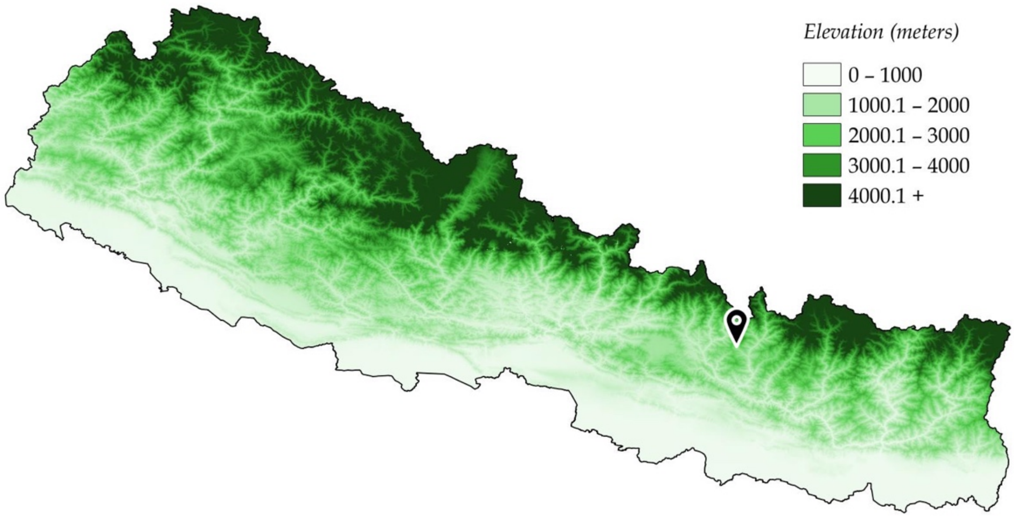

Figure 3.2. An elevation map for Nepal based on ASTER GDEM data. The pin marks the location of the fieldsite (Data: USGS, 2015b).

The complex terrain that is seen in mountain systems also means that there is potential for large local variation in climatic conditions, both vertically and horizontally (Barry, 2008). Atmospheric pressure, temperature, and clear-sky turbidity are all closely related to altitude (Körner, 2007). Precipitation, wind strength, and wind direction are, meanwhile, more closely associated with non-altitudinal factors, but topography remains a central determinant (Körner, 2007; Barry, 2008). In the same way that topography strongly influences climate, climate strongly influences mountain ecology, although neither of these relationships is by any means unidirectional. Differences in climate, along with soil and terrain, help create a wide range of different ecological niches supporting a diverse array of

[4] The world's mountain settlements range from lone households to major cities, but urban clusters are very much in the minority (Funnell and Parish, 2001). In Nepal, for example, just 21.7% of the Hill population and 2.8% of the Mountain population resided in urban areas according to the most recent census (MoUD, 2017, p.3).

flora and fauna (Gerrard, 1990; Smethurst, 2000). This makes many mountain systems biodiversity hotspots (Panos, 2002). Furthermore, it can often enable diverse combinations of crops to be grown within relatively small geographical areas (Körner *et al*., 2005). This is a plus that many mountain smallholders exploit, and one which helps them hedge against variability in individual crop yields (Maikhuri *et al*., 1996). Notably, altitude can overwhelm the effects of latitude, resulting in similar ecological niches, environmental conditions, and agricultural practices being present in diverse locations around the world. This, along with the other shared features of mountain systems that have already been discussed, means that there is often surprising kinship between mountain systems around the world, and it means that they often face similar sets of environmental stressors and shocks.

In developing countries, mountain livelihoods are most commonly based around pastoralism or mixed agro-pastoral activities, with income supplemented in many cases by off-farm labouring, remittances, cottage industries, and sale of forest products (Brush, 1976; Funnell and Parish, 2001). In some places, tourism is also offering important sources of revenue. Where practiced, pluriactivity exploits the multitude of resources and ecological niches mountains offer while reducing the vulnerability that comes from dependence on any single activity (Smethurst, 2000; Parish, 2002). Livestock and poultry can be particularly important when it comes to dealing with stressors because they constitute readily saleable assets, as well as being valuable sources of meat and dairy products (Dressler *et al*., 2019). Sheep and goats are particularly common in many of the world's mountains because of their hardiness and ability to survive on poor pastures (Parish, 2002). Crop cultivation, meanwhile, is often a mainstay of rural mountain economies. However, it can be vulnerable to climate variability and it is often "practised under conditions where at least some environmental constraints are present" (Huddleston *et al*., 2003, p.17). As previously mentioned, mountain weather, terrain, and soils can be particularly challenging. As a result we can see similar adaptations across many mountain systems in terracing, irrigation systems, resource allocation strategies, and soil management (Brush, 1976; Parish, 2002).

Of the other livelihood activities common to mountain areas, temporary and long-term migration is perhaps the most significant. Remittances[5] are increasingly a major source of outside income and provide another means by which households can increase their resilience to local stressors (Brush, 1976; Körner *et al*., 2005). The practice can, however, be problematic from a social standpoint and when it comes to nurturing more local industries and on-farm activities. In the past, it was common for men in Nepal to seek seasonal employment in India to supplement household income (Whelpton, 2005). However, in more recent times, many have sought longer-term opportunities in Malaysia and the Gulf (Pattisson, 2013). Employment opportunities in mountainous areas are often more limited and lower paid than in lowlands (Funnell and Parish, 2001). Nevertheless, they also represent a valuable source of income for many, especially during times of stress. In rural Nepal, construction dominates off-farm employment, constituting 46.5% of all waged work, followed by personal services at 21.5%, and manufacturing at 15.4% (CBS, 2011b, p.64).

Mountain cultures have also been shaped in part by the unique characteristics of mountain environments, with certain similarities evident across systems. In particular, the relative isolation of many communities is commonly cited as one of the main reasons behind the development of the great cultural and linguistic diversity that is a distinctive feature of many mountain regions (Funnell and Parish, 2001; Körner *et al*., 2005). Often these cultures are distinct from those in the lowlands and they tend to have shared features despite their variation. These are not cultures that have gestated in complete isolation though – mountain societies have a long history of assimilating elements of other cultures introduced through trade, marriage, and migration (Panos, 2002; Parish, 2002). Mountain cultures play a critical role in social organisation and in bonding communities together. Given agricultural calendars often necessitate cooperation and collaboration, this can be of critical importance.[6] The principles also hold when it comes to dealing with

[5] Remittance refers to money that is sent from a person working in a foreign country to individuals in the person's home country.

[6] A study published in *Science* (Talhelm *et al*., 2014) found that agrarian communities that are internally dependent on one another for survival – in the case of the study it was because they required reciprocal exchange of labour at certain points in the agricultural calendar – exhibit greater group allegiances, conformity, and collectivist thinking than other communities.

stressors and shocks – collectivistic communities are better placed to support one another through challenging times (Talhelm *et al*., 2014).

The relative isolation typical of mountain communities also has socio-economic implications beyond culture and livelihoods. In both developed and developing countries, mountain communities are often politically and economically marginalised (Parish, 2002). Villages can be far from centres of power and markets, with the coverage and quality of healthcare, education, transport, communications infrastructure, and other services commonly lagging behind that which is available in lowland areas (Körner *et al*., 2005). Capitalism – for better or for worse – has also been slow to penetrate some areas. The collective consequence is that mountain communities tend to have disproportionately high rates of poverty and disproportionately low political and economic influence at national levels (Smethurst, 2000). On the flip side, these communities can benefit from greater independence and capacity for self-determination than their lowland counterparts. How some of these characteristics relate to stressor experiences and vulnerability is discussed later in section *3.3*.

Despite all of the commonalities discussed above, mountain systems can "be as different from one another as from lowland areas" (Gerrard, 1990, p.29). A multitude of factors ensure each mountain system is in many respects unique – something that is important to note when conducting mountain research.

3.2 The Study of Mountain Systems

Mountain research has a long and rich history. One of the earliest formal scientific studies of mountains was conducted by Alexander von Humboldt (1769-1859) and Aimé Bonpland (1773-1858) during their five-year exploration of the Americas in 1799–1804. In his writings following the trip, Humboldt detailed the relationship between altitude, climate, vegetation, ecological processes, and human activities in the Andes (Smethurst, 2000). He also championed the idea of nature as a living, interconnected whole – a viewpoint that has resurfaced in contemporary mountain research (Wulf, 2015).

Over the subsequent century and a half, a number of other geographers, geologists, botanists, and biologists contributed to the broadening and deepening of mountain scholarship. A great deal of this work was focused on understanding the physical and environmental aspects of mountain systems with significant advances made, in particular, in the fields of geomorphology, geoecology, and climatology (Smethurst, 2000; Funnell and Parish, 2001). Research on mountain peoples was somewhat more limited and – during the late 1800s to early 1900s – flavoured by ideas of environmental determinism. Strongly influenced by Charles Darwin's[7] writings on natural selection and adaptation in his 1859 book, *On the Origin of Species*, the "belief that the nature of human activity was controlled by the parameters of the physical world within which it was set" (Johnston and Sidaway, 2004, p.46), was in the ascendancy. For example, Ellen Churchill Semple (1863-1932), a protégé of Freidrich Ratzel and a future president of the Association of American Geographers, made manifold causal connections between the environmental conditions in the Kentucky Appalachians and the culture and practices of the people inhabiting the area in a 1901 paper. She wrote:

> "The whole civilization of the Kentucky mountains is eloquent to the anthropogeographer of the influence of physical environment, for nowhere else in modern times has that progressive Anglo-Saxon race been so long and so completely subjected to retarding conditions" (Semple, 1901, pp.622–623)

Following the First World War such ideas came under increasing attack because of their simplistic assumptions, sweeping generalisation, and associations with scientific racism (Johnston and Sidaway, 2004). In response, a counter-thesis of possibilism emerged. Here, the environment was still seen to constrain human action, but greater recognition was given to the potential for human agency (Johnston and Sidaway, 2004). This notion itself came in for intense criticism for similar reasons to those that applied to determinism and it similarly receded in popularity. Nonetheless, aspects of both determinist and possibilist thinking

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[7] Darwin was himself said to have taken inspiration for his research from Alexander von Humboldt (Johnston and Sidaway, 2004)

continued to strongly influence mountain scholarship, albeit rarely framed in such terms.

In 1936, the first English language general mountain text was published in the form of *Mountain Geography* (Peattie, 1936). It would be over forty years till the next major synthesising text, *Mountains and Man* (Price, 1981), but a plethora of regionally focused and specialist publications did appear in the intervening period. Much of this work continued to disproportionately concentrate on physical processes and there was a strong bias towards the study of high mountains where human presence was typically at its lowest (Funnell and Parish, 2001). It was not uncommon for human activities to be treated like an inconvenient intrusion, to be ignored outright, or to be assumed subservient to the physical environment (Smethurst, 2000; Funnell and Parish, 2001). The majority of literature that did focus on human activities was centred around understanding traditional mountain societies, and vertical organisations and adaptations in mountain agriculture (e.g. Troll, 1968; Brush, 1976; Uhlig, 1978).

From the 1970s, there was a notable uptick in interest around mountain areas and the challenges they faced (see *Figure 3.3*). This was aided in no small part by the inclusion of mountain environments in the UNESCO Man and Biosphere Programme and a major conference in Munich on mountain development (Gerrard, 1990). These events were particularly important in drawing increased attention to the influence of human activities on mountain landscapes and to the dramatic changes that were ongoing in many mountain communities. One of the most prominent avenues of research was centred around the Theory of Himalayan Degradation.[8] Articulated by Erik Eckholm (1975) in an article in *Science* it postulated that unprecedented population growth in Nepal was leading to a surge in demand for fuelwood, construction timber, fodder, and agricultural land, which in turn was resulting in massive deforestation. This was said to be leading to a catastrophic rise in soil erosion and landslides, and accelerated runoff during the monsoon rains (Ives, 1987). In turn, the theory argued, this was causing declining

[8] Perhaps unsurprisingly this coincided with a period of heightened concern about human impacts on the environment, fostered by the publication of *Silent Spring* (Carson, 1962) and *The Limits to Growth* (Meadows *et al*., 1972).

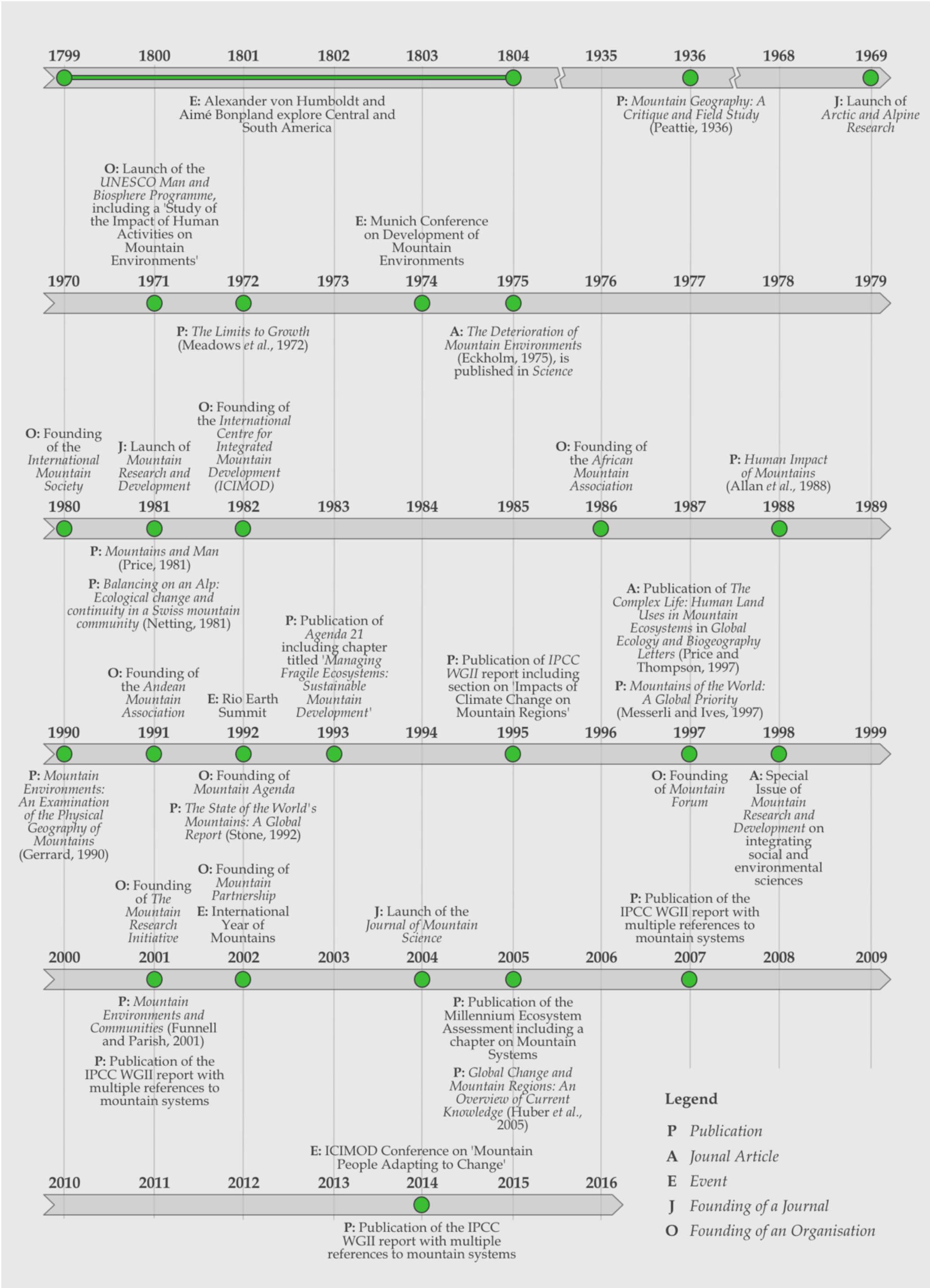

Figure 3.3. Timeline of notable publications, articles, and events in the history of mountain research (Friend, 2002; Parish, 2002; Owens and Slaymaker, 2004; Messerli, 2015).

ground water levels upstream, massive siltation and devastating flooding downstream, and a number of other impacts that ranged from large scale migration to disease (Eckholm, 1975; Ives, 1987). While the theory principally had Nepal in mind, Eckholm (1975) claimed that similar crises were ongoing in the

Andes and the East African highlands. The powerful narrative was widely accepted in academia, the media, and the development sector for a number of years, but was increasingly challenged during the late 1980s. In dissecting the theory Jack Ives (1987, p.193) argued that "most of these linkages and assumptions are founded on latter-day myths, or falsely-based intuition, or are not supported by rigorous, replicable, and reliable data". He further suggested the theory ignored "the great complexity of the region and its people" (Ives, 1987, p.193).

Critical scrutiny of Eckholm's theory also came from political ecologists, most notably in *Land Degradation and Society* (Blaikie and Brookfield, 1987). The volume challenged the idea that there was a uni-causal explanation for the perceived rise in land degradation, noting that "while there are many causes [*sic*] where 'population pressure' has contributed to land degradation, in others a marked *decrease* in population densities has led to the same result" (Blaikie and Brookfield, 1987, p.4). The authors instead highlighted the complexity of the biophysical processes that were at play, drew attention to previously neglected historical, socioeconomic, and institutional factors, and demonstrated that 'degradation' was open to definitional interpretation (Forsyth, 2001). In doing this, Blaikie and Brookfield (1987) destabilised the technocratic narrative that had formerly dominated. Through using an agent-based modelling approach in this thesis, I similarly seek to recognise the complexities at play in mountain systems.

Heading into the 1990s, there was a tendency towards more critical, holistic, politically aware, and nuanced research on mountain areas, though this was by no means universally evident. While partly a result of internal debate, it also reflected broader movements within academia – in particular the rising popularity of political ecology, postmodernism, and complexity, along with their associated methods (Funnell and Parish, 2001). One of the major theoretical developments of the decade came from Elinor Ostrom's (1990) work on institutional arrangements for managing natural resources. The socio-ecological systems approach Ostrom developed along with a number of other collaborators has also been extremely influential. However, perhaps most significant in the field of mountain research during the 1990s was the Rio Earth Summit of 1992 and the subsequent inclusion in Agenda 21 of a chapter on sustainable mountain development (Owens and

Slaymaker, 2004). The event led to a surge of interest in conservation, biodiversity, and the sustainable development of mountain areas, resulting in several new research initiatives and a stream of new literature (see *Figure 3.3*). Perhaps for the first time, it also made the social dimension central to the mountain research agenda (Funnell and Parish, 2001). The declaration of the year 2002 as the International Year of Mountains helped stimulate this interest yet further. More recently, the Millennium Ecosystem Assessment included a chapter on mountain systems (Körner *et al*., 2005), and the IPCC and IPBES have given specific consideration to mountain areas in a number of their Assessment Reports (e.g. Fischlin *et al*., 2007; IPBES, 2018). Indeed, climate change impacts and adaptation options have become a core research theme as will be discussed in the next section.

The history of mountain scholarship ultimately provides important lessons going forward. It points to the dangers of making sweeping generalisations, relying on unsubstantiated assumptions, and presuming simple causal pathways. It also demonstrates the value of taking a holistic perspective, of avoiding unduly privileging certain factors above others, of applying critical scrutiny, and of being cautious and humble when uncertainties prevail. While such an approach should be the default within mountain research, that is not yet the case.

3.3 Stressors and change in mountain systems

A popular and consistent theme of mountain scholarship over the years has been the study of stressors, shocks, and change. This reflects the profound nature of the social and environmental upheavals that have taken place in many mountain areas during the modern era, the significance of contemporary pressures, and the inherently dynamic nature of mountain regions. What is particularly evident in the literature is the sheer number of ways in which stressors, shocks, and change are manifest and the entwined nature of many of them. In this section, I examine the main areas of academic enquiry in this regard and I discuss how such processes are playing out with respect to Nepal. *Figure 3.4* provides an overview of these stressors and shocks. Of course, the processes outlined here are not being experienced in all mountain systems and they can play out in different ways in different places. Their practical impact can also vary enormously, even at the intrahousehold level. Consequently, while there are common threads in the experiences of mountain communities, diversity in experience needs to be recognised as well. In the thesis model, I focus in particular on modelling earthquakes, the impact of meteorological stressors and pests on crop yields, and the consequences of declining fertility rates.

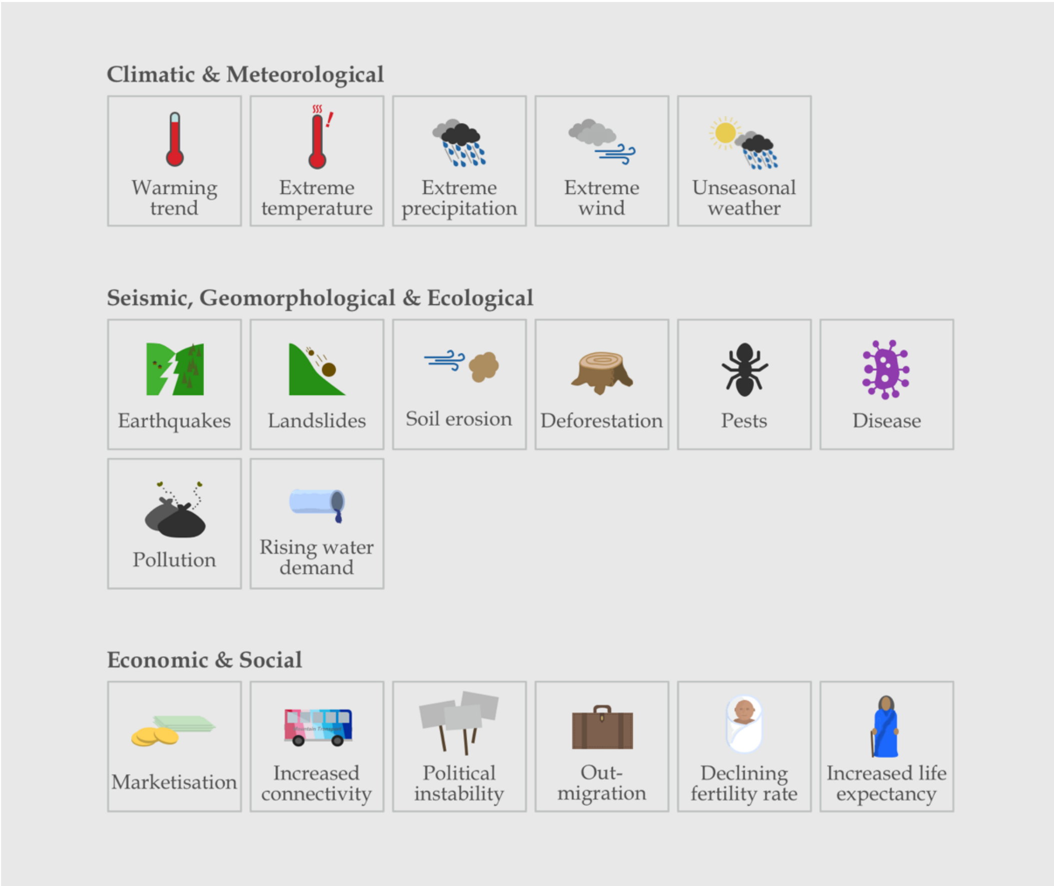

Figure 3.4. Contemporary stressors and shocks that are commonly found in mountain systems (Source: Author).

3.3.1 Climatic, meteorological and ecological stressors

Mountain weather can often be severe (Barry, 2008). The topography of mountain systems mean that they often experience precipitation extremes, large temperature fluctuations, and strong winds – all of which can pose challenges for those living within them. Heavy precipitation can lead to crop loss, flooding, soil erosion, landslides, and avalanches (Parish, 2002). Temperature fluctuations can stress both crops and animals. And strong winds can damage crops, vegetation, and infrastructure. Inter-annual climate variability also poses a challenge for rainfed agriculture which relies on judgement calls when it comes to timing crop plantation and harvesting (Subba, 2001). In Nepal, many of these challenges are exacerbated by the country's monsoon climate. Nepal's precipitation patterns exhibit significant inter-annual variability, with 80% of annual precipitation typically occurring during the monsoon season of June to September (Eriksson *et al.*, 2009; Duncan *et al.*, 2013). Temperatures also peak during these months, before dropping away during the dry season (DHM, 2015). While livelihood activities are designed to exploit the monsoon, occasionally its intensity can overwhelm, negatively affecting crops, livestock, people, and property. These are age old stressors, but they are in places being exacerbated by climate and livelihood changes.

Climate change effects are expected to be particularly intense in mountainous areas, such as the Himalaya (Mainali and Pricope, 2017). Several studies have found that observed and projected warming is greater in high-elevation regions than in lower-elevation regions at the same latitudes (Rangwala *et al.*, 2013; Wang *et al.*, 2014; Pepin *et al.*, 2015). This certainly appears to be the case in Nepal's hills and mountains which have experienced relatively high, and potentially accelerating, rates of warming in recent years (Pattnayak *et al.*, 2017; Shrestha *et al.*, 2017). Alongside this trend in mean temperatures, there has also been an increase in the number of warm nights (Islam and Uyeda, 2009; Shrestha *et al.*, 2017) and in the frequency of extreme temperature events (Baidya *et al.*, 2008). The impact of climate change on mountain precipitation is more uncertain and is likely to vary substantially between locations. Despite the uncertainty in projections, in Nepal there have already been reports of declining winter rainfall (Poudel and Duex, 2017; Poudel *et al.*, 2017), delayed onset and early ending of the annual monsoon (Poudel and Duex, 2017), a decrease in the proportion of total precipitation that falls as snow (Eriksson *et al.*, 2009), and an increase in inter-annual variability (Poudel and Duex, 2017). Furthermore, the frequency and intensity of precipitation extremes appears to be on the rise (Eriksson *et al.*, 2009; Shrestha *et al.*, 2017). In addition to these trends in temperature and precipitation, changes in atmospheric composition are also evident around the world (Porter *et al.*, 2014).

Many mountain livelihoods – such as rainfed smallholder agriculture and livestock grazing – are directly climate sensitive, as noted in the latest IPCC report

(Olsson *et al.*, 2014). Changes in temperature, precipitation, weather extremes, and atmospheric composition are all likely to impact on crop yields, as are secondary effects of climate change such as alterations to soil nutrients and moisture content, and changes in the prevalence of pests and diseases (Porter *et al.*, 2014). A climate change vulnerability index developed by Mainali and Pricope (2017) to take into account exposure, sensitivity, and adaptive capacity, suggests that 60% of the Nepalese population fall within the moderately to highly vulnerable categories. Notably, the authors argue that lack of adaptive capacity is the biggest cause of vulnerability, and their index suggests that adaptive capacity typically declines during the transition from the Terai to the Mountains (Mainali and Pricope, 2017). On a more positive note, rising atmospheric carbon dioxide levels can be beneficial for the growth of some crops, especially C3 crops like wheat and rice (Porter *et al.*, 2014) – crops which are commonly grown by mountain smallholders. Additionally, rising temperatures may enable certain crops to be grown at higher altitudes than was previously possible, opening up new opportunities for farmers (Poudel *et al.*, 2017). Furthermore, warmer winters will likely reduce the threat to crops of frost and cold damage during the November to February period – at least in some areas – assisting the growing of winter crops (Porter *et al.*, 2014).

Overall, there remains substantial uncertainty around the long-term future direction of crop yields in Nepal and in other mountain systems, but projections of an increase in inter-annual variability in yields do appear to be relatively robust (Palazzoli *et al.*, 2015). Consequently, one of the most confident conclusions must be that those engaged in agricultural livelihoods will need to deal with ever more volatility (Poudel and Duex, 2017). Of course, climate change is also likely to affect the frequency of weather-related hazards and potentially the availability of water for human consumption and livelihood use. Thus, it is closely tied to many existing stressors that mountain communities face and is increasingly being recognised as a threat multiplier (Hallegatte *et al.*, 2015).

There are a number of other environmental stressors at play in mountain systems besides weather extremes and climate change. A particularly prominent issue has been the large-scale deforestation that many mountain areas have experienced as a result of increased demand for forest resources and agricultural land. Studies have shown that this often leads to a loss of habitat for flora and fauna (Burgess *et al.*, 2002), an increase in the rate of soil erosion (Ives and Messerli, 1989), alterations to local hydrology (Ziegler *et al.*, 2004; Fohrer *et al.*, 2005), and even discernible changes to local microclimate (Larsen, 2012) – each of which may have further cascading consequences. For example, the deforestation-induced loss of forest shrubs like *Daphne papyracea* and *Daphne bholua* hampers the lokta paper industry in Nepal which relies on these shrubs for its raw materials (Groenendijk, 2008). In turn, this can lead to the loss of a valuable income source for local communities. While the issue of mountain deforestation is most commonly associated with Nepal due to the *Theory of Himalayan Degradation* (Eckholm, 1975; Ives, 1987), it is known to have occurred across a wide range of mountain systems. For example, Brandt and Townsend (2006) looked at deforestation in the Bolivian Andes, while Burgess *et al.* (2002) studied its impact in the Uluguru Mountains of eastern Tanzania. Similarly, other forms of land-cover change, and their consequent impacts, have attracted the interest of researchers around the world. Additional environmental stressors that have attracted attention – albeit not to the same degree – include pests, diseases, pollution, and rising water demand (Funnell and Parish, 2001; Parish, 2002; Körner *et al.*, 2005; Semernya *et al.*, 2017).

3.3.2 Geomorphological and seismic stressors

Alongside the stressors discussed above, there are also a number of geomorphological processes at play in mountain systems that can, depending on the circumstances, pose challenges for mountain communities. In particular, soil erosion, landslides, and avalanches (as mentioned in section *3.1.1*) are common challenges. Where and when they occur, they can harm crops, livestock, property, and people. For example, in May 2018, landslides in the far west of Nepal killed three people and forty animals, damaged at least 30 houses, and buried crops (Kathmandu Post, 2018). Such events can be very much linked to other stressors – extreme weather events and deforestation, for example. Thus, it is usually inappropriate to view their cause and effect in isolation.

The tendency for mountain systems to lie in tectonically active zones means that they are often also exposed to earthquake and volcanic hazards. Nepal is a case in point. Over the years a number of major earthquakes have struck the country, the most recent being a 7.8 M_w tremor on 25 April 2015. The tremor and the subsequent aftershocks directly affected 8.1 million people (CDPS, 2016; UN, 2016). Close to nine thousand people died, and many more were injured (NPC, 2015; UN, 2016). As relatively few buildings in Nepal were seismically designed and constructed at the time of the earthquakes, hundreds of thousands of buildings collapsed, and many more sustained damage (Goda *et al.*, 2015). In rural parts of the affected region, the destruction was particularly widespread, with entire villages razed, crops and fields damaged, and tens-of-thousands of livestock killed (Goda *et al.*, 2015; NPC, 2015; CDPS, 2016). In addition to this, education, health, transport, and communication infrastructure was disrupted, often for extended periods (NPC, 2015; CDPS, 2016). Furthermore, the need to deal with the consequences of the earthquakes resulted in labour being drawn away from agricultural tasks. Coming on top of the damage to crops and fields, and compounded by poor weather that summer, this resulted in 42% of earthquake affected households reporting a decline in harvests during the following year (CDPS, 2016).

Not only did the earthquakes have immediate social and economic consequences, they also left a lasting legacy. For some, this included the loss of family members and friends. For others, it was the drying up of previously important water sources as a result of ground movements (CDPS, 2016). Tens of thousands of households have also been saddled with substantial reconstruction debts, despite some support being provided in the form of reconstruction grants (TAF, 2016). The earthquake is, furthermore, likely to have had a negative effect on medium-term economic development, with investment being directed towards reconstruction rather than growth. All of this goes to show how stressors and shocks can have cascading impacts. Furthermore, it illustrates how the long-term welfare and coping capacity of households can be negatively impacted by certain experiences.

3.3.3 Social and economic stressors

Many mountain communities are currently facing a range of social and economic pressures in addition to the more environmentally oriented ones so far discussed. For starters, dramatic demographic shifts are being witnessed across a number of mountain systems as a result of both long-term and contemporary changes in mortality, fertility, and migration rates. According to Parish (2002), improvements in life expectancy in mountain areas have been driven over the years by four main factors: (1) the introduction of New World crops such as potato and maize to mountain regions outside of the Americas – crops that are particularly well suited to mountain environments and that will have brought many nutritional benefits; (2) the eradication of diseases such as malaria in certain areas; (3) the introduction of modern healthcare; and (4) the increased opportunities to diversify livelihoods and thus reduce vulnerability in the event of crop failures. Whelpton (2005) suggests that a reduction in conflict is another important factor. In Nepal, life expectancy has improved from around 20 years in the 1930s to 70.25 years today (World Bank, 2016b). The consequences, of course, include an increase in elderly dependents which can be an economic burden on households. However, more positively from an economic standpoint, improved survival rates mean fewer households lose economically important members at a young age – something that can greatly undermine their capacity to cope with stressors.

In respect to fertility, there is some global variation in trends, but most mountain systems have seen a decline in recent decades (Funnell and Parish, 2001). In Nepal, the decline began in the 1960s (Feeney *et al*., 2001). The fertility rate went from roughly 6 children per woman prior to 1960, to 4.6 as of 1996, and to 2.12 as of 2016 (Feeney *et al*., 2001; World Bank, 2016a). This fall appears to have been driven by a number of modernising and developmental currents. Wealth, educational attainment, and urban residency are all negatively correlated with fertility rates in Nepal, while access to contraception and culture changes have also been highlighted as important (MHP, 2012a). The potential consequences of this for the ability of households to cope with stressors are explored later in the model simulations – this is something that been relatively unexplored up to now.

A final demographic factor of particular significance in mountain areas is migration. In places such as the Georgian Caucasus, this has predominantly taken the form of permanent out-migration in recent years (Kohler *et al*., 2017). While there has also been substantial permanent out-migration from Nepalese mountain communities, more significant has been the practice of temporary migration by young men seeking comparatively well-paid work abroad (Sunam and McCarthy, 2016). Government statistics obtained by *The Guardian* in 2013 showed that the number of migrants leaving annually had almost doubled since 2008 to near 400,000 – most of them heading to the Gulf states, Malaysia, and India, with the intention of returning at a later date (Pattisson, 2013). Remittances from Nepalese migrant workers now account for more than a quarter of Nepal's GDP, making them a significant contributor to poverty reduction and economic growth (ILO, 2016). In respect to stressors, remittances are important because they increase and diversify the income of recipient households – something that is captured in the model that is set out later. They can also help countries like Nepal cope with the youth bulge that labour markets are not always able to provide for. On the other hand, temporary emigration of individuals can result in social challenges, and may be a contributory factor to the reduced birth rate observed in recent years. The fact that these emigrants tend to be disproportionately made up of young adults has particularly important consequences for mountain communities, in respect to labour availability and the age structure of the remaining population (Sunam and McCarthy, 2016).

Many local labour markets are also changing in a way that is significant for mountain communities. In recent decades there has been a substantial rise in local off-farm paid employment opportunities in sectors such as construction and services (Parish, 2002). This reduces household dependence on agriculture and other traditional livelihood activities. In turn, this reduces their vulnerability to shocks within those livelihoods. That said, labouring opportunities can be sporadic. Of the twelve million Nepalese people that make up the domestic labour force, only two million are in regular paid employment (Acharya, 2015, p.24).

Another important economic trend in mountain areas is that of agricultural marketisation. Traditionally, most households with smallholdings will have been largely self-sufficient and consequently each village will have been largely independent of the next (Crone, 2013). Most mountain smallholdings will therefore have historically been classified within the bottom left corner of *Figure 3.5*. However, most mountain communities have now been at least partially incorporated into the global capitalist system (Parish, 2002). As mentioned in *Chapter 1*, rather than growing a plurality of crops with domestic consumption in mind, households are increasingly specialising their production with the intention of selling their output and then using the funds raised to buy an alternative mix of foodstuffs and goods (Crone, 2013). This integration into larger markets can have both benefits and drawbacks. On one hand, it exposes households to price fluctuations both for the produce they sell and the produce they buy, the negative potential of which was illustrated vividly during the global food price crisis of 2008 (United Nations, 2011). Climate change may well contribute to further food price spikes in the coming years (Porter *et al*., 2014). On the other hand, marketization and monetisation offers households access to the broader cash-centric economy and reduces their vulnerability to local crop failures which, as Crone (2013) notes, could often be fatal in earlier times.

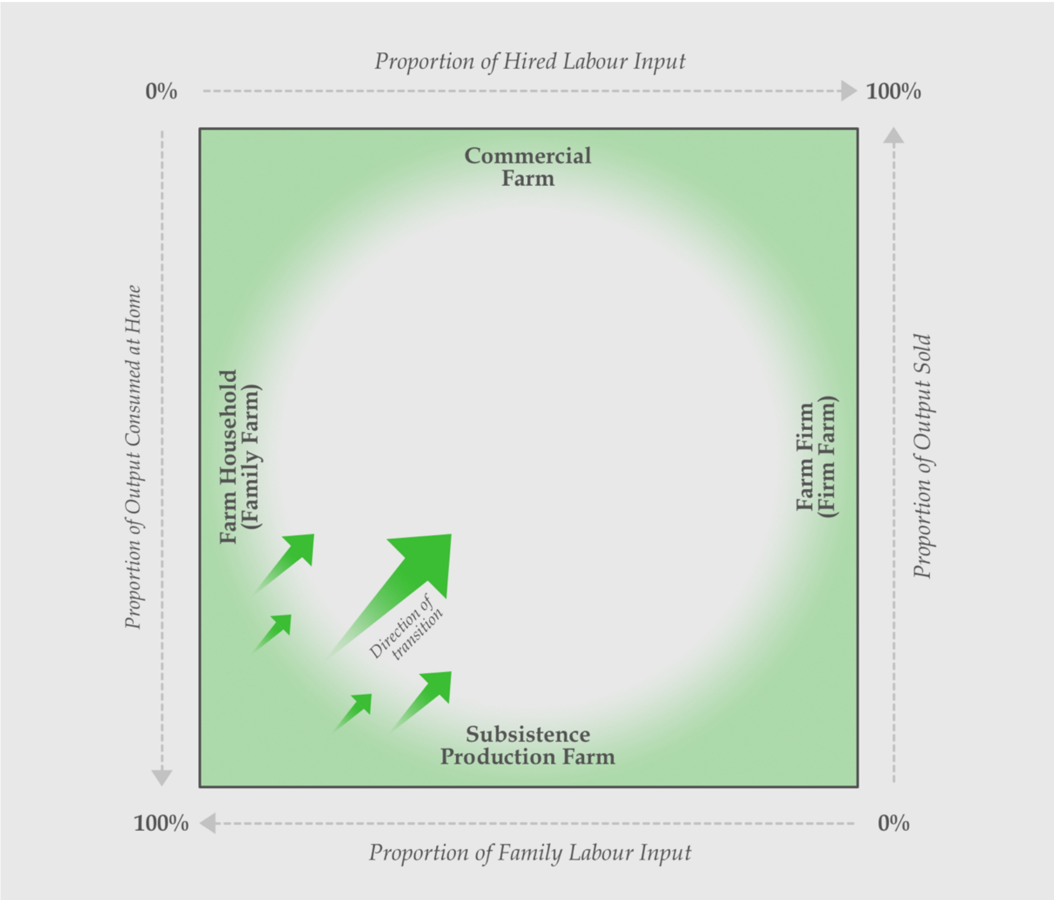

Figure 3.5. Farm classification system based on the proportion of family/hired labour used as input and the proportion of output consumed at home/sold. Farms rarely constitute a pure form of any of the categories. Instead they tend to sit somewhere within the labour/consumption continuums (Adapted from Nakajima, 1986).

Another important trend has been improvements to the connectivity of mountain areas and in the provision of services to mountain communities. As Crone (2013) points out, severely limited transportation and communication infrastructure meant that most previous generations will have lived in very local worlds. That has progressively changed in recent decades, although the technical difficulties and financial costs of building and maintaining infrastructure in mountain regions means they are still typically less well served than other areas (Funnell and Parish, 2001). These connectivity improvements have been critical to enabling the marketisation process discussed above, as well as many of the other developments. Consequently, they have had an indirect, yet important role in shaping stressor experiences.

A final set of factors of particular importance when it comes to mountain stressors are conflict, corruption, and political instability. Within nation states, mountain groups often constitute minorities. As a consequence, it is not unusual for them to feel they have limited voice within the political sphere. Funnel and Parish (2001) cite Thailand, Morocco, Turkey, and the Andean states as examples of where this has led to tensions. Differing values and priorities can create conflict over a variety of issues including land reform, forestry, water extraction, taxation, and development initiatives. Where groups feel particularly disenfranchised, it can even lead to violent conflict. Indeed, mountain regions have disproportionately played host to violent conflicts over the years (Rieder and Wyder, 1997). For example, civil war ravaged Nepal between 1996 and 2006, leaving 13,000 dead and 1,300 missing (Valente, 2013). Thousands of others were forced to endure economic hardship, displacement, and large-scale disruption to services as a consequence (OHCHR, 2012). Since the end of the war, corruption and political instability have continued to hamper the development of the economy (Acharya, 2015). In particular, frequent strikes have been a feature of life in Nepal and an impediment to economic development (Dixit *et al.*, 2009).[9] Such experiences can inevitably lead to difficulties for households and damage their future prospects, contributing to the maintenance of long-term vulnerability.

[9] The International Labour Organization (International Labour Organization (ILO), 2016) estimate that general strikes alone decelerated annual GDP growth by between 0.6% and 2.2% between 2006 and 2013.

3.3.4 Experience of multiple stressors in mountains

Of course, many of the stressors and processes discussed above occur in parallel, potentially interacting with one another and posing a collective challenge that is likely to be greater than the challenge posed by any one stressor alone (see *Chapter 2*). There is also a possibility that some of the processes have mitigating effects on one another. Some of the linkages between them have been touched on here, but as explained in the previous chapter, there is a need for much more research on how they affect one another and what their collective consequences can be. There is also a need for more knowledge on how impacts vary across scales – something that was lacking in much of the literature discussed above. Both of these issues are addressed in the coming chapters, using the innovative approach that is set out in *Chapter 6*.

3.4 Concluding remarks

The goal of this chapter has been to provide an overview of the socio-ecological and stressor contexts of mountain systems. Past research on mountain areas has also been summarised in order to highlight both the depth and breadth of existing knowledge, and some of the knowledge gaps. In doing all of this, the chapter has built on the previous one to demonstrate the significance of the challenges that many mountain communities face and the need for greater research on how multiple stressors could play out in the years to come. In the next chapter, the fieldsite selection process in outlined, as well as the fieldwork research tools. The fieldsite that was ultimately chosen has many of the characteristics that were discussed at the start of this chapter, and it is experiencing many of the stressors and processes of change that have been documented in section *3.3*. But as with all communities, it also has its particularities. Indeed, while the characteristics and processes discussed in this chapter are common in mountain systems, they are not necessarily universal. This is important to recognise.

Chapter 4: Fieldsite Selection & Data Collection

Fieldsite selection: Selection criteria & sites considered | Data collection methods | Analysis of findings | Approach to uncertainty, error, positionality, & ethics

In this chapter, the fieldsite selection process is explained along with the data collection methods. The former includes a discussion of the criteria that were used to shortlist candidate sites and to select the final site, plus an overview of each of the locations that were visited. The latter, meanwhile, includes an explanation of the data collection strategy and details of each of the data collection tools that were used. I conclude by discussing how I dealt with issues around uncertainty, error, and positionality, and I explain the ethical considerations which went into the design and implementation of the fieldwork. The fieldwork findings are then detailed in *Chapter 5*.

4.1 Fieldsite Selection

The diversity of mountain communities and environments within Nepal precludes the possibility of designing a generalised socio-ecological model of a Nepalese village. Instead, a case-study based modelling approach was chosen whereby an in-depth study of a single village was used to inform the design of the ABM subsequently outlined in this thesis. Case-study approaches allow complex phenomena to be explored within their context (Yin, 2008; Ford *et al.*, 2010). This is particularly valuable when the “boundaries are not clear between the phenomenon and context” (Baxter and Jack, 2008, p.545) – a condition that holds for many of the stressors operating on mountain communities. The focused nature of the case-study approach also facilitates the acquisition of a deep and rich understanding of the systems in question (Yin, 2008; Ford *et al.*, 2010). This is advantageous when it comes to modelling socio-ecological systems because it offers a detailed knowledge base upon which to make design and parameterisation decisions. Furthermore, fieldsites offer a clear baseline for model validation and verification, and they can help keep models naturalistic (Janssen and Ostrom, 2006). The main drawback of a limited case-study approach, however, is that it restricts the claims that can be made about generalisability of findings (Baxter and Jack, 2008; Ford *et al.*, 2010). That said, careful case-study selection can ensure a chosen fieldsite is reasonably illustrative of the issues at hand, and thorough sensitivity analyses of model parameters and components, can offer insights into how robust findings are likely to be across different contexts. Ideally, several case-studies would have been conducted across Nepal and, indeed, within other mountainous countries to further mitigate issues with generalisability, but time and resource constraints meant that was not possible for the purpose of this thesis.

4.1.1 Fieldsite selection criteria

To identify a fieldsite that constituted a reasonably representative example of a Nepalese mountain community experiencing multiple stressors, a purposive selection approach was used. Firstly, a shortlist of potential fieldwork sites was compiled based on the criteria set out in *Table 4.1*. The first three criteria enabled the narrowing down of potential study sites to a handful of regions, while the remaining criteria focused on identifying specific candidate villages within those regions that would be practical to work in from a logistical perspective. The latter criteria relied on the support and guidance of iDE, an American INGO that had recently collected data on a number of villages across Nepal as part of its own work identifying potential sites for development interventions. Their data included details of village names, locations, and population counts, and had been collected between 2012 and 2014. One of their Nepalese staff members was also able to advise on the accessibility and approachability of the villages. Combined with data from the Nepalese census (CBS, 2012), this information enabled me to assess the ostensible suitability of a variety of villages.

Table 4.1. Case study shortlisting criteria.

	Criteria
1	**Located in a mountainous region of Nepal.** The UNEP-WCMC definition of a mountainous region (see Huddleston *et al.*, 2003) was used in this case, as explained in *Chapter 3*. This criterion is clearly important given the focus of the study is on mountainous areas.
2	**Located in a region vulnerable to climate change and climate variability.** This judgement was based on the NCVST (Nepal Climate Vulnerability Study Team (NCVST), 2009) report on climate change vulnerability in Nepal. This criterion ensured that one of the main stressors of interest would be applicable.
3	**Located in a region undergoing economic and social changes.** This was assessed using a variety of sources (e.g. MHP, 2012b; CBS, 2012). The purpose of this criterion was to maximise the chance that the villages we scouted were experiencing a number of the stressors known to be important nationally.
4	**Village was known to iDE.** This was to aid identification of, and access into the communities.
5	**Village is within one hour's walking distance of a highway.** This increased the likelihood that the communities would be exposed to many of the processes of change that are currently being witnessed in Nepal. It was also important logistically.
6	**Village population did not exceed 250.** This was considered the practical upper limit if my research assistant and I were to be able to survey every household.

Working in conjunction with iDE greatly simplified the process of narrowing down candidate sites as it allowed a wealth of existing knowledge to be drawn upon. It also meant that I would have contacts at each of the shortlisted sites, facilitating initial access. On the other hand, several of the sites that were considered had gone on to receive support from iDE to construct new irrigation and domestic water infrastructure, somewhat contravening the stated desire for representative sites. However, as the villages were initially chosen by iDE because they had been under-privileged in respect to water access, the effect of the infrastructure improvements was primarily to bring access in line with that of most other communities.[10] The purposive selection approach to shortlisting as used here is inevitably more vulnerable to researcher induced selection biases than pure statistical reasoning or randomised selection methods. However, the limited amount of survey data and secondary information that was available proved the former infeasible and the latter rarely yields representative examples when the sample size being selected is so small (Seawright and Gerring, 2008).

In all, three villages were shortlisted based on the initial criteria in *Table 4.1*. As shown in *Figure 4.1*, they were each located in very different parts of the country, thus reflecting the diversity of social and environmental circumstance that is seen in Nepal's hills and mountains. Between October 2014 and February 2015, scoping trips were conducted to each site by my research assistant, Umesh Pariyar, and me. During these trips, we sought to assess the villages against a second set of criteria – those set out in *Table 4.2*. The first four criteria in *Table 4.2* focused on assessing how representative the sites were of typical rural Nepalese mountain communities, both in terms of their socio-economic characteristics and their exposure to stressors and national trends. The final criterion, meanwhile, focused on the pragmatic case for and against each site based on our ability to

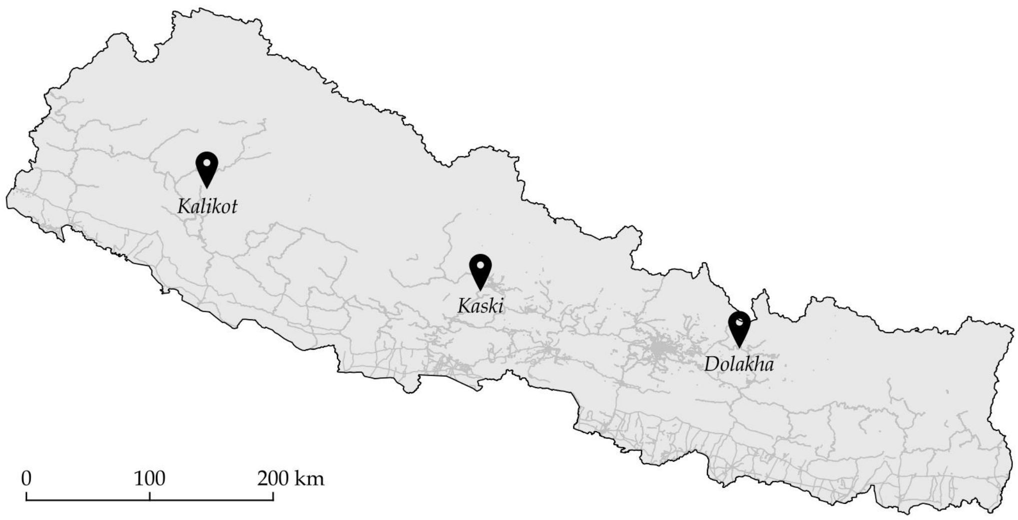

Figure 4.1. Location of the shortlisted villages, each of which was visited and assessed against the selection criteria. The labels refer to the districts in which the villages are located (Source: Author, 2015; OSM, 2015).

[10] For example, the projects would usually involve the construction of stand pipes near dwellings, negating the need for extended walks to traditional water sources. The latest Demographic and Health Survey (MHP *et al.*, 2012b) shows that this brings the communities into line with the 53.9% of rural households in Nepal that already had access to drinking water on their premises.

communicate clearly with the villagers, and what we perceived to be their willingness and enthusiasm to participate in the research. This was especially important for the research as for both ethical and practical reasons we wanted all of the households in our chosen fieldsite to be open to engaging in the project. The assessment process was based on discussions with groups from each village (consisting of the iDE contacts[11] where available, and between two and ten other men and women who were free during the ~3-4 hours we spent at each site) as well as somewhat ad hoc discussions with other people from the surrounding area.

Table 4.2. Final selection criteria for the fieldsite.

Criteria	
1	**Agriculture remains an important part of village livelihoods.** This criterion was chosen because agriculture continues to be the main livelihood activity in Nepal. This needed to be reflected in the fieldsite if it was to be considered reasonably representative.
2	**Village is at least half an hour away from an urban area.** This was important because the village was meant to be typical of a rural community.
3	**Circumstances of the village are not locally or regionally anomalous.** The purpose of this criterion was to ensure that the chosen village could be considered reasonably representative of its area.
4	**A number of nationally significant stressors and transitions are being, or have been, experienced within the village.** This criterion was vital for ensuring that the chosen fieldsite was typical in its experience of multiple stressors. The judgement was based on discussion with villagers about their perceptions/experiences of extreme weather, climate change, changing fertility preferences, migration, connectivity improvements, marketisation/ monetisation of their local economy, and changes in livelihood opportunities and the local labour market.
5	**Households are willing to partake in the research and are not experiencing research fatigue.** This was important as I hoped to survey every household. It was also critical from an ethical standpoint.

4.1.2 Site 1: Kaski District

The first site that we visited was in the district of Kaski, located around two hours' travel by vehicle and foot from Nepal's second largest city, Pokhara. The village was nestled high in the foothills that overlook the Annapurna mountain range, in an area with a relatively high precipitation rate (DHM, 2015) – a feature we had the honour of experiencing. It was also an area that was being intensively farmed as evidenced by the terracing that dominated the landscape. According to the iDE

[11] The iDE contacts were individuals who had been nominated by the community to liaise with the INGO. I therefore worked under the assumption that they were trusted and knowledgeable representatives of the villagers.

Figure 4.2. View of the village in Kaski district (Source: Author, 2014).

survey data, the community consisted of 46 households and almost 250 individuals, although these figures appear to have been based on a rather hazy demarcation of village limits. According to the iDE contact, his wife, and another man from the village (all aged between 40 and 60), the main occupation for most households was agriculture with a significant transition having taken place in recent years from subsistence crops towards vegetable cash crop farming, aided by new INGO funded irrigation infrastructure. A small number of households were also increasingly engaged in the tourism industry, aided by the village's location near the edge of the Annapurna trekking circuit. The shift towards cash crops and the rise of tourism both represented significant drivers of change for the village, although limited vehicular access was felt to be hindering their full exploitation at that time. The individuals we spoke to also told us that there had been substantial improvements in access to education and healthcare thanks to the relatively recent construction of a school and clinic in the village. The increase in male out-migration and inward remittance flows seen elsewhere in Nepal was also noted within the community. All of these changes are in line with the trends reported in *Chapter 3*. However, while the village fulfilled some of the selection criteria, it was apparent that it was far from being typical of other villages in the region or the country more broadly. The new irrigation infrastructure, school, and clinic were all funded by international donors, collectively demonstrating a level of development assistance that very few other villages will have received. Furthermore, no marked changes in the climate had been perceived by the villagers – a finding that ran contrary to the prevailing academic commentary (Nepal Climate Vulnerability Study Team (NCVST), 2009; Eriksson *et al.*, 2009; Bartlett *et al.*, 2010) and which breached another one of the selection criteria. Given this, the location was deemed unsuitable as a fieldsite.

4.1.3 Site 2: Kalikot District

The second location we visited was a village of 25 households in the Mid-Western district of Kalikot. Compared to the first site, this community was much more remote. Reaching the village from Kathmandu required a sixteen-hour coach ride to Surkhet, followed by a further twenty-four hours of travel and stay-overs along the famously dangerous Karnali Highway. District-wise HDI scores for Nepal place Kalikot third from bottom with a value of 0.374 (UNDP, 2014, p.15). By way of comparison, only two places have worse scores in the UNDP's (2015) country-wide assessments – the Central African Republic and Niger. Kalikot is not, however, unrepresentative of the region in which it is set. Many of the surrounding districts that, along with Kalikot, make up the Karnali Zone, share similar social, environmental, and economic challenges. Furthermore, the state of the region today reflects the state of many other parts of Nepal in decades past. It is therefore anomalous more in the sense of lagging behind than in the sense of being fundamentally different.

Figure 4.3. View of the village in Kalikot district (Source: Author, 2015).

Arguably the main contributing factor to the region's difficulties is its inaccessibility – the Karnali Highway, which is the sole road connecting the

Karnali Zone to the rest of the country, was only completed within the last ten years (WFP, 2010). However, the Nepalese Civil War – which affected the region badly – is also credited with severely hindering development (UNFCO, 2013; see *Chapter 3*). The community we visited was a short distance from the Highway with a population of around 150, made up of people from two of the lower castes – Dalit and Sarki. When we arrived, we spoke to a group of three women and two men (aged 22 to 55) who were gathered near the roadside. A number of other people subsequently joined them, curious as to what was going on. As in Kaski, we learnt that the vast majority of people were primarily engaged in agriculture and the village had benefited from the installation of new irrigation infrastructure in recent years thanks to international donors. However, rather than this leading to a reorientation towards commercialised farming, its main impact had been to simply improve the village's food security and nutritional intake through allowing them to grow a second crop of maize and barley and enabling an expansion of vegetable farming. As they remain water limited, they generate limited surplus which, one of the men explained, meant they could not attract wholesale buyers to the village, so they had to sell their surplus produce directly. Still, this increased food security is significant as it means they do not generally go hungry anymore, whereas in the past they say they sometimes had a "really hard time" pulling together two meals a day. Indeed, food security is a major issue for the region as it commonly produces insufficient food for its population (UNFCO, 2013). The irrigation infrastructure is complemented by standpipes within the village which have delivered a second significant benefit to the communities in that the taps negate the need to make the hour-long, twice daily round trip to their traditional water source. Consequently, they have more time to work their fields and search for animal fodder, while the children can now go to school on time – something that often did not happen previously. Nonetheless, educational attainment remains low in the village. Most young people, we were told, do not finish primary school, let alone get as far as completing their School Leaving Certificate exams.

Alongside the improvements to water access and its associated impacts, the Highway appears to have brought substantial benefits through making access to other towns and services much easier. The villagers told us how – prior to the building of the road – many people died while travelling to markets or seeking work elsewhere as a result of falling on the steep mountain paths, or being unable to find shelter when temperatures fell or the weather closed in. A trip to the nearest major market town, Surkhet, to barter potatoes for rice and salt would previously have taken around eight days, while taking up seasonal labouring opportunities in India would require a round journey of almost a month. Now both of those journeys can be completed in a couple of days. The road has also made access to smaller local markets easier and has brought more local labouring opportunities which offer further economic security to households.[12] Interestingly, we were told that this meant fewer of the villagers were now migrating abroad as a result which, if the case, would run counter to the trend seen elsewhere (see *Chapter 3*). Other trends do, however, mirror what has been witnessed across large parts of the country. Electricity came to the village several years ago, although the service has subsequently been cut off due to lack of payment by those in the local ward. Mobile phones have also arrived and are now widely owned – apparently even more so than radios which represent the main link to news and information from elsewhere in the region.[13]

The main environmental changes noted were a significant reduction in snowfall over the last decade and, in keeping with this, an increase in temperatures. The former was said to have particularly important consequences for farming as the snow acted, as they explained it, like a 'pesticide.' Other stressors of note were landslides during the monsoon season and shortages of fuelwood and fodder stemming from deforestation in the surrounding hills. Overall, it was clear that the village was beginning to feel the effects of many of the same forces that have acted on other parts of Nepal in recent decades as a result of the opening up of the Karnali region, making it a suitable candidate site. While it had received development assistance, it was more modest than in the case of the Kaski village and replication of such schemes in other communities in Kalikot may reasonably be expected over the coming years. Unfortunately, though, we encountered

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[12] For all the benefits of the road, it should be noted that travel along it is not always reliable or safe. The single lane, fair weather construction is vulnerable to landslides and collapse, can often be blocked by broken down vehicles, is not easily passible during the rains, and has been the scene of a number of serious accidents (UNFCO 2013).

[13] It was notable that none of the people we spoke to knew who their own Prime Minister was, let alone the President of the United States. They were, however, familiar with the region's Moist leaders – an observation that suggests information flows remain very local.

language difficulties which made communication hard, and my research assistant felt that there was limited enthusiasm about taking part in the research. Consequently, we opted to rule out the Kalikot site in addition to the Kaski site.

4.1.4 Site 3: Dolakha District

The final community we visited was located in the mountain district of Dolakha, around four hours travel from Kathmandu. Compared to the other villages it was relatively small at just fourteen households, although the neighbouring villages were so close that, as in Kaski, the demarcation between them was in many respects illusory. This time, we spoke to a group of ten men (aged between 16 and 57) who were chopping wood in preparation for a wedding. Once again, we learnt that livelihoods in the village were largely based around agricultural activities, with off-farm labouring and migratory work also constituting important sources of income for several households. And once again, new irrigation infrastructure had been installed, allowing households to grow a second potato crop each year and to increase vegetable and fruit production – usually with the aim of selling to agricultural middle men or directly to traders at the local market. During our discussions it became apparent that the community was also experiencing many of the other trends discussed in *Chapter 3*: a significant number of young men had emigrated for work, several going to the Middle East; educational attainment was rapidly improving with most of the children now expected to complete secondary school; connectivity had advanced significantly since the 1980s thanks to the construction of a nearby road connecting the district to Kathmandu; electricity had also arrived during the 1980s; mobile phones were now widely used by villagers; and, climate change was beginning to manifest itself through a reduction in winter snowfalls as had been experienced in Kalikot. Taken together, this meant the village comfortably fulfilled the criteria set out in *Table 4.2* for fieldsite selection in terms of stressors and transitions, and in terms of livelihoods and economic status. Furthermore, communication with the villagers proved relatively straightforward and the community was interested and receptive to the research. The relatively small size of the population also meant it was realistic to survey every household in detail despite having limited resources. Consequently, the site was chosen for the main fieldwork phase of the project and forms the basis of the model subsequently discussed in this thesis. It was clear that the Force was strong with this one. Henceforth, it will be referred to by a pseudonym name: Namsa.

Figure 4.4. View of the village in Dolakha district (Source: Author, 2015).

4.2 Data Collection

The majority of the fieldwork at the chosen site was conducted during March and April 2015, with a week-long follow up visit occurring in March 2017. The purpose of the initial fieldwork was to gather all of the data necessary to design and parameterise the ABM which meant collecting – in a thorough and systematic way – information on almost every aspect of village life. It also meant assessing the trajectories of change the village was on and the possible future pathways that that change could take. This was done because the model was going to be simulating an extended period of time – fifteen years as it ultimately transpired – so the village's future evolution needed to be taken into account alongside potential future stressors. The follow up visit, meanwhile, involved gauging the impact of the April and May 2015 earthquakes on the village and obtaining feedback on tentative designs for the ABM as part of the model validation process.

During the course of the fieldwork, a variety of data collection techniques were employed. The early stages were characterised by the use of relatively non-prescriptive exploratory methods, designed to provide a holistic overview of village life and to identify topics potentially unforeseen when the fieldwork was originally planned, but which merited inquiry (Weller and Romney, 1988).

Building on the outcome of these initial activities, a range of more formal techniques were then used to generate the detailed, rigorous datasets required for the modelling – some quantitative and some qualitative. The adoption of a multiple methods approach is valuable not only because it allows findings to be cross-checked, but also because it ensures that issues are explored through a variety of lenses, enabling the multiple facets of the phenomena of interest to be "revealed and understood" (Baxter and Jack, 2008, p.544). Most of the methods employed are used commonly within ethnographic research including participant observation, household surveys, focus groups, and secondary data analysis, meaning there were many examples of good practice that could be drawn upon to inform their design. However, several of the tools also included innovations that helped tailor them to the particular needs of the modelling process.

4.2.1 Village walk and village mapping

The first task undertaken at the fieldsite was a village walk. This simply involved my research assistant and me exploring the village and the surrounding area on foot, guided by a member of the local community (a 26-year-old male). This allowed us to familiarise ourselves with the site and to map key features such as dwellings, footpaths, roads, water points, and approximate village boundaries. The tour also gave us an opportunity to ask some initial questions about day-to-day life in the village and to re-introduce ourselves to the villagers, many of whom we had previously met during the earlier scoping trip. We used this opportunity to once again explain the nature of the research we planned to conduct and to answer any questions that arose. We also made clear that informed consent would be sought prior to individuals or households being involved in any of the research activities.

4.2.2 Wiki

The next stage of the fieldwork involved the creation of a comprehensive summary of information about the village and its surrounding area in the form of an encyclopaedic wiki. To do this, two villagers – one male and one female (both 26 years olds) – were recruited to provide details on a near-comprehensive hierarchy of topics with their responses being typed up as mini articles by my research assistant. This was primarily done while the four of us sat in a café beside the highway, a half-hour walk up from the village – the purpose being to minimise the chance of interruption. However, we also did some of the work in the village and in a few cases the recruits worked by themselves, bringing their notes to us later in the day to be translated and typed up by my research assistant. This enabled them to consult with others about topics they were less sure about. A gender balanced team was chosen for the wiki due to the potential for knowledge and perceptual differences between men and women in the village (Momsen, 2006). The individuals who were recruited were chosen because of their availability during the first week of the fieldwork and their ability to write in Nepali. During the follow-up fieldwork in 2017, an additional individual was recruited to help fill some of the gaps in knowledge in the wiki, particularly around livestock rearing. This was a woman in her 50s who we were able to talk to as she prepared aggregate for the new home that she was having built. Being from an older generation, she was not able to write so my research assistant transcribed to paper what she said as she spoke.[14] Her recruitment was based on her availability and experience with animals. We also tried to work on the wiki with another man and women of a similar age, but we had difficulties in focusing the discussions on the particular topics in hand, so we abandoned the plan.

The topic categories that were covered in the wiki included village history, geography, demographics, culture, services and connectivity, politics, education, health, water and sanitation, energy, housing, livelihoods, and economics – these categories reflect the main topics that I encountered in the ethnographic literature (Miller, 1990; Fricke, 1993; Adhikari, 2000; Whelpton, 2005). Within each of the categories several sub-topics were suggested, with the addition of further sub-topics encouraged as new subjects arose in discussions. After each session working on the wiki, I would look through the typed-up articles and make notes where I wanted further details or clarifications, with these points then addressed during the next sessions. While the bulk of the wiki took around a week to complete, further refinement and crosschecking continued to be done for the duration of the fieldwork.

[14] These notes were then typed up during the evenings.

The use of the wiki method, while not conventional, offers a number of benefits when it comes to the type of research outlined in this thesis. Firstly, wikis are a knowledge management system well suited to handing “non-linear, evolving, complex and networked text” (Wikipedia, 2016).[15] Given knowledge and understanding continually evolve over the course of fieldwork and given rural communities represent complex socio-ecological systems which do not lend themselves to linear explanation, these attributes are highly appropriate. Secondly, the method – as exemplified by Wikipedia – lends itself to collaborative content production and thus allows participants significant agency in the research. In this case the recruited villagers dictated the content of the articles and they were able to add topics as they saw fit – my role was simply to ensure as-broad-as-possible coverage of topics and to ask probing questions where articles seemed underdeveloped or lacked clarity. The wiki, therefore, also had the related benefit of reducing the power of researcher preconceptions on shaping the data that was gathered. Thirdly, the hierarchical, interconnected, almost algorithmic logic of wikis closely fits with the logic needed in ABM design. It reduces complex systems to neat, digestible elements[16] while not divorcing these elements from context. Finally, the process of writing and testing ABMs can reveal all sorts of surprises when it comes to identifying what processes and entities are important within a wider system. Going back to a fieldsite after initial data collection is not always possible so by covering a near-comprehensive set of topics, wikis hedge against uncertainty when it comes to determining what data to collect. The downside of the method, however, is that writing a near-comprehensive set of articles is very time consuming. For this reason, rather than being asked to volunteer their time, the villagers who assisted with the wiki were paid a daily rate. Mindful that the choice of recruit could influence the content of the wiki, a gender balance was sought, as mentioned earlier. Other studies might also consider the potential implications of ethnic, caste, age, and socio-economic differences between potential recruits, but I felt these would have marginal impact in this instance. This is because all of the villagers were Tamang, inequalities in wealth were not overly

[15] While citing Wikipedia is usually frowned upon in academic circles, it is arguably the authoritative voice in this instance, so I beg forgiveness.
[16] ‘Wiki’ comes from the Hawaiian word for ‘quick’.

stark on a per capita basis, and the recruits engaged with others in the village where necessary to cover their knowledge gaps.

4.2.3 Household survey

The third method employed was a detailed household survey. This allowed descriptive data to be collected on household composition, assets, income, expenditure, livelihoods, farm characteristics, produce, food security, water consumption, sanitation, and preferred coping mechanisms. The income, expenditure, and produce data was collected for the twelve-month period leading up to our visit, while the other household data was documented simply for that moment in time. The survey also enabled the collection of individual level data such as the age and gender of household members, their relation to the head of household, education level, main occupation, migration history, and household duties. The migration history was asked for the previous decade (although some detailed it right back to the start of the millennium), while the other individual-level data was captured, again, just for that moment in time.

The survey was designed primarily with the parameterisation needs of the ABM in mind, but it also helped provide context to some of the *how* and *why* questions that were explored using the other data collection methods. While some of the survey questions were bespoke to the fieldsite, many of them drew inspiration from the Demographic and Health Survey (MHP *et al.*, 2012a) and from ICIMOD's 'Framework for Community-Based Climate Vulnerability and Capacity Assessment in Mountain Areas' (Macchi, 2011). This helped ensure incorporation of regional best practice and meant many of the questions had already been well tested in the field. Nonetheless, the survey was piloted with two households[17] before the final design was locked down. One change was made following the pilot: the length of the survey was shortened to reduce the demands it placed on respondent time. Following this, the survey was administered to the remainder of the households in the village. This 100% coverage meant the possibility of non-response bias was avoided. However, other challenges did arise when the surveys were administered. In particular, we struggled to obtain accurate land ownership

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[17] I was able to include these pilot surveys in the final data as none of the questions changed.

Figure 4.5. Household surveys were conducted with all fourteen households (Source: Author, 2015).

information from some households, sometimes because of the fragmented nature of their holdings and sometimes because the interviewees simply did not know. We therefore needed to use the volume of seeds these households had planted over the previous year for each of the crops they grew in order to estimate the likely quantity of land farmed. This was possible because during the resource flows focus groups (see section *4.2.4*) we had been able to get a reasonable consensus on the way that volume of seeds planted translates into land area for different crop types. As it transpires, Fricke (1993) encountered a very similar problem during his study of a Tamang village in Nepal decades previously and used exactly the same methodology to overcome it.

The wide-ranging topics covered meant even the shortened survey often took over an hour to complete. While relatively long, this did not prove to be a significant obstacle as it was usually possible to conduct the survey while respondents were going about their daily activities, whether that be feeding livestock, weeding their potato crop, caring for children, or cooking dinner. This approach proved valuable as it meant that we could minimise disruption to the respondents and, in doing so, maximise our response rate. It felt like the informality and familiarity of the contexts also allowed people to relax and open up more than they might otherwise have done. Furthermore, as yards and fields are essentially considered social spaces in Namsa, there was never much sense that we were encroaching on someone's personal space by spending time with them there. In terms of arranging the surveys, recruitment was done a day or more in advance of them being administered in order to give households time to consider whether or not to participate and to allow us to determine a mutually suitable time to run through the questionnaire. In each case we sought a senior member of the household to be the lead respondent in order to ensure they would have the requisite knowledge of household matters, though it was not uncommon for multiple family members to ultimately assist. We found that this actually helped people with the questions that required a degree of recall or estimation as they could deliberate over their answer together.

4.2.4 Focus groups

At the same time as administering the household surveys, we also conducted a number of focus group discussions. These discussions provided an opportunity to explore people's perceptions, opinions, and experiences with regards to a range of topics. In this way, the focus groups served to answer many of the outstanding *how* and *why* questions not covered by the other methods, as well as offering an opportunity to discuss community level issues, and a chance to validate content from the wiki. Focus groups are a valuable tool in ethnographic research because they allow people to describe and explain the complexities of their lives (Valentine, 1997)[18] and they can help determine which perceptions, opinions, and experiences are common within a community and which are not (Gibbs, 1997). Furthermore, the interactive nature of focus groups can be valuable in aiding recall of historical events or factual information as they let people question and prompt one another, facilitating exploration of pooled memory.

[18] Valentine (1997) described this as an attribute of interview methodologies in particular, but it can also very much apply to focus groups.

A total of seven focus group discussions were conducted during the main fieldwork, each involving between five and twelve participants (see *Table 4.3*). Some of the participants took part in more than one focus group. The discussions were guided by my research assistant who would explain the purpose of the focus group, ask questions on the topics we wished to cover, probe for details, and manage group dynamics in an effort to promote broad participation and debate. He would also provide *in situ* translations for me so that I could follow the discussions, interject questions, and ensure the objectives of the activities were being accomplished. The focus groups typically took between sixty and ninety minutes – roughly the limit of what most people could spare – and usually occurred early in the morning before people dispersed for the day.

Table 4.3. Overview of focus group participants.

Focus group	Female participants	Male participants	Age range
Community history / Institutions	3	2	24 to 84
Seasonal calendar	8	2	24 to 71
Resource flows	2	2	26 to 58
Decision-making / Typical life (Male)	0	5	24 to 63
Decision-making / Typical life (Female)	7	0	19 to 71
Young persons	2	3	13 to 26
Multiple stressors	3	3	24 to 63

The main challenge that we found was in engaging some of the older female participants and the younger women (those who had married into the village) as they tended to be more reticent. We discovered that the other members of the village were better at drawing them into the discussions than my research assistant was when he attempted to engage them directly. We therefore encouraged this. Another challenge was in keeping the discussions on topic. We found that some of the participants had a tendency to launch into long anecdotes, the relevance of which was often not at all clear. My research assistant would try to ask probing questions in an effort to understand how what they were saying linked to the topic, but this was not usually successful. As is common, there were also times when one individual would essentially dominate discussions, with others deferring to them (Smithson, 2000). Often these contributions were insightful, so we did not prevent them, but we did need to make an active effort to allow others the chance to interject.

- *Community history:* The first focus group aimed to identify significant events in the community's history, especially those that influenced livelihoods, activities, and wellbeing. This helped provide historical context to the current state of the village and gave a sense of the rate of change over the previous half-century. As it can be challenging to recall events and corresponding dates, we organised the discussion around a visual timeline with major milestones set out first to act as an *aide memoire* – an approach suggested by Macchi (2011).

- *Institutions:* Following the community history exercise, we discussed local institutional arrangements with the same focus group. The aim was to identify organisations and groups that play an influential role in village life, to understand how they function, the role they fulfil, and where decision making power lies. In particular, we were interested in those groups that played a role in livelihood activities and in supporting households in the event of shocks and stressors.

- *Seasonal calendar:* The next focus group discussed monthly changes in the climate and environment over the course of a typical year, as well as intra-annual changes in livelihood activities. This was useful for establishing the links between the various human and non-human dynamics and for understanding the ebb and flow of labour demand, land use, income, expenditure, and migration. The activity also provided an opportunity to discuss variability and change in the climate, and the impact of this and other historical changes on seasonal livelihoods. As age and gender can have a strong bearing on livelihoods and perceptions of change, a particular effort was made to include a cross section of the community in the focus group.

- *Resource flows:* The resource flows focus group was intended primarily as a sanity check for the production, consumption, income, and expenditure values obtained through the household surveys. For agricultural activities, inputs per unit of land were quantified and costed for each of the crops grown in the

Figure 4.6. View of one of the larger mixed gender focus groups (Source: Author, 2015).

village, and average output was estimated, as was sale value. Meanwhile, typical wages were discussed, and individual level consumption of foodstuffs was estimated and costed. This information was required to calibrate the resource flows in the model and also to inform the market interaction submodels. Given the particular knowledge required, participant selection was biased towards those who were involved in buying, selling, and using produce.

- *Decision-making:* The task of this focus group was to explore the decision-making process employed by villagers in respect to a range of different issues, and to discuss who within a household makes those decisions. The issues covered included major and minor household purchases, loans and savings, livelihoods, migration, agriculture, conflicts, crises, day-to-day life, family planning, and relationships. In each instance, we sought to provide an example scenario in addition to discussing the issue directly as we found the scenarios helped elicit more nuanced explanations. Care was also taken to identify how decisions were made under conditions of uncertainty or limited information. Ultimately, the intention was to craft decision trees based on the discussions, and to translate these into the agent decision-making mechanisms in the ABM, although only a few of the issues discussed ended up being explicitly modelled (see *Chapter 6*). For the decision-making focus group, two groups were separately convened – one all-male and one all-female. This was done because of the potential gender sensitivities of the topic. However, within each group, we sought a cross section of ages as with the other discussions.

- *Typical life:* The typical life focus groups looked to identify the life course of a typical male and female villager from the community, including phases such as school and milestones such as marriage. Variability in the frequency of occurrence and timing of each phase or event was also discussed as was generational changes – for example, very few of the villagers over 40 years of age went to school, but all youngsters now do so. The all-male and all-female participants from the decision-making focus groups also formed the focus groups for this task because of the gender specific nature of the discussions.

- *Young persons:* The penultimate focus group was conducted with young people between 13 and 26 years-of-age to discuss their day-to-day lives and their plans for the future. The former topic focused on daily routines, holiday and exam periods, education costs, and involvement in household chores and labouring, while the latter topic was orientated around issues relating to education and livelihood opportunities – two of the most important factors governing their long-term options and, consequently, the village's future. To aid translation into model parameters, preferences and perceived probabilities were placed on a wide range of possible education and livelihood pathways.

- *Multiple stressors:* The final focus groups explored the various stressors and shocks that the community recalled experiencing. In particular, we discussed the frequency, timing, and impact of these events, and the response of the villagers to them. Hypothetical questions were also posed in an effort to gauge likely responses to possible future scenarios that had no historical analogue at that time. The focus group required participants from a broad cross section of the community as different pressures are pertinent to different people and perceptions can vary considerably between individuals.

4.2.5 Participant observation

The final method used during the main fieldwork phase was a form of participant observation known as process tracing[19] (Bennett and Checkell, 2015). Four community members were shadowed for a day as a means of establishing individual daily schedules and time budgets. Through asking the participants to describe their various actions in real time, along with the reasoning behind them, it was possible to gain further insights into their life worlds and their decision-making processes. We spent most of the daylight hours with the participants, asking them to explain what they had done or were going to do during the periods when we would not be present to fill in the blanks and allow us to construct a complete 24-hour timeline. As roles vary by villager, we recruited individuals from across the age spectrum and from both genders. Nonetheless, significant limits to representativeness do arise from the fact that the main livelihood activities people engage in vary substantially across time – a reality that must be recognised when analysing the timelines.

Figure 4.7. Three individuals were shadowed for a day in order to observe typical daily schedules (Source: Author, 2015).

4.2.6 Secondary data

In addition to collecting new data, a substantial number of existing texts and datasets have been explored in order to fill certain knowledge gaps, to aid

[19] Process tracing is a technique for examining the underlying reasons behind human behaviour. It originated in the field cognitive psychology (Bennett and Checkell, 2015).

parameterisation decisions, and to allow sanity checks to be performed on the data collected at the fieldsite. For example, the birth timing probabilities that are used in the model (see *Chapter 6*) are drawn from a paper by Karkee and Lee (2016), the mortality probability distributions are derived from the 2015 WHO (2016) life table for Nepal, and the calorific requirements of the agents are based on data from MoAD (2012). A number of the sources cited in *Chapter 3* were also drawn on to guide the design of the model stressor scenarios, and to assess in what respects the fieldsite is and is not typical of other Nepalese villages. Secondary sources are therefore frequently cited alongside the fieldsite data in *Chapter 5* where the particularities of the village are discussed.

4.3 Analysis of Findings

The data that were collected using the various methods described above is drawn together in *Chapter 5*. The wiki formed the framework for this synthesis. The focus group, household survey, participant observation, and secondary data was coded thematically according to the same categories that were used in the wiki. I then re-wrote each section of the wiki to reflect the additional details that were elicited from these sources. When the non-wiki data did not fit within the existing categories, new categories were added. For the most part, the non-wiki data simply added depth and detail to what was already in the wiki, but just occasionally there was a contradiction. As the wiki had been created early on during the fieldwork, most of these contradictions could be investigated while I was still in the field, enabling an explanation to be found and, with it, resolving the conflict. However, in a few cases, the contradictions were not noticed until after the fieldwork. To deal with this, a list of these issues was compiled for discussion with the original wiki authors during the follow up fieldwork in 2017. A decision was made following these discussions on which of the conflicting findings would be considered valid for the purpose of the modelling exercise.

The quantitative data typically required an additional stage of analysis before it was integrated into the wiki framework. Usually, this involved little more than calculating basic descriptive statistics. However, in a few instances, regression techniques and timeseries analysis were drawn upon. In designing the model, further data processing and analysis was also conducted, as explained in *Chapter 6*. For example, probability curves were fitted to life table, fertility, and marriage data, and data on villager life courses was mapped into probability trees.

4.4 Approach to Uncertainty, Error, Ethics, and Positionality

A number of challenges and limitations were encountered during the data collection process - some of which have already been touched upon. While in many instances, issues could be overcome through the use of well-established research tactics, others proved more intractable. Aspects of the research also raised questions around positionality and ethics. Again, many of these issues could be addressed through careful planning, but others problematise the act of fieldwork at a more fundamental level. It is therefore important to reflect on the potential implications of research limitations, positionality, and research ethics.

4.4.1 Uncertainty, error and sufficiency

Many of the challenges outside of the positionality and ethics questions come back to matters of uncertainty, error, and sufficiency. One of the issues we frequently faced during the fieldwork was respondents expressing uncertainty about their answers. Several examples of this were discussed in the preceding section – difficulty recalling events and exact dates during the village history focus group, and doubts over land ownership figures. It was often possible – depending on the particular circumstances – to derive approximate answers or boost confidence in answers through the use of proxies, *aide memoires*, and collective discussion. Ultimately, however, a degree of uncertainty typically remained. Where such data is referred to in this thesis, this is explicitly recognised.

Some possibility of error and misjudgement also exists within the field data. Error and misjudgement can be caused by a number of things. These include cognitive biases such as the availability heuristic (Tversky and Kahneman, 1973), social desirability response bias (Edwards, 1957), the misinterpretation of questions by respondents, and the misinterpretation of the answers or observations by my researcher assistant and me. To reduce the chance of such issues affecting the results, multiple data collection methods were used (as discussed above) so that most of the findings could be triangulated – an approach recommended by Flick (2000). Comparison of field data with secondary data also allowed sanity checks to be performed in many instances, although this approach is arguably only effective at detecting clearly anomalous data.

A further approach that can be used to curtail uncertainty and error, and to increased depth of knowledge, is simply spending more time in the field. The more time researchers spend at a site, the more they can immerse themselves in the local culture, and the more they can examine the socio-cultural dynamics of a community (Whitehead, 2005). Given the significance of seasonal changes on livelihoods and social rhythms, spending a year or more in the village would probably have been ideal. Indeed, this is something that many anthropologists seek to do. However, due to time and resource constraints, this was not possible in this instance. Still, the extent to which this can be considered a significant limitation can be overplayed. Substantial data can be collected within a relatively short period, and extended fieldwork can be affected by diminishing returns. Furthermore, it should be recognised that fieldwork represents something of an intrusion into village life – one that may be welcome for a short period, but that may prove attritive over time. Thus, a balance must be struck. Social science research is rarely going to elicit perfect, error-free, uncertainty-free datasets. The aim instead needs to be to gather datasets that the researcher has high confidence in; datasets that are sufficiently robust overall as to make negligible the effect of any potential imperfections.

4.4.2 Research ethics

Fieldwork – especially cross-cultural fieldwork – raises a whole plethora of ethical issues which must be recognised and addressed in advance of the work commencing. Before all else, researchers need to consider the potential effects that their fieldwork activities and research outputs could have on the subjects of the study and put adequate safeguards in place to protect the rights, dignity, and welfare of those people (Association of Social Anthropologists, 1999). This process is helped a great deal by the wealth of guidance made available on good ethics practices by individual academic institutions (e.g. University of Leeds, 2016) and by groups such as the Association of Social Anthropologists (1999). Much of this advice is reflected in the ethics application (ref. AREA 14-103) that was submitted to the University of Leeds Ethics Review Committee and which gained approval in advance of this study. This document formed the basis of how my research assistant and I conducted ourselves at the fieldsite and how the data has subsequently been handled. Advantageously, my research assistant had assisted with another University of Leeds project shortly before I recruited him, so he already had an understanding of how to undertake research and how to conduct himself in the field.

One of the leading ethics issues identified was the need to obtain informed consent from participants in the study prior to their involvement in any of the research activities. In particular, it was important to explain the nature of the project, the activities they were being asked to partake in, what data was to be collected, how that data was to be used, and the measures that would be taken to ensure their confidentiality and anonymity. Furthermore, the voluntary nature of their involvement was emphasised along with their consequent right to decline answering certain questions or to wholly discontinue their involvement in an activity at any point prior to the data being anonymised, should they wish. All of these issues were explained verbally when participants were recruited for an activity – something that usually occurred a day in advance to provide them with sufficient time to make a considered decision – and once again at the start of the activity proper. A Nepali language information sheet was also offered along with the opportunity to ask questions. As many of the older villagers could not read, this sheet was read to them. Prior to the activity commencing, each of the participants was then asked whether they understood the implications of taking part and whether they consented to being involved. Verbal consent rather than written consent was sought due to the low literacy rates in the village.

Ensuring the confidentiality of the participants was an important concern as a great deal of personal data was gathered, some of which may be considered sensitive. A number of measures have therefore been taken to make it extremely difficult to trace the data presented in the research outputs back to specific individuals or households. Firstly, a pseudonym has been used for the village.

Secondly, certain other details that could overly assist in identification of the fieldsite have been omitted. And thirdly, no individuals or households are named.

A different issue, though one closely related to the voluntary nature of involvement, was that of participant compensation. One of the principles the Association of Social Anthropologists (1999) set out in their ethics guidance is that researchers "should do their utmost to ensure that they leave a research field in a state which permits future access by other researchers". This means treating participants in a way that ensures their continued good will towards the research community, but it also means not elevating expectations among participants that they will be financially remunerated for participating in research. Such expectations can create barriers for other researchers who do not have the means or the authority to remunerate. Furthermore, financial remuneration is arguably coercive in that it may unduly sway into participating individuals who would not otherwise choose to take part (TREG, 2016). For this research, a decision was therefore made not to provide financial remuneration except in the case of the individuals recruited to assist with the wiki, as this involved a week of work and therefore a significant opportunity cost in respect to paid labouring. It was also deemed reasonable and appropriate to provide compensation in the form of food and soft drinks for those participating in focus groups given the time they took and the inconvenience the activities caused to morning routines.

On a more philosophical level, there are also ethical questions surrounding the very legitimacy of conducting cross-cultural fieldwork, with many of these questions stemming from post-modernist critiques of historical practices. As Scheyvens and Leslie (2000) explain, numerous past studies conducted by western researchers in developing countries have been criticised for being exploitative, for not adequately reflecting on the implications of researcher positionality, for neglecting the possibility of multiple cultural readings, for disregarding the impact of power imbalances between the researcher and participants, and for ignoring certain voices (Chambers, 1994a; Chambers, 1994b). The exploitative claims are based on the belief that many past research projects were ultimately of no benefit for the countries or communities concerned – instead, the benefits that were accrued were often associated with the researchers' own career advancement

(Scheyvens and Leslie, 2000, p.120). This has led to researchers being asked to justify their studies as part of many ethical review processes (e.g. University of Leeds, 2016). In the case of this thesis, it was felt that the research questions that were being pursued were highly pertinent to the participating community as well as numerous similar communities. Furthermore, it was felt that these questions were as yet inadequately understood, thus the research was deemed to be merited on the basis that it would contribute to filling important knowledge gaps. The community was made aware that they would receive no direct near-term benefits for participating, but they were kept informed of research findings and they were given the opportunity to discuss the research implications and to ask questions.

4.4.3 Positionality

Positionality concerns relate to the idea that many academics, in seeking to present an objective scientific demeanour, historically downplayed or wholly ignored the role of their own gender, class, race, nationality, politics, history, and experience in shaping their research and their interpretations of the world (Schoenberger, 1992, p.218). Today, by contrast, the positionality of the researcher is widely recognised as having an inescapable influence which must be reflected on, rather than denied (Valentine, 1997; Twyman *et al*., 1999).[20] For example, it is now recognised that different presuppositions can lead to different interpretations of evidence; rather than there being a single objective truth, there can be a plurality of valid readings (Paltridge, 2012). In light of these issues I have looked to critically scrutinise my approach to the research throughout the fieldwork and analysis stages, and I opened the ABM to scrutiny by the villagers to allow them to critique my interpretations. Furthermore, I was able to draw on the advice of an experienced Nepalese research assistant. Nonetheless, my positionality *will* leave an indelible influence on the research, but this should not necessarily be seen as a negative. There can be a great deal of value in approaching a research subject as an outsider. It is also important to reflect on the significance of my research assistant's background. In common with most of the villagers, he is Nepalese, was brought up in a rural community, and speaks Nepali. He was also of a similar age to a number of them at the time. These things will have helped him to build a

[20] Nonetheless, it is arguable that latent ideology still heavily informs many research framings, especially within the grey literature.

rapport and understanding with the respondents, as will his naturally empathetic personality. On the other hand, he is male, has a different ethnic background, is from a different part of the country, and was working for me – things which potentially marked him as an outsider. However, he felt at ease in the community and seemed well liked. In an effort to develop a deeper understanding of life in the village and to improve our relationship with the villagers, we ate lunch with one of the households each day, we would drink tea and chat between tasks, and we would socialise with them in the early evening. That said, during the main fieldwork phase I was always aware that I was an outsider. This was much less the case when I returned in 2017. The fact that I was now a familiar face made a difference, as did our mutual experience of the earthquake and its aftermath.[21] There was a sense that I could perhaps understand what they had been through – at least in part. For a couple of the men, it was also significant that I had honoured a promise to return. During the main fieldwork, they had expressed their frustrations that people often just disappear after getting what they need.

Concerns around power imbalances between researchers and participants are also nested within the debates around positionality. As Valentine (1997) notes, researchers typically occupy a privileged position relative to the subjects of their study, especially when the fieldwork is being conducted within developing world contexts. One way this manifests itself is through the researcher having control over the subject of the research, the methods of research, who is allowed to speak, what is recorded, and how the data gathered is represented in research outputs (Paltridge, 2012). Another way is through the generation of expectations on the part of respondents that can lead them to "feel beholden to cooperate with researchers" (Valentine, 1997, p.124). The latter issue is one of the core reasons that informed consent procedures now place so much emphasis on explaining participant rights, while the former is a core driver behind the growing interest in participatory and collaborative research – both of which were approaches adopted during the fieldwork for this project. While there is often a focus on the negatives in fieldwork critiques, it should be recognised that if done well, research can be a positive and empowering experience for participants, providing them with a

[21] Even though I had been in Kathmandu at the time of the earthquake, rather than in Namsa.

chance to voice their concerns, share their opinions, and affirm their self-worth (Pratt and Loizos, 1992; Scheyvens and Leslie, 2000). One of the ways that I tried to mitigate the impact of power imbalances was to let people ask questions about me and where I am from when they were curious. It seemed only appropriate that I should be as open and willing to talk as they were being. We also spent time with people when not conducting research so that we did not seem like we were solely interested in extracting information. And throughout the whole fieldwork process, we travelled, slept, and ate just like local Nepalese people travelled, slept, and ate. Furthermore, I deliberately employed a number of fieldwork tools that offered the villagers scope to shape discussions within the topic areas of interest so that they could exercise a degree of agency.

The concerns around neglect of certain voices, finally, are a result of past studies frequently ignoring or misrepresenting certain groups, or allowing others to speak on their behalf (Scheyvens and Leslie, 2000). Historically this has been particularly so in the case of women, a factor that has led to many recent studies making concerted efforts to ensure they are heard. In this research, single gender focus groups were used in certain instances for this reason. Although these focus groups relied on my male research assistant to chair them, they did allow the women to express their thoughts without the potential for interruption or challenge by the other men. Furthermore, it stopped the men from framing the discussions from the off. Similarly, a young persons' focus group was held so that young people would be able to speak freely for themselves without needing to be overly concerned about what the older generations might think.

4.5 Concluding remarks

In this chapter, an overview of the fieldsite selection process has been provided, along with details of the data collection and analysis methods that were employed. The approaches taken to dealing with issues of uncertainty, error, positionality and ethics were also outlined. Data collected at the chosen fieldsite using the data collection tools set out here is presented in *Chapter 5*, which is formatted like a pared-down version of the expanded wiki that was discussed in section *4.2.2*.

Chapter 5: Fieldsite Ethnography

Community history | Demographics | Housing, land & inheritance | Culture | Education & health | Livelihoods | Wealth, income & expenditure

This chapter presents and overview of the findings from the data collection phase. It takes a deep dive into the various features and processes that shape village life in Namsa and discusses, within this context, the stressors and drivers of change facing the community. It also looks at how the particularities of the fieldsite sit in relation to mountain communities elsewhere in Nepal, identifying both commonalities and idiosyncrasies. In keeping with the requirements of the modelling process, the ethnography pays particular heed to causal processes. Essentially, the coming pages document the 'reality' that I seek to model in *Chapter 6*.

5.1 Community History

5.1.1 Prior to the 25 April 2015 earthquake

During the community history focus group, a timeline of significant events that influenced the community's wellbeing, activities, and livelihoods over the last seventy or so years was elicited. These events are set out in *Figure 5.2*. Broadly speaking, they fall into one of two categories – socio-economic developments or shocks and stressors. The first significant socio-economic development that was recalled came in 1952 with the opening of a small shop fifteen minutes' walk from the village. Prior to this, the villagers would have to make a three-day return journey by foot to the nearest market. The shop therefore marked a significant

Figure 5.1. The village prior to the 2015 earthquakes as seen from the dirt road that connects the community to the VDC headquarters and the Lamosangu-Jiri highway (Source: Author, 2015).

moment in the opening up of the local economy – a process that still continues to this day. A couple of decades after the shop opened, a Swiss funded horticultural research centre was built near the village and soon started offering improved seed varieties to local farmers, including the households in Namsa. The centre still operates today, providing advice to farmers on how to boost yields, and experimenting with new crops. This could be particularly valuable going forwards as farmers grapple with changing agricultural produce markets and climate change.

According to the older villagers in the focus group, the horticultural research centre was built during a time when the local population was growing rapidly. This resulted in a rapid conversion of land for agriculture, and a decimation of the local forest and vegetation cover. As discussed in *Chapter 3*, this has been a common experience across much of Nepal. By the mid-1970s much of the landscape was denuded leading to large scale soil erosion, an increase in landslides, and a decline in ground water levels and soil fertility. However, a Swiss-led afforestation programme that was initiated in response to the seeming crisis managed not only to halt the decline, but also to restore large areas of forest. A 56-year-old man warmly recalled to us promises made at the outset of the programme to "make the area like Switzerland." Today, it appears that the forests are well managed.[22] They cover sizable parts of the upper slopes and represent a crucial source of timber, fuelwood, and fodder for Namsa and its neighbouring communities. Consequently, while deforestation was a significant challenge in the past, it is no longer a prominent issue.

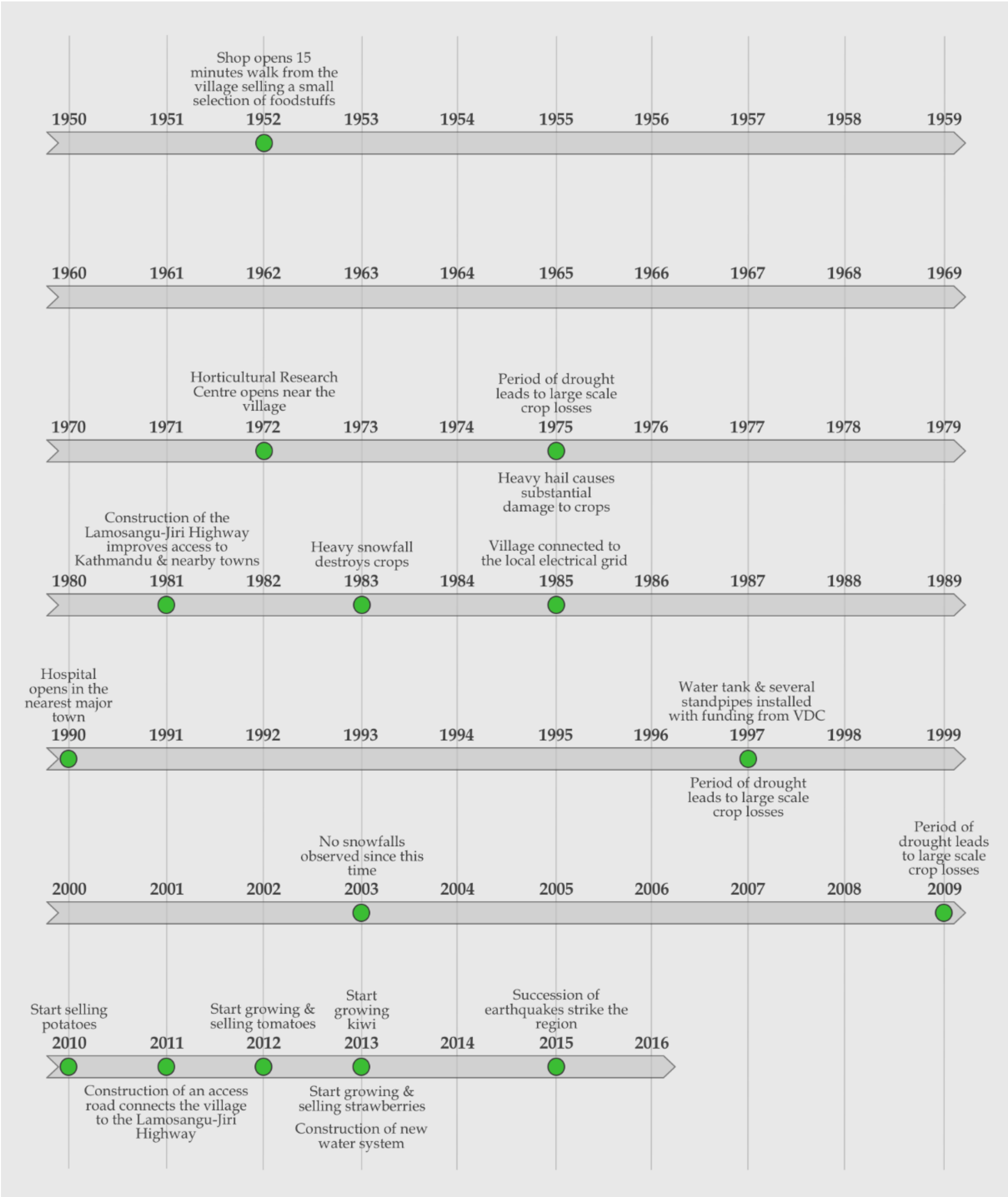

Figure 5.2. Historical timeline of key events in the village's recent history as elicited through focus group discussions. Note that while efforts have been made to validate the timing of events, dates should be considered approximations rather than absolutes.

[22] They are managed by a Community Forest Committee which was created around the turn of the millennium. The role of the committee is to manage the community forest on behalf of the villages that rely on it, ensuring the forest remains in a healthy state by regulating the use of forest products and by planting fresh trees each year.

Perhaps the biggest development of all occurred during the late 1970s and early 1980s with the construction of the Lamosangu-Jiri Highway, funded by the Swiss Agency for Development and Cooperation (Pokharel and Mahat, 2009). The older male villagers in the focus group remember being paid to work on the construction, but it was the benefits it brought after opening that were of greatest significance. It meant that Namsa – previously remote from Kathmandu and largely disconnected from national and international markets – was now just a few hours travel from Nepal's capital. Consequently, households could start to engage regularly with the country's emerging cash economy, buying and selling foodstuffs and other items with much more ease than was previously the case. Since the opening of the highway it was agreed that the village had not suffered any significant food shortages – this in contrast to times past when the village was heavily reliant on local production.[23] Consequently, the road all but eradicated the threat of famine. It also marked something of a watershed for livelihood opportunities with barriers to labour migration reduced, improved access to markets making the growing of cash crops increasingly attractive, and new local labouring opportunities emerging as a number of small industries took root along the roadside and in nearby towns. The highway therefore played a big part in opening local society up to the forces of modernity, transforming the local economy, and enabling many of the later developments that were to take place. Again, these experiences are very much in keeping with those seen in other mountain communities, as discussed in *Chapter 3*. The road is not explicitly modelled in the ABM that is set out in *Chapter 6*, but its ramifications for the likes of labour market and produce market access are, of course, implicitly featured.

At the start of the 1990s, households in the village started to use chemical fertilisers in their fields for the first time according to the focus group members who could recall the period. Soon after, they also began using pesticides, the combined effects greatly increasing the yields of certain crops.[24] Village agriculture was further

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[23] Prior to the construction of the highway, the older cohorts in the focus group said food could become scarce between mid-April and mid-August and on occasions they suffered from hunger as their food stocks had to be rationed.

[24] Compared to the period prior to improved seed varieties, fertilisers, and pesticides being made available, wheat and millet yields are said to have trebled, while maize yields have reportedly increased five-fold.

boosted in 2010 with the tentative commencement of commercial potato production by three of the households. This proved to be a profitable enterprise, leading other households to join in. Since then, there have been experiments with other cash crops as well. Cabbage and cauliflower farming are now well established alongside potato farming, and tomato cultivation has also become a significant source of income, although it is limited to just three households. Thus, for some, though not all of the households in Namsa, there has been a rapid diversification and commercialization of farming activities. This is discussed more in section *5.6.1*.

The shift into cash crops was facilitated by the construction of a dirt road connecting Namsa to the nearby highway in 2011. This enabled produce to be collected directly from the village by merchants – particularly valuable in the case of bulky foodstuffs like potatoes and cruciferous vegetables. A new irrigation system that was built in 2013 has also been a critical enabler as the village was previously water limited.[25] The arrival of tomato cultivation, meanwhile, owes thanks to the Japan International Cooperation Agency (JICA) who provided materials and training to the three households that now grow the crop. It was unanimously agreed in the community history focus group that the improvements in crop yields since the 1990s and the more recent move into cash crop farming have boosted income and improved food security. That said, from the household survey data it appears that the benefits of cash crop farming have primarily been felt among the larger households who appear to have had more capacity to exploit the opportunities such crops present. The differential impact on households of stressors and other processes of change is one of the things that is explored in *Chapter 8* in relation to the model results.

A number of shocks were recalled by the community history focus group during our discussions in 2015, many of them recurrent in nature. Droughts are said to have occurred in 1975, 1997, and 2009 leading to the loss of millet, maize, and potato crops. The monarchy provided assistance following the earlier drought, but in the latter instances loans needed to be taken out in order to purchase food until

[25] This was funded by iDE – the organisation that assisted me with identifying potential fieldsites.

the next cycle of crops could be harvested. Also, during the mid-1970s there was said to have been a heavy hail storm which caused severe damage to the crops. Similarly, heavy snowfall in 1983 destroyed wheat crops. The two eldest members of the focus group additionally mentioned that pandemics had struck the village when they were younger, including one known by the Tamang as *deshan*. It was said to have killed a number of the villagers and also many of the animals.[26] These events go to show that stressors and shocks are by no means a new feature in village life – a point I made more generally in respect to mountain communities in *Chapter 3*.

5.1.2 The 25 April 2015 earthquake and its aftermath

Namsa was struck hard by the 7.8 M_w earthquake of 25 April 2015 and then again by the 7.3 M_w aftershock of 12 May 2015. The village lay very close to the centre of the USGS (2015a) shake map for the latter event, experiencing severe (VIII) shaking as defined by the Modified Mercalli Intensity Scale. Although none of the villagers were killed as a result of either event, the impact was otherwise extremely significant. Several homes collapsed completely, and the remainder suffered irreparable damage. Approximately five percent of livestock died, and the terraced fields collapsed in multiple places. Due to ground movement, the village water system suffered extensive damage and flow from the spring that serves the system dipped, resulting in a substantial reduction in water availability. Mobile networks were also down during the first few days and electricity outages lasted for around a fortnight. Furthermore, landslips cut off the road links to Kathmandu and other urban centres for close to a week. Around a month after the road had been cleared, a nearby bridge was washed away as a result of monsoon rains, again disconnecting Namsa from its main market for a period. While food prices did not rise initially and food did not run out, it did become scarcer and, as time went on, food prices began to progressively rise, albeit roughly in line with general inflation. Besides the direct and quantifiable impacts, the earthquakes also had a profound effect on the day-to-day lives and medium-term aspirations of the villagers. As one man put it: "All the basics were challenged. Life came to a halt. Psychological damage is enormous."

[26] It was not possible to identify the diseases involved.

Following the initial earthquake, most of the villagers opted to stay in temporary shelters constructed from materials salvaged from the remains of their homes. More robust temporary homes were then constructed during the months that followed using materials supplied by international donors. Upon my return to Namsa in March 2017, most households were still living in these temporary homes, despite almost two years having elapsed since the initial earthquake. Just one household had completed construction of a permanent, earthquake resilient home, while a further two houses were under construction. In all, four households had chosen to leave Namsa by the time of the return visit. Among them was a 63-year-old man who had been living on his own and a young family of four. The former had left to join family near the roadside, while the latter had moved to Kathmandu where the husband was already working – the earthquake was apparently the catalyst in both cases.

Also apparent upon my return to Namsa in 2017 was the heavy toll the earthquakes had taken on village agriculture. Several households reported not engaging in agriculture much at all in the months immediately following the earthquake. According to one of the men: "During the earthquakes, farming was completely overlooked." While this contributed to diminished harvests, several other factors exacerbated matters including poor weather, the need to scale back irrigation due to the reduced availability of water, and the effect of the frequent tremors on soil aeration and crop roots.[27] The poor harvests led to reduced income from sales of produce and also forced greater dependence upon food markets, compounding the difficulties that households were already facing. Most households responded by reducing their non-essential expenditures and drawing on savings. At least one also took out a loan. Other notable livelihood changes had also taken place since the main fieldwork spell. In particular, regional reconstruction projects led to a steep rise in the availability of off-farm labouring opportunities, which proved a boon for those working age men who did not have permanent employment at the time. This provided some relief after the initial

[27] As one farmer explained, the tremors meant the soil "held tightly and didn't allow roots to grow well." This proved particularly catastrophic for the strawberry plants that some of the households were growing. Most of them apparently failed to fruit again as a consequence.

shock, although not all households benefited. Indeed, it was clear in 2017 that the long-term impact of the earthquakes varied somewhat from household to household – demographic and livelihood differences being particularly important in shaping experiences. Unfortunately, time constraints and ethical considerations meant I was not able to systematically explore the differential impact of the earthquake on households during my 2017 visit, but the topic is examined in *Chapter* 7 and *Chapter 8* using data from the simulations.

5.2 Demographics

5.2.1 Population structure and migration

At the time of the first fieldwork visit, the population of Namsa was 58, with roughly equal numbers of men and women but an irregular population structure (*Figure 5.3)*. This is partly a product of the small population size which meant there is little of the smoothing effect that comes from having larger numbers. But it also reflects a number of underlying trends in the population dynamics. Most significant of all is the huge influence of migration on the 20-39 cohort, in particular the high levels of male absenteeism within this age group. During the 15 years preceding the household survey, twelve men had left, with all but one of them moving for work reasons.[28] A further fifteen women had emigrated after marrying men outside of the village, but their loss was partially offset by other women marrying into the community. Some of the men who had left were expected to return to the village at a later date – indeed, several of them had wives and children still in the village – but in the meantime, their absence meant that the in-village labour force was heavily skewed towards the older generations. That said, it is not uncommon for the men living outside of the village to return briefly at times of peak labour demand to assist with farm work. While high rates of male absenteeism can be problematic in certain respects – particularly from a social standpoint – these external income earners provide many of the households with a reliable source of income that is far in excess of what can be earnt locally. Remittances from familial diaspora can also serve as a financial lifeline during

[28] Five of the men were working in other districts – primarily in the Kathmandu Valley – while two were working in the Middle East, and the remainder were based in other countries.

periods of stress. For example, a 77-year-old woman who lives alone was sent cash by two of her sons following the earthquake to help tide her over.

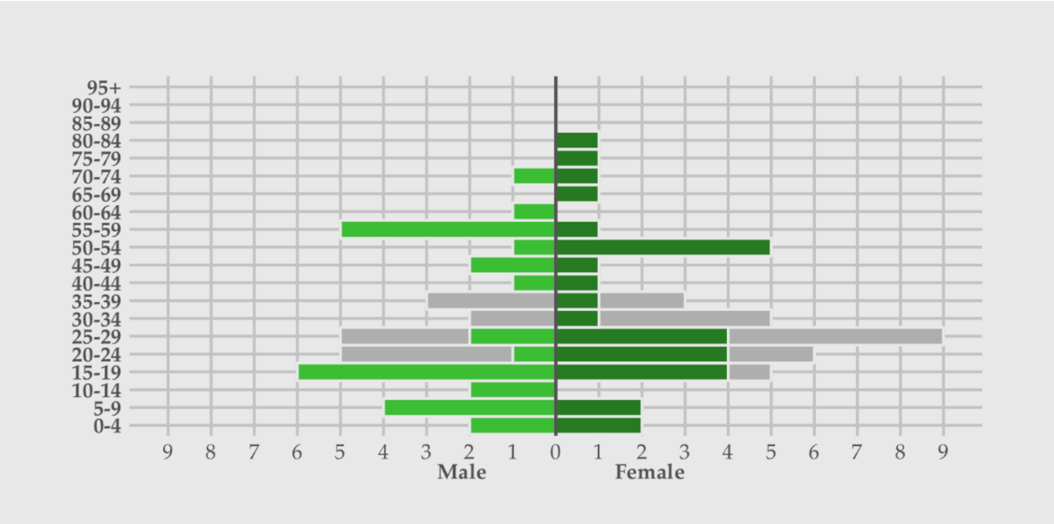

Figure 5.3. The population pyramid for the village. The grey bars represent individuals who emigrated during the previous 15 years. This data comes from the household surveys that were conducted in 2015.

The migration dynamics within the 20-39 cohort are not particularly novel or new. Almost all of the older women in the community were born outside of the village and almost all of the older men spent some time working outside of Namsa when they were younger, sometimes seasonally and sometimes for extended periods. What is new, however, is the rise in the number of households in the area that are emigrating as a collective. Prior to the earthquake, this had not significantly affected Namsa, but the participants in the decision-making focus group were clear that the trend, which started around a decade ago, was on an upward trajectory. In particular, households were being attracted to live nearer urban hubs or closer to the highway due to easier access of transport, healthcare, education, markets, and off-farm employment – something that echoes the urbanisation trend seen elsewhere in Nepal (CBS, 2012). Of course, by the time of my return visit in 2017, four households had made the decision to move – two remaining close by and continuing to farm their land, and two opting for urban life in Kathmandu. Thus, the earthquake appears to have accelerated matters, with people forced to re-evaluate their futures in wholly fundamental ways. That said, most of the older villagers who remain said that they could not envisage leaving the village permanently under any circumstances. The younger generations tended to be more open to the possibility of moving their family permanently to a place such as

Kathmandu if they could afford to buy a property there. They felt there would be more work opportunities and that their children would receive better education and healthcare. Nevertheless, they did express a degree of reluctance about the idea of leaving Namsa. In the model that is presented in *Chapter 6*, both livelihood and marriage induced migration is simulated.

5.2.2 Fertility rates

Another notable feature of *Figure 5.3* is the constriction of the younger cohorts relative to the 15-39 age groups. This is indicative of a possible decline in fertility rates – a trend that that the decision-making focus group affirmed, and which once again is in keeping with what is being seen elsewhere in the country (see *Chapter 3*). While children do assist around the family farms, the demands of their schooling today mean they are increasingly seen as dependents rather than economic assets according to the focus group. Added to this, there is also a feeling that children's chances in life are more likely to be maximized if parents are able to focus their efforts and finances on supporting a limited number of them. As a result, the participants in the young persons' focus group were unanimous in expressing their desire to have two children at most, regardless of gender. This contrasts starkly with the number of children that had been born to the older women in the village. The potential long-term demographic and financial implications of alternative fertility rate scenarios for the village has been explored using the model – the results are discussed in *Chapter 8*.

5.2.3 Mortality rates

The final core determinant of population dynamics besides migration and fertility is mortality. It is not possible to determine age specific mortality rates or life expectancy for the community as the available population data is so limited. Nonetheless, during the household survey, households were asked to give the age of the last individuals in their households to pass away in order to provide a rough guide. Ages of the deceased ranged between 12 and 95, with a mean of 68.1 and a median value of 73. This compares to a national life expectancy of 70.3 (World Bank, 2016b). Discussions during the typical life focus group revealed that infant mortality has fallen significantly over the last couple of decades and for the most part people are living longer than previous generations did. This is likely to be due to a wide variety of factors including improvements to sanitary conditions, increased access to medical care, changes in nutritional intake, reductions in extreme socio-economic stressors, and better living standards. When they occur, deaths constitute a significant shock for households. Not only do they have substantial social repercussions, they can also deprive households of a potentially important source of labour and income, and funerals in Namsa are costly affairs. This makes the decline in the mortality rate significant. Once again, this change is taken into account in the model that is set out in *Chapter 6*.

5.2.4 Household structures

Prior to the earthquake, the population of the village was divided between 14 households, with household membership ranging between one in the smallest instances and eight in the largest, with a mean of 4.1. Four households had elderly dependents,[29] while two households were composed entirely of over-65s. Nine households, meanwhile, had young dependents.[30] Only two households were without any dependents. This reflects the fact that household fissure traditionally only tends to occur around the time of marriage and couples tend to have their first child soon after this point. Furthermore, elderly family members are often supported by the household of one of their children. As a result, it is unusual for individuals or couples from the working age cohorts to live alone. The demographic profile of households is significant because it plays a big role in determining the economic potential of the households at any given time (Fricke, 1993). It can also affect both the vulnerability of households to certain stressors, and their ability to bounce back from adversity – topics that were raised in *Chapter 2* and which are revisited in *Chapter 8*. As the demographic profile of households inevitably evolves over time, their economic potential and vulnerability to stressors invariably fluctuates as well. The simulation methodology that is employed in this thesis is ideal for capturing such changes. Of course, many of the demographic changes that are significant at the household-level are a result of individual-level life events. It is therefore important to take a multi-level approach to understanding demographic change, as argued in *Chapter 2*. The individual-level life events that were considered particularly important during the typical life

[29] Defined in the conventional sense as over-65s.
[30] Defined in the conventional sense as under-15s.

focus group are set out in *Figure 5.4*. A number of these are again included in the model.

Figure 5.4. The typical life of a villager as elicited through focus group discussions.

5.3 Housing, Land and Inheritance

5.3.1 Housing

The homes prior to the earthquake were traditional unreinforced mud-stone constructions with corrugated iron gable roofs. Most of them had been built by the households themselves in a style typical for the area. Unfortunately, such buildings are susceptible to damage from ground shaking (Dizhur *et al.*, 2016). This proved the case when the earthquakes of 2015 occurred. All of the houses in Namsa suffered severe damage, rendering them uninhabitable. Prior to my return to the village in 2017, most of the households had spent the best part of two years living in improvised temporary housing near the site of their old homes. A couple of new households also formed in the interim period as a result of two of the younger men marrying. Most of the structures were built using a mixture of salvaged and donated material so they required minimal expenditure on the part of the households – the cheapest one cost just NPR 500.[31] That said, some of the households did invest in upgrading their accommodation over time.

The process of constructing permanent replacement housing was slow to begin with, just as it was elsewhere in the country (see *Chapter 3*). The villagers put this down to a number of factors – the occurrence of aftershocks throughout the first year following the initial earthquake; the weather being too wet during the monsoon seasons; the days being too short during the winter months; the inflated cost of skilled construction workers and materials due to the high demand the mass-reconstruction effort had generated; the shortage in engineers required to conduct the necessary checks to enable construction to begin and progress; and inadequate personal funds to pay for the work. However, at the time of my 2017 visit, most of the households had plans in place to build new earthquake resistant houses, part paid for using government provided reconstruction grants and part self-funded (see section *3.3.2*). One of the houses had already been completed at a cost of NPR 500,000. Another one was mid-build. The amount that the households were expecting to pay varied depending on the size of the home they were planning on building and the construction materials they wished to use. The former was primarily guided by the number of members the households had. Interestingly, current financial circumstances did not seem to be a big factor in the decision, although several of the households I spoke to expressed concern about the debt burden they would face. This was particularly true in the case of one 77-year-old woman who was living alone and already had little income to spare.

5.3.2 Land ownership

The households in Namsa own a total of 7.98 hectares[32] of agricultural land, making the mean holding 0.57 hectares. This is notably similar to the district

[31] This was the price of a bag of nails.
[32] This translates into just over 150 ropani (~12 football pitches). A ropani is the traditional unit for measuring land in Nepal. One ropani equals 0.05087 hectares.

median land holding of 0.55 hectares (CBS, 2013). On a per capita basis, the village land is distributed relatively equitably – as can be seen in *Figure 5.5* – with household holdings being reasonably correlated to household size ($\tau b = 0.59$, $p = < 0.05$). Ten of the households have holdings that lie within the interquartile range of district holdings in terms of area, while two more households lie either side of the interquartile range. This suggests that the village is relatively representative of the wider area in terms of distribution of land. The majority of the land that is owned by the households is concentrated within the perimeter shown in *Figure 5.6*. Due to the sloping nature of the terrain, this land is broken into dozens of terraced plots, sometimes as little as a metre in width. This terracing and the scattered nature of people's holdings can constitutes a competitive disadvantage when compared with agricultural land in the Terai and India (Fuwa *et al.*, 2007). This is one of the reasons why agricultural margins are extremely tight in Namsa – a topic that is revisited in *Chapter 8*.

5.3.3 Household fission and inheritance

Land is the core component of a household's wealth and central to the Tamang inheritance traditions (Fricke, 1993). According to the wiki authors, when a son marries, should he intend to remain in the village, he will be given a share of his parents' land upon which he can establish a farm of his own. The egalitarian nature of Tamang society means that each son is entitled to an equal share, with the parents ultimately being left with a similarly sized portion to each of their sons. It is because of this that the land fragmentation that was mentioned in the previous section has arisen.

When there is more than one son in a household, the older sons traditionally built a new home on their inherited portion of the family's land around the time that they had their first child. However, the process of household fission is now increasingly being delayed. Initially, this was because of the tendency for men in their twenties to now spend extended periods working abroad. Rather than forming their own households soon after marrying, many chose to wait until their return. Wives and children often live with the husband's parents in the meantime. The earthquakes of 2015 mean that this tendency to defer household fission is likely to become even stronger as the events led to the cost of building new homes

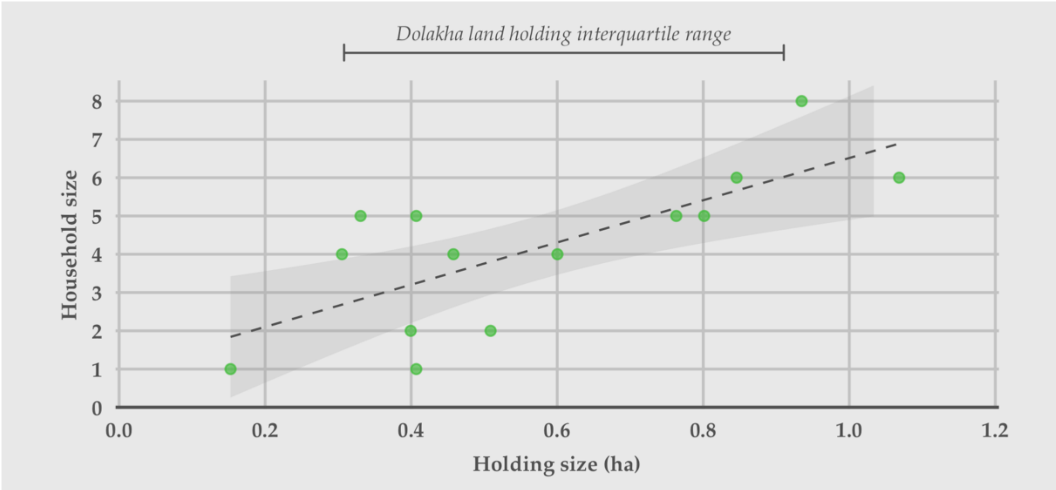

Figure 5.5. Size of household land holding by number of household members in Namsa (Data: Household survey; CBS, 2013, p.1).

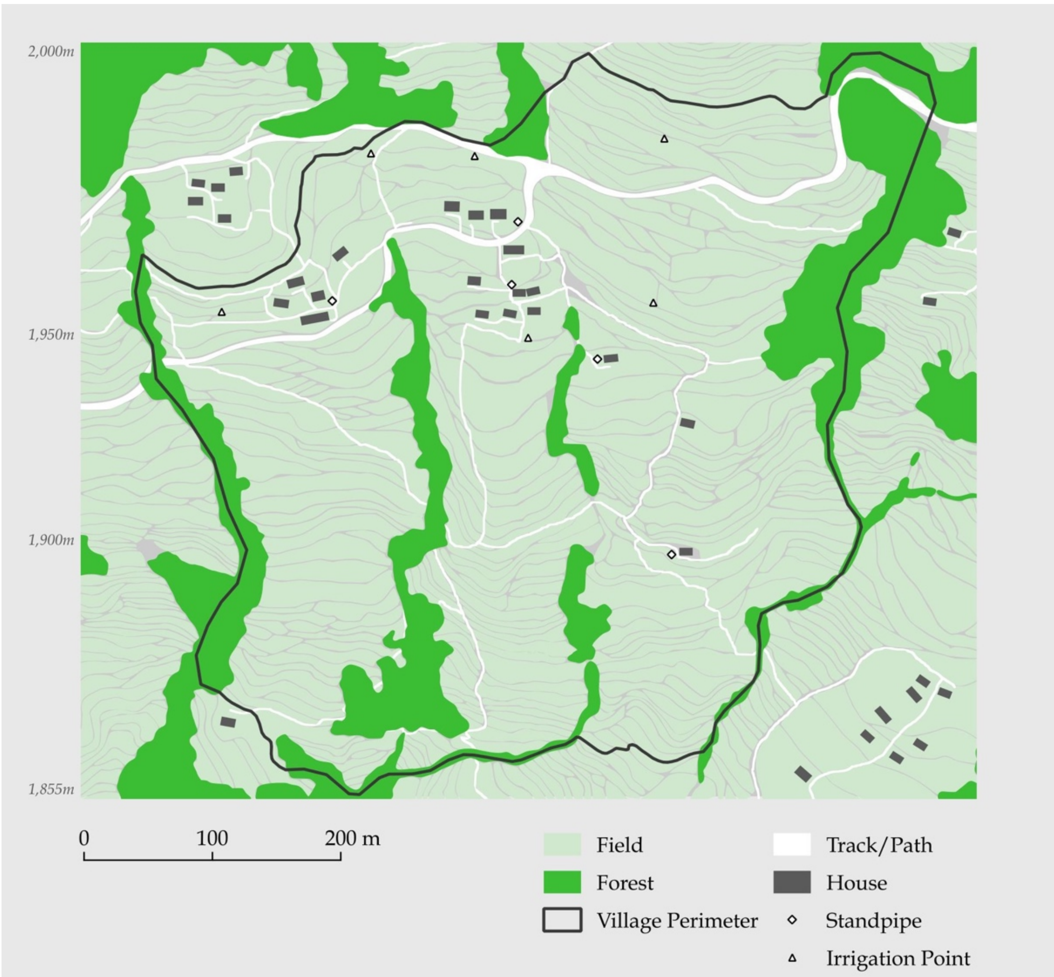

Figure 5.6. Map of the village prior to the April 2015 earthquake. It was created using a combination of photographs, GPS coordinates logged during the fieldwork, and satellite imagery from DigitalGlobe (2015).

jumping. A nineteen-year-old man who I spoke to felt it would be many years until he could afford to build his own home due to the high costs associated with the new generation of earthquake resistant houses. These changes are less problematic for the youngest sons as they traditionally inherit their parents' home instead of needing to build their own. In return, they are expected to look after their parents in their old age. In contrast to sons, daughters do not usually inherit a share in their parents' land. Instead, they typically move to their husband's village following marriage and therefore benefit from the land inheritance the husband receives from his family.

5.4 Culture

5.4.1 Festivals

In Namsa, the villagers celebrate both Buddhist and Hindu festivals, in keeping with their somewhat hybrid belief system and reflecting the ever-increasing adoption of wider Nepalese culture. Events are scattered right across the yearly calendar according to the wiki authors, but there is a particular crescendo during September to November when the major Hindu festivals of Dashain and Tihar take place (see *Figure 5.7*). The celebrations are often marked by the decoration of homes, time off from work, and the consumption of luxurious meals and alcohol. During Dashain, gift giving is also common. Consequently, these occasions represent not just religiously and socially important events for the village, but also financially significant ones for the households (see section *5.7.2*). The seasonal calendar focus group revealed that the amount a household spends depends on a mixture of income, personal preferences, and social pressures. Occasionally, households that are short on cash in the lead up to a festival will take out a loan to cover the expenses rather than cut back their spending. In contrast to festivals, other occasions, such as birthdays, remain something of a fringe event. They are, however, gaining increased weight amongst the younger generations as global cultures start to permeate.

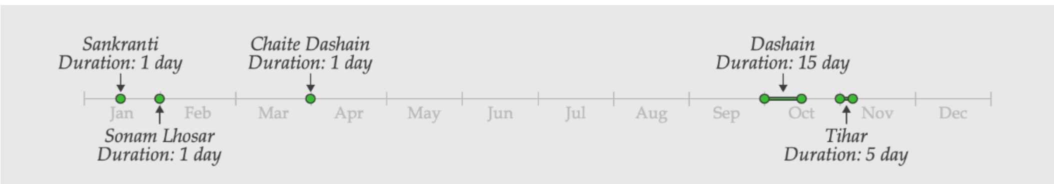

Figure 5.7. The main festivals that the villagers celebrate, the approximate date they occur, and their duration. The dates shown are approximate in nature – they can vary year-to-year.

5.4.2 Marriage

Historically marriages were arranged by the parents of the bride and groom, with partners usually sought from other Tamang communities. However, in recent times – as in China – there has been something of a romantic revolution with young people now increasingly choosing their own marriage partners and marrying for love (Paltridge, 2012, p.31). During the young persons' focus group, it was revealed that the arrival of mobile phones and Facebook have fuelled this trend as it is now much easier to foster relationships with individuals outside of the village. Many parents are also increasingly accepting of their children's self-determination on this matter, although they still expect to be asked permission and can be reluctant to give their approval if caste or socio-economic boundaries are infringed.

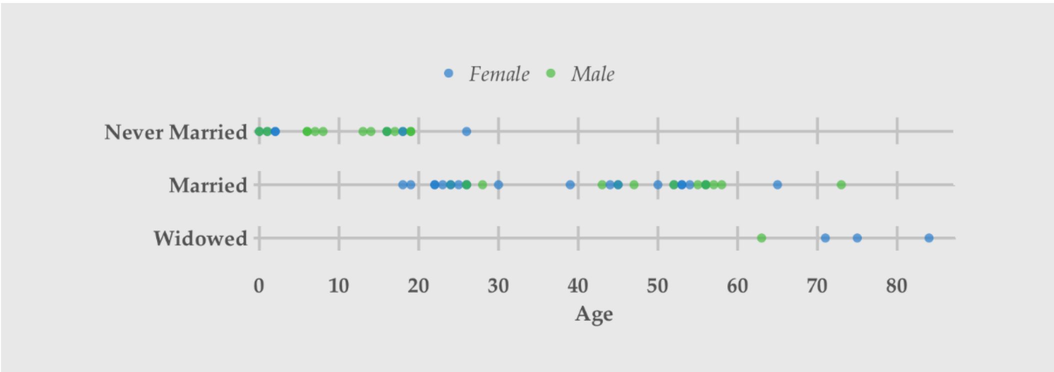

Figure 5.8. Marriage status by age for those living in Namsa.

As can be seen in *Figure 5.8*, most of the youngsters in Namsa nowadays marry during their late teens or early twenties, with women usually marrying at a slightly younger age than the men. We were told during the focus group that "everyone gets married at some point." Marriage is an extremely significant event both socially and economically for the households involved. A ceremony that occurred in Namsa a month prior to the fieldwork in 2015 lasted for three days and involved the parents of the groom hosting upwards of 1,000 people. While the ceremony and celebrations cost a substantial amount, donations from the guests roughly offset this expenditure. However, the parents of the bride and groom will have taken a financial hit from the wedding gifts that they provided the newlyweds with – gifts which, according to the wiki authors, are often worth NPR 100,000 or so. This can unsurprisingly be a big strain on many households, but they are apparently viewed as near-obligatory. While weddings and festivals are not usually considered stressors or shocks, financially they can be challenging so they have been included in the model.

5.4.3 Cremations & funerals

In Tamang culture, rituals associated with death are imbued with huge significance (Fricke, 1993). This is reflected in the elaborateness of the cremation and funeral ceremonies, and the amount that households are willing to spend on them. According to the wiki authors, when a household member dies, their body will usually be kept in the home overnight. The next day, it will be taken into the hills above the village where it is cremated on a funeral pyre after being wrapped in cloth and coated in ghee. Some weeks later, households will host relatives, friends, and locals for a funeral ceremony, if they can afford to. The most recent funeral of a Namsa resident had reportedly involved the deceased's family hosting around 400 mourners. In all, the various hosting responsibilities and rituals cost the family approximately NPR 400,000 – a very substantial sum given typical household incomes in Namsa (see section *5.7.1*). In this instance, the expense was relatively affordable because the family of the deceased was affluent by village standards. However, they still needed to borrow to cover some of the costs. The scale and exuberance of the rituals that are desired – and expected – can pose a significant financial dilemma for many less affluent households. While some decide to shoulder the risk of loans, others feel they have little choice but to scale back certain aspects of the ceremonies, or even delay the final rituals. Of course, deaths can also lead to a loss of income and labour as well. Consequently, they often constitute very significant shocks – something that the model results in *Chapter 7* confirm.

5.4.4 Food

According to the resource flows focus group, households in Namsa tend to eat two main meals a day – a brunch at 11 am and a dinner in the early evening. Normally these meals consist of a large serving of rice, a lentil soup, and a small curry or spicy chutney. Occasionally, chapati or dhido – a traditional flour-based food – may be served instead of the rice. Meat consumption varies somewhat between households depending on what they can afford, but on average, two to three meals a week are served with meat. Villagers also consume eggs, milk, and cottage garden produce, when available. Instant noodles, biscuits, and French toast (bizarrely), are more modern additions to the Namsa diet – typically consumed as afternoon snacks. The multiple stressors focus group revealed that one of the first things that households do when finances become tight is adapt their diet. In particular, they will usually cut back on meat consumption – something that is relatively costly. This is also one of the first things that is increased when household finances improve. Another means by which households reduce their food related expenditure is substitution of rice for grain-based foodstuffs which tend to be cheaper. Adaptive consumption is included in the model, although only for meat as this represents the greatest cost outlay.

5.5 Education & Health

5.5.1 Education

The older generation in Namsa received little to no education during their younger days. Many of the elderly villagers remain practically illiterate. As can be seen in *Figure 5.9*, some of the men currently aged between 40 and 60 did receive some formal education – representing the first cohort to do so – but it has only been in the last 30 years that both genders have been consistently entering the school systems and that some of the villagers have been able to complete their SLC.[33] Currently, around half of the youngsters from the village are also going to college to complete their +2.[34] The value and prestige placed on education is very high nowadays, both among children and adults, so the tier of attainment is likely only to rise going forward – something that should improve the career prospects of villagers in the future. On a more negative front, there is still a gender gap when it comes to years of education completed – females on average lag behind males. This, it was suggested, was due to female education being less valued by some parents relative to male education, as well as being due to females typically marrying at a younger age. As the simulations run for 15 years, the long-term impact of improvements in educational attainment are captured. In particular, the

[33] School Leaving Certificate: the final examination in the Nepalese secondary school system. Equivalent to GCSEs.
[34] The two-year college degree that is equivalent to A-levels.

results reveal the benefit of obtaining salaried employment for a family's financial security – a decent education is a prerequisite for such jobs.

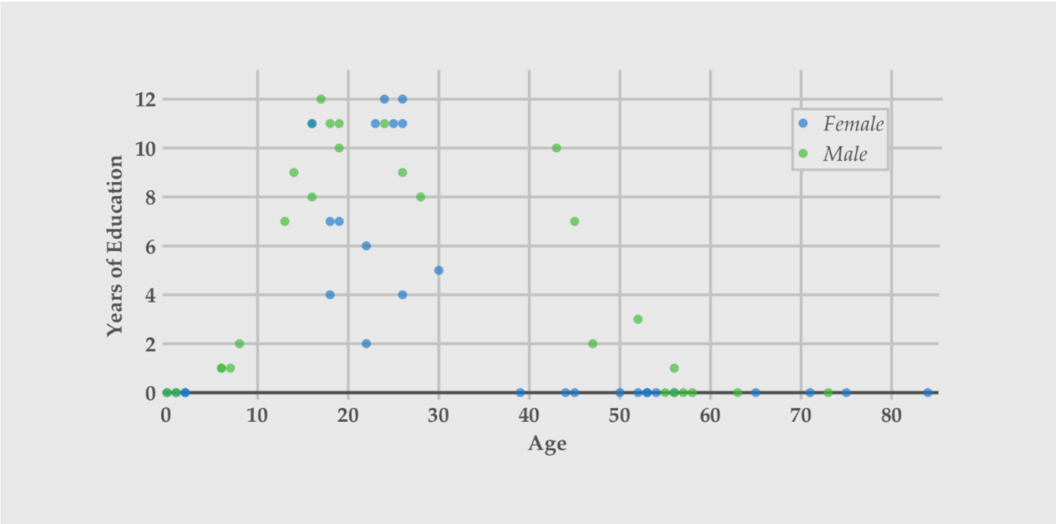

Figure 5.9. Completed years of education by age of the villagers in Namsa. Twelve years is equivalent of reception to completion of GCSE exams in the English system.

5.5.2 Health

When asked in the household survey about the frequency of serious illness within their household – as defined by one of the members being so ill that they cannot work for a time – four of the households stated that this had been the case once or twice during the preceding year, while the remainder said they had had no issues. The most common health problems were flu, fevers, diarrhoea, and injury while working in the fields or in the forest – matters that only occasionally stop them from working. When asked how readily their household could afford professional treatment for serious illness or injury, six of the households said they probably could afford the expenses, seven said they would need to borrow money, and the remaining household said they could not foresee being able to afford the costs. Health problems clearly have the potential to place a strain on households, but they are so unpredictable in nature and occurrence that it is difficult to model them. They have therefore not been included in the model that is set out in *Chapter 6*. However, they could be added in future iterations. The model is built in such a way that adding components is relatively straightforward.

5.6 Livelihoods

Villagers in Namsa partake in a range of different livelihood activities. Agriculture and livestock rearing have long been at the core of the local economy, with seasonal labour migration also having a lengthy heritage. Today they remain extremely important, but the livelihood options open to the villagers have been augmented by the emergence of new opportunities locally, nationally, and internationally. Another significant change has been the rise of the monetary economy in Nepal, a development that has led to many of the households shifting from predominantly subsistence-oriented livelihoods and lifestyles, towards predominantly market-oriented livelihoods and lifestyles. Below, the main livelihoods the villagers participate in – and the trends associated with them – are discussed. The stressors and shocks that these livelihood activities are exposed to are also highlighted.

5.6.1 Agriculture

All of the households in Namsa are involved in farming. Most households lie somewhere on the spectrum between subsistence farming and commercial farming, rather than at either extreme. In nearly every case, a proportion of produce is set aside for household consumption, a proportion for livestock feed, a proportion for brewing alcohol, and a proportion for sale. This diversity of uses means that a multitude of crops are grown – the main ones in terms of area farmed are shown in *Figure 5.10*.

The grain crops tend to be used within the village as food and animal feed, while the vegetable and fruit crops are primarily grown with sale in mind. Contractors bring trucks directly to the village to collect the potato, cabbage, and cauliflower crops – a necessity given their bulk. These collections are arranged in advance, with households individually or collectively negotiating a price with the various contractors that serve the area. According to the wiki authors, the price that the households get tends to fluctuate in line with fluctuations in the Kalimati market prices – Kalimati market being the main vegetable market in Kathmandu. This exposure to national market price fluctuations is a potential challenge for households, although it was not flagged up during the multiple stressors focus group as having been a significant issue in recent years. Consequently, it has not been included in the model at this time. When it comes to selling high value perishable produce like tomatoes, villagers have to instead sell directly to traders at the local market or to other households. This is because markets for these goods are poorly developed outside of the Nepalese capital. Grains tend not to be sold in large volumes as low cost grain supplied from the Terai and India has supressed market prices making commercial grain production unattractive in upland areas. However, according to the resource flows focus group, it remains more economical to grow grains than to buy them, and their straw and stover by-products are valuable sources of animal fodder.

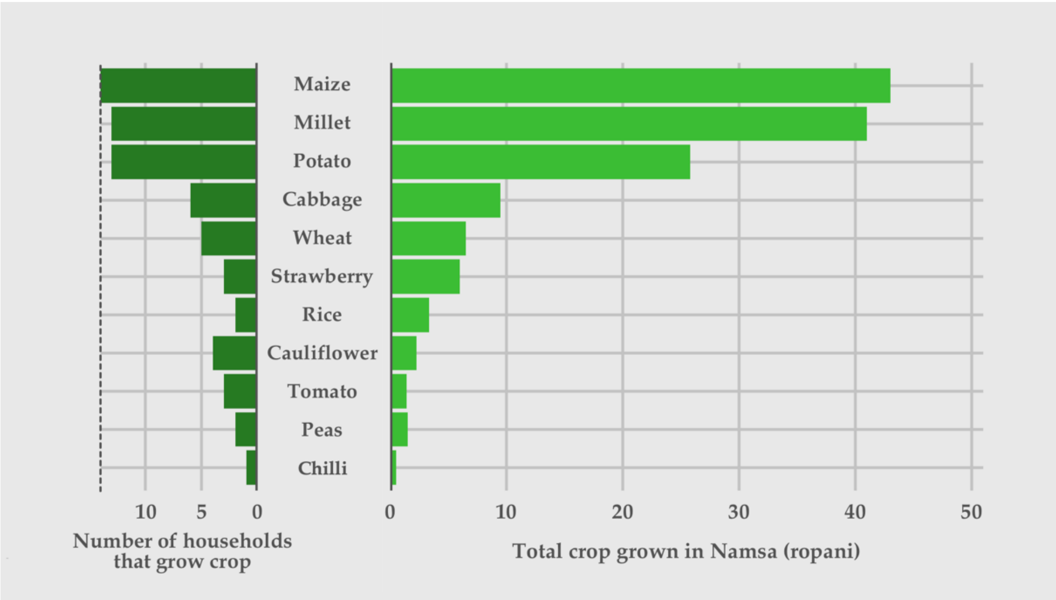

Figure 5.10. The main crops grown in Namsa in the year preceding the fieldwork in March/April 2015. Total crops grown is stated in ropani – the standard unit of area in Nepal (1 ropani = 0.05087 hectares). The data was obtained from the household surveys.

As shown in *Figure 5.10*, the most common crops that were grown at scale in the calendar year leading up to the fieldwork in 2015 were maize, millet, and potato. Other popular crops included cabbage, wheat, strawberry, rice, cauliflower, and tomato, although these were grown more selectively. According to the decision-making focus group, the particular crop mix that a household chooses to grow over the course of a year depends on factors such as: labour, land, and capital availability; household food needs and preferences; past experience; economic ambition; market expectations; and risk aversion. For example, the households that engage heavily in commercial agriculture tend to be those with large numbers of working age members as cash crops tend to be relatively labour intensive to farm. These households also tend to have more draft animals, a better sense of market trends, and they are usually more ambitious and less risk averse than, say, households composed solely of elderly members. In large part, this lesser risk aversion is because they will typically have more alternative income sources open to them should harvests go awry. Consequently, they are usually more willing to experiment with new crops and to risk growing relatively climate sensitive, yet valuable, vegetables and fruits. Past experience, meanwhile, can play an important role in crop choice as it influences the perceived merits of each potential option and the confidence households have in their capacity to grow the crops and to attain a good harvest. Consumption preferences do not always shape crop choices as many households will supplement their meals with produce purchased at the market such as rice and wheat instead of growing such crops themselves. The relative economic merit of such contrasting approaches is somewhat ill-defined due to the variability of food prices and yields, and because household labour is not monetised. Indeed, the need for fuzzy logic and subjective decision making characterises many choices in village agriculture. In the model, households base their crop strategy on empirically informed heuristics that take into account the size of their holdings, their grain needs, and their knowledge of past crop performance. Risk aversion and individual consumption preference are not currently accounted for but could be included in future iterations of the model.

The diverse selection of crops that are grown in Namsa means that agriculture can be a year-round occupation for many households. That said, labour requirements can fluctuate enormously through and between the seasons. This means that there can be certain pinch points in terms of labour demands. Eight of the households said they either rarely or never have sufficient household members available to meet all of their own farm's labouring requirements. They therefore have to hire additional labour or, as is more common, practice reciprocal exchange of labour with other households at certain times of the year. Many households also need to hire or reciprocally share draft animals when ploughing is required. As a 56-year-old villager explained: "If I have two oxen and you have two oxen, we do my field together and then we do yours."

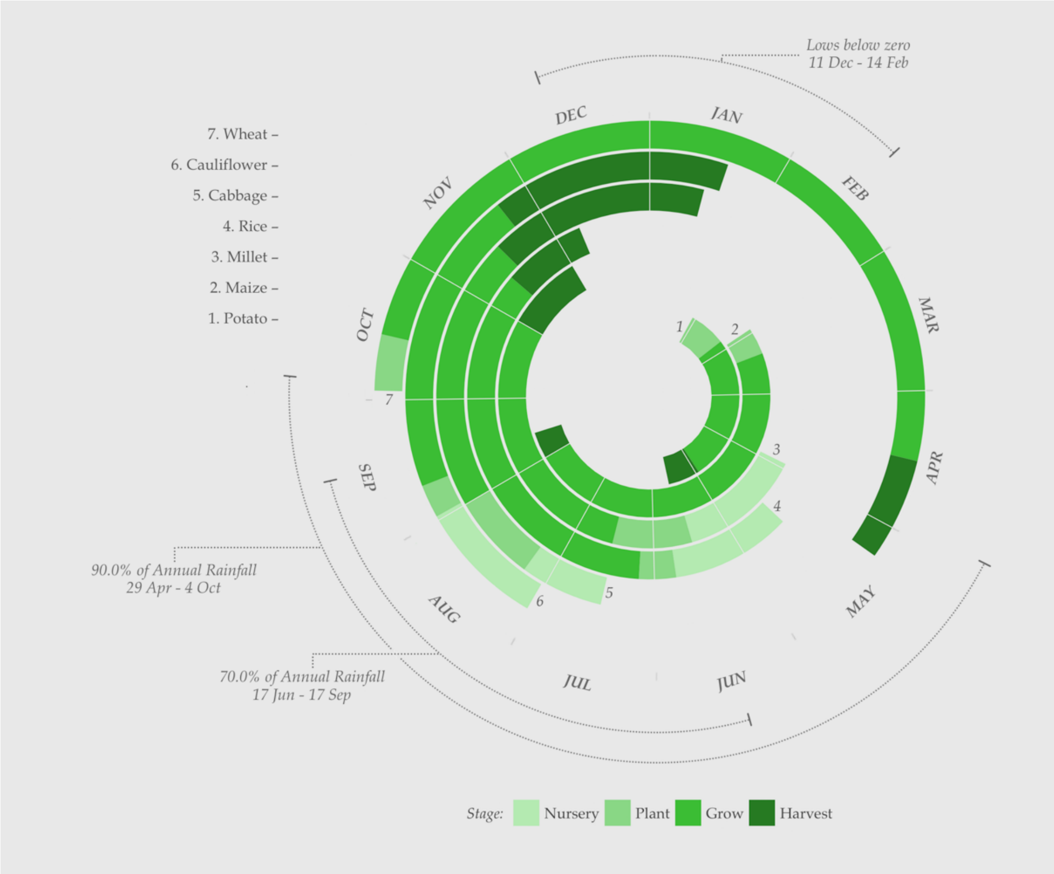

Figure 5.11. The agricultural calendar in Namsa for the main non-perennial crops that are grown by households. The planting and harvest periods represent windows during which the activities may take place. The precise timing of harvests in particular will tend to vary somewhat year to year. The climate data comes from the nearby Jiri weather station (DHM, 2015).

As agriculture is central to the livelihoods of most households, villagers tend also to be vulnerable to the variability in crop yields that is an intrinsic part of farming life. Historically, below average yields have usually been the result of crop damage caused by heavy winds, heavy rain, hail, or drought, although disease and pests have been an issue at times – this is according to the community history and seasonal calendar focus groups. The villagers said that in the past they would expect to experience greatly diminished crop yields (<50%) every 10 to 12 years on average, with fluctuations of 5% to 20% otherwise being relatively normal year-on-year. There was, however, a feeling that the weather is now deteriorating and that yields are suffering more frequently as a result. In particular, 2010, 2015 and 2016 were all said to have produced poor returns due to extreme or unseasonal weather, although the earthquake also played a negative role in 2015. The climate change projections that were discussed in *Chapter 3* would suggest that such challenges are only likely to increase in the coming years. That said, participants in the seasonal calendar focus group did speak of the increase in winter temperatures that they had experienced[35] as being beneficial – a wider selection of winter crops could now be grown.

5.6.2 Livestock and poultry

As shown in *Figure 5.12*, every house owned goats at the time the household surveys were conducted, and all but three owned chickens. Only one household did not own a buffalo, cow, or bull, and that household consisted of just one individual. Pigs were also owned at the time, but only in one instance.[36] Animals are valuable assets for a number of reasons. Firstly, they can provide meat which can be eaten at home or sold. Secondly, they are a source of organic manure which can help restore soil fertility. And thirdly, the cattle can be used to till the land.[37] Consequently, they are an integral part of village livelihoods. Conceivably, their sale could help households during times of financial difficulty, but the multiple stressors focus group indicated that this is rarely done because it would compromise households economically further down the line. Just as all members of a household are typically involved in planting, managing, and harvesting crops, all household members tend to contribute to animal care.

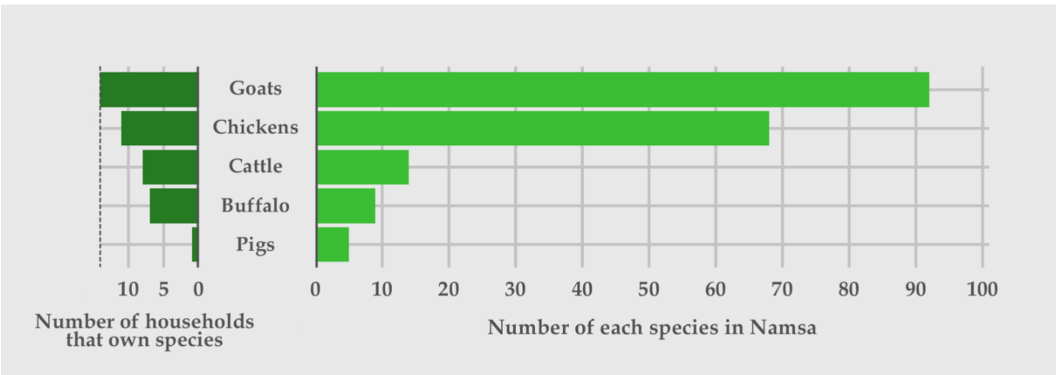

Figure 5.12. The number of households in Namsa that own each type of animal is shown on the left and the total number of animals owned in the village is shown on the right. The data was gathered during the 2015 household surveys.

[35] It had been a decade since snow had last fallen in the village – this despite snowfall having previously been a common occurrence.
[36] When we returned in 2017, the household that had owned the pigs told us they were no longer keeping them as they were short on space in the household compound.
[37] Animal power, rather than mechanised power, remains the dominant means of ploughing fields as the animals are simply more adept at negotiating the complex terraces.

5.6.3 Cottage industries

In addition to agriculture and animal rearing, there are a couple of cottage industries in Namsa that supplement household incomes. One of these is the production of millet-based alcohol – a popular drink in the area. Since 2017, the villagers have also started brewing a kiwi-based alcohol, again with sale in mind. The second industry involves women collecting and preparing the raw material needed in the production of lokta paper (see *Figure 5.13*), and then selling this on to the local paper factory. This is overseen by the local area's Lokta Group which manages the local lokta industry on behalf of the Community Forest Committee. One of its aims is to engage poor households, and particularly women, in the industry. This is a useful supplementary source of income for those who are involved, but the total sums that can be earnt are relatively small.

Figure 5.13. A woman from Namsa processes the lokta bark in the yard of her house (Source: Author).

5.6.4 Employment outside of the village

The male villagers commonly take up labouring opportunities locally during lulls in the agricultural calendar according to the typical life focus group, although some manage to also pursue off-farm work in parallel with their farm work.[38] The employment they get tends to be short term and either construction or farming related. Permanent salaried employment in Nepal is significantly harder for

[38] For example, one of the men who is in his fifties spends two hours each weekday morning feeding animals and tending to crop's before doing paid work on construction sites for the remainder of the day.

villagers to find and such opportunities tend to be open only to those who have completed further education. Should a villager get such work, they will often need to move in order to take up the position. Sometimes their family will move with them, but usually they will remain in the village where living costs are lower. For those who do get salaried employment, a typical wage is often in excess of NPR 10,000 per month – much greater than the NPR 3,000 per month that can typically be earnt through short-term labouring.

Due to the limited employment opportunities in Nepal and the relatively low domestic wage rates, many of the younger men seek foreign employment instead of domestic work. After living costs are accounted for, the young persons' focus group said that roughly NPR 10,000 can be saved or sent home in remittance each month – similar to an entry salary for a job in Nepal. However, the process of attaining foreign employment can be costly, so it can be some time before the net financial benefits are realised. Most of those who engage in such work apparently plan to eventually return to the village to raise their families and to farm – the money they earnt abroad having helped set them up for the future. Others will make a life for themselves elsewhere in Nepal. Of course, the availability of off-farm employment is in large part dependent on the health of the national and international job markets. However, as long as such work is relatively attainable it will continue to represent an important and relatively reliable income source for the households that are in receipt of it. As one of the twenty-six-year-old villagers said: "Farm income is uncertain. Outside the village I can earn more, and I know what I will be paid." In other words, such jobs provide greater financial security. Not only do they provide income surety, they also help smooth the income fluctuations that are an inherent part of smallholder farming, and they enable individuals and households to save money for the metaphorical 'rainy day.' As a result, these kinds of jobs help diminish vulnerability to stressors and shocks.

5.6.5 Division of farm & household responsibilities

Due to the pluriactivity nature of livelihoods, constraints on labour availability, and occasional periods of upsurge in labour requirements, households have to be flexible in how they allocate responsibilities between members. By adapting to the circumstances of any given day, they are able to deal with tasks as they arise

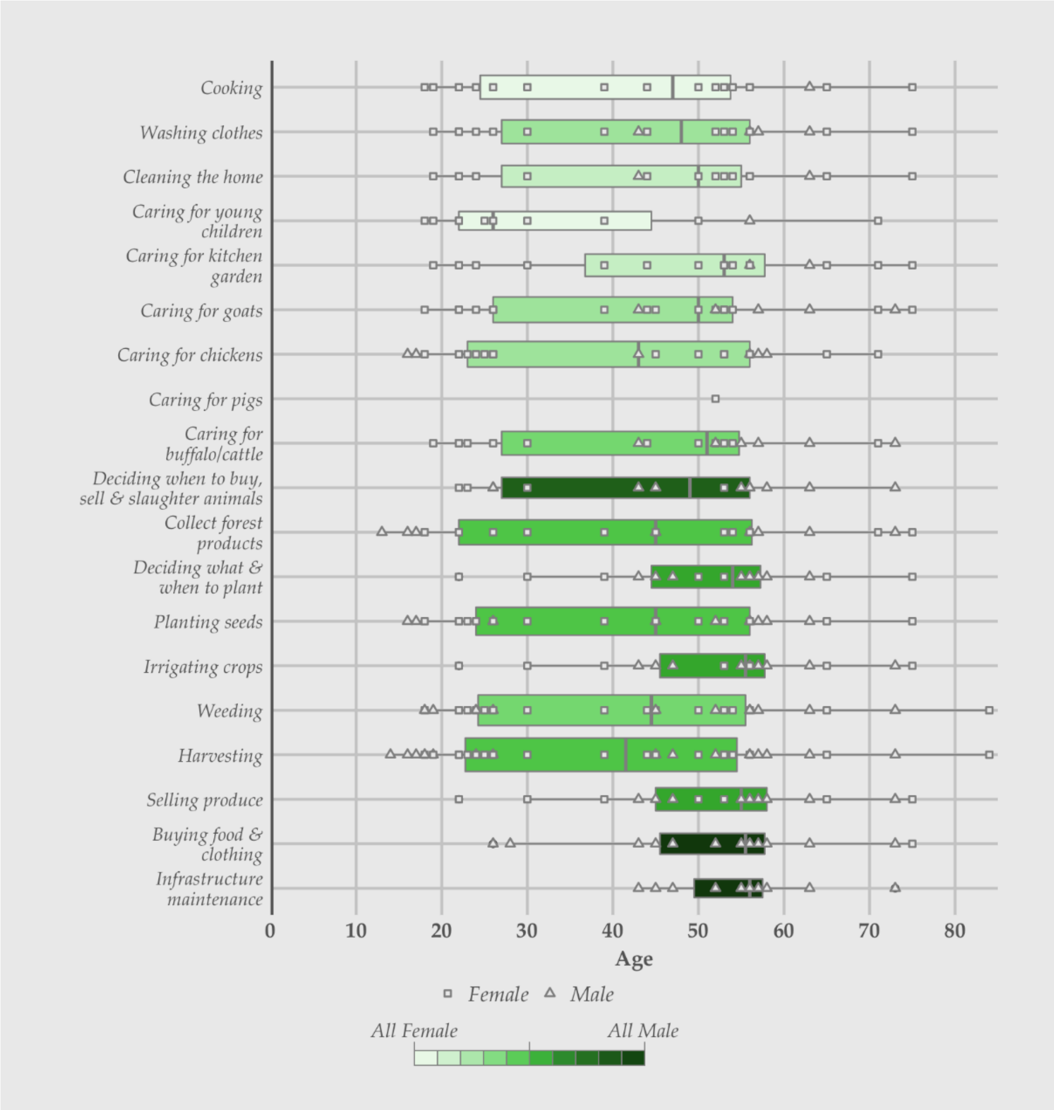

Figure 5.14. Household tasks by main persons responsible. Colour indicates village-wise gender bias while box widths are proportional to the square-roots of the number of individuals cited as being responsible. The data that informed this was gathered during the household surveys.

without the need for complex task scheduling between members and without an excessive burden falling on any single member of the household. It also allows members to take up opportunities as they arise which enables them to maximise their income as a household. The tradition of reciprocal labour exchange within the village at times of peak labour pressure also helps in this respect. Having said all this, there are certain conventions in how tasks are *usually* allocated, as shown in *Figure 5.14* – the data that informed the figure was collected during the household surveys. During the decision-making focus group, it was notable that the gender-based division of household workloads was perceived by both the men and the women as being relatively equitable. While the women typically work for a longer period each day, the men will usually do somewhat more physical work. Consequently, the respective contributions are felt to balance out. Disparities do, however, tend to arise between generations. According to the older members of the focus group, this is partly due to age-linked differences in capabilities and partly because younger generations are becoming increasingly independent of their parents, economically and socially.

5.7 Income, Expenditure and Wealth

Household income and expenditure proved difficult to measure accurately in Namsa for a number of reasons. Firstly, the villagers did not keep written records of their earnings and expenses. This meant that many of the figures obtained had to be based on a mixture of guesswork and calculation. Secondly, household incomings and outgoings can vary substantially – and erratically – over the course of a year, further exacerbating the challenge of estimating figures. Thirdly, household members do not necessarily disclose all of their income and expenditure to one another. This means that our respondents may not have had a complete picture of financial flows within their own household. And fourthly, some of the respondents may conceivably have chosen to downplay or exaggerate their financial circumstances for a variety of potential reasons.[39] Collectively, these issues mean that the figures presented in this section must be treated with a degree of caution. That said, they do provide a ballpark sense of monetary economic activity in the year preceding the household surveys.

As might be expected, stated income and stated expenditure tends to rise with household size – see *Figure 5.15* – although the correlation is far from perfect. The income and expenditure of the most incongruous household is marked by a blue point. This household runs a small grain mill in the local area – an enterprise which contributes substantially to their income. Excluding this outlier household, average stated per capita income in the village was NPR 43,685 and average stated per capita expenditure was NPR 32,260. However, my impression from conducting the household surveys was that, in a normal year, most households

[39] Similar issues were identified by Rutstein and Johnson (2004) when they wrote about the development of the Demographic and Health Survey (DHS) wealth index.

actually spend roughly what they earn so the true net income figure will likely be closer to zero.

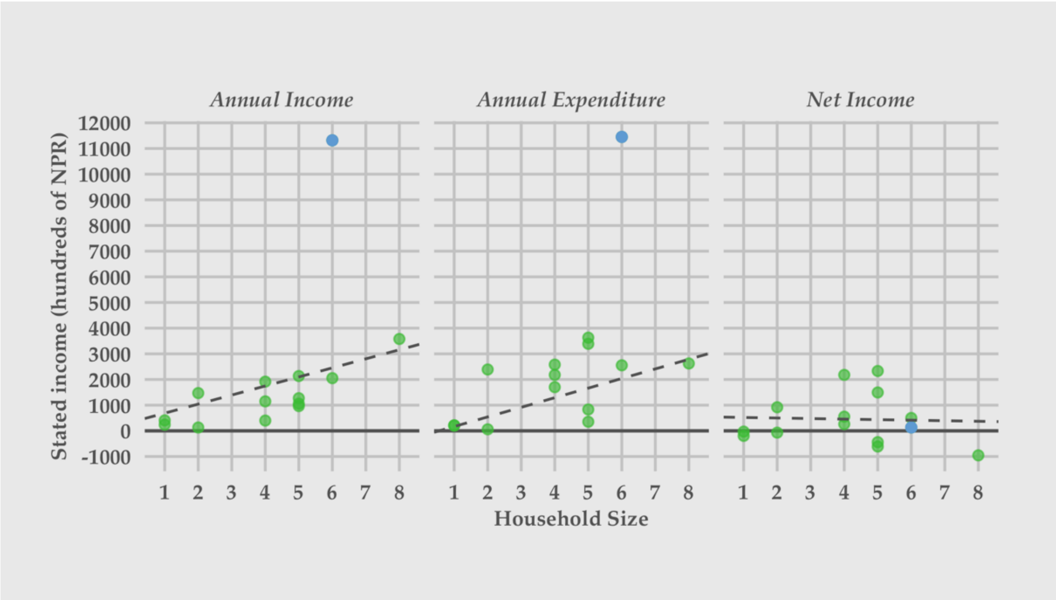

Figure 5.15. Stated income, expenditure, and net income of each household in Namsa in the year up to April 2015. The blue point represents a household that runs a grain mill. Their income and expenditure set them apart from the rest of the village, so these values are treated as outliers and not factored into the line of best fit calculation.

5.7.1 Income composition

The total income of households in Namsa in the year preceding the 2015 fieldwork was estimated at NPR 3.42 million, as can be seen in *Figure 5.16*. Crop sales were the largest single source of income, closely followed by household businesses, and salaries from work conducted outside of the village. While almost all households had crop and livestock income, just seven households said they had income from remittances, five from salaries, four from local labouring, three from household businesses, and three from pensions and benefits – all but one of the households had earnings from at least one of these more niche income streams. As age and gender heavily influence the off-farm livelihood opportunities that individuals have open to them, the demographic composition of households plays an important role in shaping income sources. Young adults, for example, are more likely to have salaried work than other cohorts, while elderly individuals tend not to conduct work beyond their own farm. Pension income, meanwhile, is of course dependent on households having a member who is above a certain age and entitled to a pension.

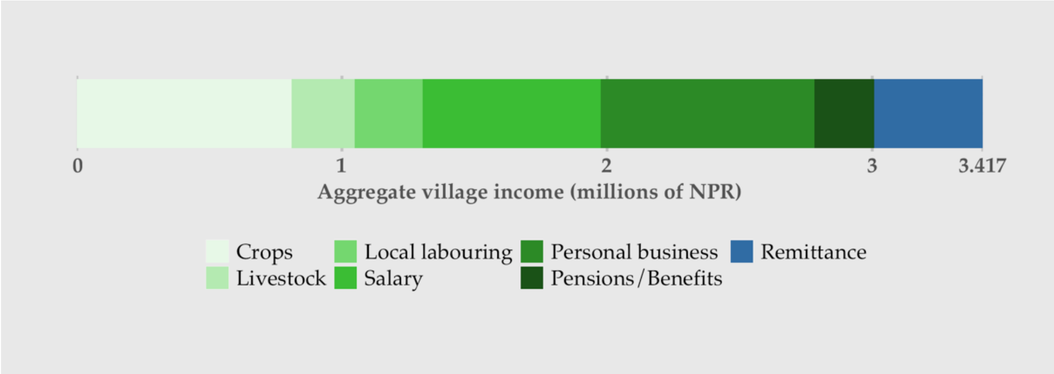

Figure 5.16. Total income of households in Namsa, broken down by source.

The households with the lowest income were composed of individuals from the older cohorts. They are able to support themselves to a large degree through subsistence-centric farming. However, dependence on livestock and crops leaves them relatively vulnerable to pests, diseases, and the weather. The same is true of households for whom agriculture is the dominant source of monetary income. It is important to note that the values outlined in *Figure 5.16* are but a snapshot of income at a particular moment in time. Income streams can vary enormously as circumstances change, and income shocks are by no means unusual. For example, farm incomes were hit hard in the year following the main fieldwork due to a combination of the earthquakes and poor weather. Other off-farm opportunities were also affected.

5.7.2 Expenditure composition

The total expenditure of households in the year preceding the 2015 fieldwork was estimated at NPR 2.81 million – see *Figure 5.17*. Livelihood expenses were the single largest cost. However, two households were responsible for over 85% of the sum. For most households, livelihood expenses represented a much more moderate share of total expenditure. Food constituted the second largest share of village expenditure, followed by education, and celebrations. Food and celebration costs were purportedly the only two expenditures common to all households and they were both reasonably correlated with household size. Education costs, like health, transport, and home expenses, were less common and varied substantially in sum. As with the income figures, it is important to note that these values are but a snapshot in time. They will invariably change year-by-year as circumstances alter.

According to a majority of participants in the decision-making focus group, the most influential factor in determining household expenditure is household income. However, household composition, crop yields, the health of members, the price of goods and services, the occurrence of weddings and funerals, and personal preferences also play prime roles. As these factors differ between households, the scale and composition of expenditures differ. When incomes decline, the focus group participants said they typically cut back on discretionary consumption expenditures first – meat consumption and celebration expenses in particular. If the income drop is particularly dramatic, they may also consider taking out a loan (usually from another household or from the Mothers' Group),[40] but only if they have confidence in their ability to repay it in the medium term. Selling assets is very much seen as a last resort. Other challenges that households can face include unexpected costs and price rises. For example, the earthquake reconstruction process is forcing households to make huge investments in new housing, albeit supported through low interest bank loans.

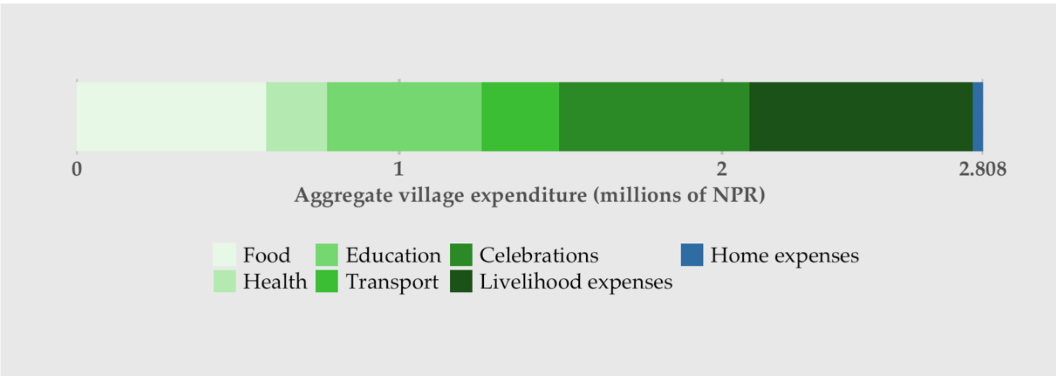

Figure 5.17. Total expenditure of households in Namsa, broken down by type.

5.7.3 Debts and savings

Prior to the earthquakes, five households said they had outstanding loans. These ranged between NPR 10,000 and NPR 150,000, with the highest debt-to-income ratio being 47.4%. The loans were taken out for a variety of reasons including to cover education expenses, livelihood investments, marriage costs, and income

[40] The Mothers' Group is composed of women from Namsa and the surrounding villages. Its primary role is to support the interest of women in the area, but it also provides loans to its members at better interest rates than can be obtained from banks.

shortfalls following poor harvests. Typically, they have a 20% interest rate attached. Five households also had savings, these ranged between NPR 10,000 and NPR 400,000. Interestingly, there was no clear correlation between savings and income. In the model, households are initialised with savings or debts, mimicking what was seen at the fieldsite. This was important to do as household finances are central to how the impact of stressors and shocks is gauged in the simulations.

5.7.4 Household wealth

In assessing socioeconomic status, it is worth also considering non-monetary wealth, as this can represent a more permanent and less volatile measure of socioeconomic status in places like Namsa than financial flows (Rutstein and Johnson, 2004). In order to do this, questions were asked during the household surveys about ownership of a range of assets and access to a range of resources that were deemed indicative of wealth – the choice of indicators mirrored those used in the Demographic and Health Survey Programme wealth index (Rutstein and Johnson, 2004).[41] Most of the households were found to have relatively similar housing standards and access to water, sanitation, and electricity. The main differentials were found to be in land endowments, and livestock, radio, mobile phone, and television ownership.[42] Even then, when considered on a per capita basis, land ownership differentials were relatively constrained, as noted earlier. Many of the assets where differentials do exist are luxury goods rather than essentials. In the model, households are initialised with heterogeneous land holdings that reflect the kind of variations seen in Namsa. They also have different numbers of livestock and poultry. As household circumstances evolve, and as household fission occurs, ownership of these assets also changes, mirroring the kind of changes that occur in Namsa over time.

5.8 Concluding Remarks

In this chapter, an overview of the fieldsite has been provided, drawing on data collected during the fieldwork stage. The village's historical experience of stressors

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[41] The assets and services considered included: type of flooring, water supply, sanitation facilities, electricity, radio, television, mobile phone, refrigerator, vehicles, persons per sleeping room, ownership of agricultural land, ownership of livestock.

[42] The household survey revealed that eleven had at least one basic mobile phone, four had at least one smartphone, seven had televisions, five had radios, and one had a laptop.

has also been detailed, as has its potential future socio-ecological trajectory. All of this has helped to inform the design of the agent-based model that is detailed in *Chapter 6*. The chapter has also served to set the fieldsite in context with mountain communities more generally, flagging up both similarities and peculiarities. This has been important to do given that the fieldsite is being held up as an example of a relatively typical mountain community.

Chapter 6: The Nepal Stressor Interaction Model (Nepal SIM)

Nepal SIM: Overview & details | Scenarios | Calibration | Number of replicates | Validation | Sensitivity analysis

In this chapter, the understanding of the study site that was set out in the previous chapter is translated into an agent-based model of a Nepalese mountain village. Furthermore, several stressor scenarios are developed for use within the model – their design informed by the experiences and expectations of the villagers, as well as by national trends. Each scenario incorporates certain assumptions about how three particular stressors – earthquakes, changing fertility rates, and increasing crop yield variability – may play out between 2015 and 2030. By simulating different configurations of these stressors in parallel, insights can be gleaned into how stressors interact and the implications of these interactions for individuals and households. The chapter wraps up with an overview of the calibration and validation process, and the results of a sensitivity analysis.

6.1 The Nepal Stressor Interaction Model (Nepal SIM)

The Nepal SIM has been developed in order to address the following research objectives, outlined in Chapter 1:

> ***Objective 2.*** Develop an empirically informed agent-based model of a rural Nepalese mountain village into which various stressor scenarios can be concurrently simulated.

Objective 3. Conduct simulation runs for a number of future stressor scenarios for the period 2015-2030, examining the impacts on village demographics and household finances.

In the section that follows, I describe the model using an abbreviated version of the ODD protocol (Grimm *et al*., 2006; Grimm *et al*., 2010). This is a standardised protocol for describing agent-based models. Ordinarily it consists of three main parts: an *overview* section; a *design concepts* section; and a *details* section. However, due to the elaborate nature of the Nepal SIM model and the need for brevity in the thesis, the description that is presented here is by-and-large restricted to the overview and details sections. That said, design concepts are touched on when relevant. The design decisions and parameters that are documented below are primarily informed by the Namsa fieldwork, although other sources are occasionally drawn upon as well, and certain parameters have undergone calibration. Where the latter two cases apply, the source or rationale is stated. Relative to most socio-ecological ABM studies, the model can be considered on the descriptive side. While modellers have traditionally tended to strive for simplicity and elegance in their model design, I subscribe to the view promoted by Edmonds and Moss (2004, p.130) that it is better to start with a model that "relates to the target phenomena in the most straightforward way possible," simplifying only when the "model and evidence justify this." Favouring description over simplicity and elegance complicates the model design and analysis process, but it should lead to a more useful model that is more faithful to the realities of the target domain.

The Nepal SIM model includes all of the main processes identified in *Chapter 5* that influence village economics and demographics and that interact in a significant way with the three stressors that are being considered. This means that there are a lot of factors at play. However, the individual processes are depicted in a relatively parsimonious fashion. The aim is to capture important characteristics and behaviours of the system while avoiding creating something of Daedalian complexity. An outline of the abbreviated ODD is shown in *Table 6.1*. Each sub-section has an associated code to aid cross-referencing.

Table 6.1. Outline of the abbreviated Nepal SIM ODD protocol.

Sections	Sub-Sections	Section code
Overview	Model purpose	M
	Entities, state variables, and scales	E
	Process overview and scheduling	P
Details	Sub-models	S
	Initialisation	I
	Scenarios	Sc

M. Model Purpose

The model is designed to simulate how multiple stressors could affect agrarian communities in the Mid-Hills of Nepal in the years leading up to 2030. The model incorporates all of the main social and agricultural systems that were identified in Namsa and is populated with artificially intelligent agents designed to behave in ways that, as closely as possible, match how the villagers at the fieldsite behave. Various stressor scenarios can be simulated within the model with each one combining a different set of assumptions about how stressors will play out. In this iteration of the model, I focus on assessing the potential long-term impact of the 2015 earthquakes, changing fertility rates, and increasing crop yield variability on household finances and village demographics (see *Sc*). These processes were chosen because they exemplify the types of stressors, shocks, and changes that are being experienced in many mountain systems around the world, as discussed in *Chapter 3*.[43] But, most critically of all, they were all flagged as being particularly significant during the fieldwork visits.

E. Entities, State Variables, and Scales

***E1*. Entities.** The model consists of eight kinds of entity: villagers, households, chickens, goats, cattle, buffalo, fields, and polytunnels.

- ***E1.1 Villagers*** are characterised by their gender, age, and household, their relatives, their personal cash and loans, their education level, their career, and

[43] They constitute a cross section of stressor types both in terms of the thematic classes outlined in *Figure 3.4*, and in terms of the temporal scales over which they operate.

their finance controller. The latter is an important concept within the model. It refers to the party within the villager's household who receives their income and funds their expenditure. Villagers who are a household referent (see *E1.2*), a wife of a referent, a parent(-in-law) or grandparent(-in-law) of a referent, a daughter or widowed daughter-in-law of a referent, or a still in education son of a referent, will have the household itself as their finance controller. In contrast, sons of referents who have completed their education manage their own income and expenditure, along with that of their wife and their children. This approximates how finances are managed in Namsa. Finally, villagers have variables stating the timing of their marriage and the timing of their death which are either determined at model initialisation (see *I4* and *I6*) or at birth (see *S5*), and married women have additional variables stating their desired number of children and the timing of their next child's birth (see *S5*).

- ***E1.2 Households*** are characterised by their members, fields (some of which may be specialist paddy fields), polytunnels, livestock, cash, loans, a crop strategy, a referent individual, and potentially a monthly remittance income (see *I11*). The crop strategy is a list of the number of fields the household is provisionally allocating to each of the available crop types during the year ahead. The referent individual is the youngest adult (defined as being over-18 years of age) male who does not have siblings within the household. Alternatively, in the absence of an adult male without siblings, the referent is the youngest widowed adult female.[44] The referent is a role invented purely to aid management of the demographic processes in the model. It is not an actual role in the village.
- ***E1.3 Chickens*** are characterised by the household they belong to, their age, their gender, and the stage they are at in their egg laying cycle (see *P2*) in the case of females.
- ***E1.4 Goats***, ***cattle*** and ***buffalo*** are characterised by the household they belong to, their age and their gender.
- ***E1.5 Fields*** and ***polytunnels*** are characterised by the household they belong to and their current usage in the model.

[44] In the unusual case that no such individuals exist within a household, the youngest adult male will be chosen, regardless of whether siblings are still present. If such a person is not available either, the youngest adult female will be chosen, regardless of whether they have been married before.

E2. Globals. The model includes a number of global variables which are accessible by all agents and processes in the model. These include past and present crop yields (see *I12*), forecast crop yields (see *S6*), produce prices and expense parameters (see *Table 6.2*), and scenario settings (see *Sc*).

Table 6.2. Key model parameters, their default values, and their source.

Parameter group	Parameter	Unit	Standard value	Source
Animal purchase price	Chicken purchase price	NPR	400	Wiki
	Goat purchase price	NPR	5,000	Wiki
	Cattle purchase price	NPR	3,000	Wiki
	Buffalo purchase price	NPR	10,000	Wiki
Animal slaughter price	Chicken slaughter price	NPR	1,200	Wiki
	Goat slaughter price	NPR	7,600	Wiki
	Female buffalo slaughter price	NPR	28,000	Wiki
	Male buffalo slaughter price	NPR	42,000	Wiki
Career advancement probability	Prob. of doing +2 post-school	-	0.5	Young persons' focus group
	Prob. of obtaining salaried job if completed +2	-	0.25	Young persons' focus group
	Prob. of advancing to level II from level I salaried job	-	0.75	Typical life & young persons' focus groups
	Prob. of advancing to level III from level II salaried job	-	0.5	Typical life & young persons' focus groups
	Prob. of advancing to level IV from level III salaried job	-	0.5	Typical life & young persons' focus groups
Subsistence crop yield	Standard maize yield	kg/ropani	84.8	Resource flows focus group
	Standard millet yield	kg/ropani	104.9	Resource flows focus group
	Standard wheat yield	kg/ropani	55.3	Resource flows focus group
	Standard rice yield	kg/ropani	150.1	Resource flows focus group
Cash crop yield	Standard potato yield	kg/ropani	793.1	Resource flows focus group
	Standard cabbage yield	kg/ropani	1,017.4	Resource flows focus group
	Standard cauliflower yield	kg/ropani	610.4	Resource flows focus group
Subsistence crop price	Maize price	NPR/kg	25	Wiki & resource flows focus group
	Millet price	NPR/kg	19	Wiki & resource flows focus group
	Wheat price	NPR/kg	22	Wiki & resource flows focus group
	Rice price	NPR/kg	20	Wiki & resource flows focus group
Cash crop price	Potato price	NPR/kg	22	Wiki & resource flows focus group
	Cabbage price	NPR/kg	18	Wiki & resource flows focus group
	Cauliflower price	NPR/kg	25	Wiki & resource flows focus group

Cottage industry income	Egg sale price	NPR/egg	7	Resource flows focus group
	Milk income from cow for one-person household	NPR/day	135	Wiki & survey
	Milk income from cow for two-person household	NPR/day	90	Wiki & survey
	Milk income from buffalo for one-person household	NPR/day	225	Wiki & survey
	Milk income from buffalo for two-person household	NPR/day	150	Wiki & survey
	Tomato tunnel income	NPR/harvest	4,140	Survey & resource flows focus group
Day-to-day expenses	Other living expenses	NPR	27	Survey
	Other food expenses	NPR	52	Survey & resource flows focus group
Educational expenses	Monthly school expenses	NPR	400	Wiki
	Monthly +2 expenses	NPR	800	Young persons' focus group & wiki
Festival, funeral & wedding costs	Festival expenses	NPR	200	Survey & seasonal calendar focus group
	Wedding gift	NPR	100,000	Wiki
	Funeral cost	NPR	200,000	Wiki
Salaried job abroad	Foreign job salary	NPR/month	10,000	Young persons' focus group & wiki
Salaried job in Nepal	Level I job salary	NRP/month	12,000	Typical life & young persons' focus groups
	Level II job salary	NPR/month	15,000	Typical life & young persons' focus groups
	Level III job salary	NPR/month	20,000	Typical life & young persons' focus groups
	Level IV job salary	NPR/month	25,000	Typical life & young persons' focus groups
Short-term labouring	Short-term labouring wage	NPR/day	500	Wiki
	Daily short-term labouring probability	-	0.19	Survey & seasonal calendar focus group
Remittance	Remittance income	NPR/month	10,000	Survey

E3. Scales. Each field equates to half a ropani of land (254.35 m^2), each polytunnel equates to 68.34 m^2, and one time-step corresponds to one day.[45] Simulations run for 5,475 time-steps which equates to fifteen years. For simplicity, leap days are not accounted for in the model. The simulations begin on 1 January 2015 and end on 31 December 2029.

E4. Visualisation. For visualisation purposes, fields are represented by hexagons, households by house symbols, villagers by arrowheads, animals by circles that are coloured according to species, and polytunnels by grey rectangles. Although the relative location of the agents is meaningless in respect to model dynamics, fields

[45] Processes and changes that happen within any given day are "represented by how they make state variables jump from one time-step to the next" (Railsback and Grimm, 2012).

are clustered by the household they belong to in order to aid visual interpretation and households, villagers, and animals are placed together on a uniformly randomly chosen field that is owned by their household. Polytunnels are placed on a separately chosen household field. An example snapshot of the model as visualised in NetLogo is shown in *Figure 6.1*.

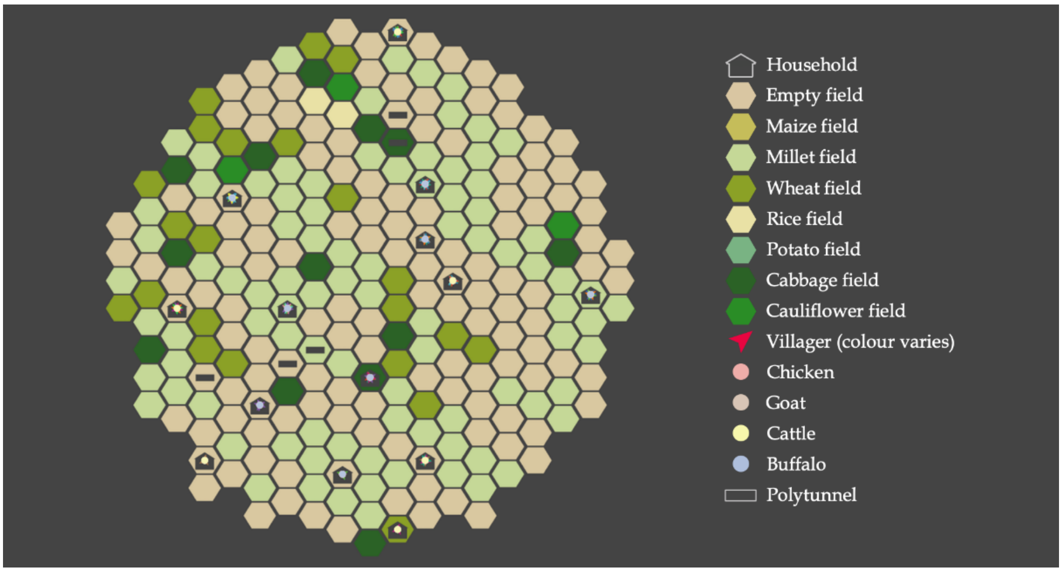

Figure 6.1. An example snapshot of the model during October in the first year of one of the runs, as visualised in NetLogo.

P. Process Overview and Scheduling

P1. Villagers. On each time-step, villagers age by one day. A check is then performed on each villager to see whether they have reached an education or career juncture. If they have, their education status and/or career is updated (see *S1*). Next, a check is performed to determine whether villagers are due to receive a salary, a wage, or a pension on the current time-step. Villagers with salaried jobs are paid at the end of each month at the rate shown in *Table 6.3*, while villagers who are engaged in short-term labouring are paid NPR 500 on the days that they work. Whether or not short-term labourers work on a given day is determined stochastically. By default, work opportunities are assumed to be available on 19% of non-festival days[46] and never declined. Villagers who are entitled to a pension,

[46] The typical short-term labouring wage rate was established during the fieldwork, as was the aggregate village income from short-term labouring during the year proceeding the fieldwork, but substantial variability across the year in terms of short-term labouring opportunities meant that estimating a parameter for the daily short-term labouring probability parameter proved difficult. I therefore ran a series of one-year simulations in order to identify the parameter value which led to

meanwhile, will receive NPR 10,000 on the first day of each month. Any income received will be transferred to the villager's finance controller (see *E1.1*).

Table 6.3. Monthly salary by job type.

Job type	Monthly salary (NPR)
Salaried job abroad	10,000
Salaried job in Nepal (Level 1)	12,000
Salaried job in Nepal (Level 2)	15,000
Salaried job in Nepal (Level 3)	20,000
Salaried job in Nepal (Level 4)	25,000

Next the personal expenditure of each villager – which is paid for by their finance controller – is determined. Each day, villagers who are not abroad will incur food expenses and non-specific other living expenses[47] – the latter is fixed at NPR 27 by default, while the former varies depending on personal circumstances (see *S2*). On the first day of each month, villagers who are attending school also incur an expense of NPR 400, while those who are attending college incur an expense of NPR 800. Should the day be one of the 23 festival days[48] that are celebrated in Namsa, each villager who is not working abroad will incur an additional expense of NPR 320. Next, villagers who are their own finance controller will assess their monetary situation (see *S11*). As part of this assessment, the villager will determine how many portions of meat they and they dependents can afford to consume each week. After these financial matters have been processed, checks are performed for each villager to see whether they are due to die (see *S3*), to marry (see *S4*), or to give birth (see *S5*) on the current time-step. Some of the simplifications in the way that villagers have been modelled are discussed in *Chapter 8*.

P2. Chickens. On each time-step, chickens age by one day and consume 32g of maize, 32g of millet and 10g of wheat, the cost of which is deducted from the cash stock of their household. When a female chicken reaches six months of age, it will

the best match between the survey and simulated aggregate short-term labouring income values. This proved to be 19%.

[47] The other living expenses parameter is intended to capture expenses that do not fall under the banner of construction, maintenance, education, food, celebrations, funerals, or livelihoods. As with the short-term labouring opportunities parameter, the other living expenses parameter was determined by running a series of one-year simulations in order to identify the parameter value which led to the best match between the survey and simulated aggregate other living expenses values. This proved to be NPR 27.

[48] The following days of the year are defined as festival days in the model: 14th, 30th, 89th, 274-280th, 290th, 282-288th, and 303-307th.

begin a cycle of laying an egg a day for thirty days, followed by three months of no eggs. These eggs are each sold for NPR 7 by the chicken's household. This money is added to the household's cash stock. Male chickens will be slaughtered when six months old (183 days), while female chickens will be slaughtered when five years old (1,825 days old). It is assumed that the carcass is sold for NPR 1,500 and a replacement 14-day-old chick is purchased for NPR 400. The net income is added to the household's cash stock. In the real world, there is of course more variability in poultry life courses and economics. The processes and parameters set out here are designed to represent what is typical. This is also true for the livestock.

P3. Goats. On each time-step, goats age by one day and consume 25g of maize and 25g of millet,[49] the cost of which is deducted from the cash stock of their household. At 329 days of age and 612 days of age, females will give birth – 62.2% of the births will yield one kid, 33.3% will yield two kids, and 4.4% will yield three kids. It is assumed that the kids are sold immediately for NPR 5,000 each. The adult goats are sold at two years of age for NPR 8,800 and a replacement 112-day-old goat is purchased for NPR 5,000. The net income is added to the household's cash stock.

P4. Female Cattle (Cows). On each time-step, cattle age by one day and consume 240g of maize and 240g of millet, the cost of which is deducted from the cash stock of their household. At 913, 1461, 2009, 2557, 3105, 3653, and 4201 days of age, cows will give birth to one calf. The calves are sold for NPR 3,000. Cows will provide milk each day post-pregnancy up until two months before they next give birth or until they reach 4,688 days of age. It is implicitly assumed that some of this milk is consumed within the household, but households with just one or two members are assumed to have surplus to sell. One-member households receive NPR 135 per day for selling their surplus milk, while households with two members receive NPR 90. This money is added to the household's cash stock. Cows will die upon reaching 18 years of age and are replaced by a 548-day-old calf at a cost of NPR 3,000.

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[49] Goats, cattle, and buffalo also consume fodder and left-over food from meals, but this is not explicitly modelled as it does not have cost implications for the households.

P5. Male Cattle (Oxen). On each time-step, cattle age by one day and consume 240g of maize and 240g of millet, the cost of which is deducted from the cash stock of their household. Oxen will die upon reaching 18 years of age and are replaced by a 548-day-old calf at a cost of NPR 3,000.

P6. Buffalo. On each time-step, buffalo age by one day and consume 280g of maize and 280g of millet, the cost of which is deducted from the cash stock of their household. At 1642, 2220, 2798 and 3376 days of age, female buffalo will give birth. The calves will be sold immediately for NPR 10,000. This money is added to the household's cash stock. Female buffalo will provide milk each day post-pregnancy up until three months before they next give birth or are slaughtered. As with the cows, it is implicitly assumed that some of this milk is consumed within the household, but households with just one or two members are assumed to have surplus to sell. One-member households receive NPR 225 per day for selling their surplus milk, while households with two members receive NPR 150. This money is added to the household's cash stock. Female buffalo will be slaughtered at 10 years of age, and males will be slaughtered at 14 years of age. Their meat will be sold for NPR 26,500 in the case of males, and NPR 19,875 in the case of females. They are immediately replaced by a 548-day-old calf at the cost of NPR 10,000. The net income is added to the household's cash stock.

P7. Households. Households begin each time-step by checking whether the current day is a crop planting or harvesting day (see *Table 6.4*). If it is the former, the household will re-evaluate its existing crop strategy in order to determine how many fields, if any, it wishes to allocate to the relevant crop (see *S6*). Once this is known, the particular fields that are to be allocated to the crop are selected uniformly randomly from those that are not currently in use, except in the case of rice cultivation which is only done in the specialist paddy fields. Planting then takes place (see *S7*). If the day in question is instead a harvesting day, fields will be harvested, and crops will be sold (see *S8*). The newly harvested fields will then become available for planting once again.

Table 6.4. Crops that are included in the model and their associated details. These values were determined during the resource flows focus group and by the wiki authors. They represent agreed averages.

Crop	Timing of planting (day of the year)	Seed requirement (kg per ropani or NPR per ropani)	Cost of fertiliser / pesticide (NPR per ropani)	Timing of harvest (day of the year)	Standard yield (kg per ropani)	Market price (NPR per kg)
Potato	29th	110 kg	627	170th	793.1	22
Maize	57th	0.8 kg	313	256th	84.8	25
Millet	166th	1.2 kg	313	334th	104.9	19
Wheat	275th	6.4 kg	313	127th	55.3	22
Rice	174th	28.8 kg	313	342nd	150.1	20
Cabbage	219th	300 NPR	1506	15th	1017.4	18
Cauliflower	244th	300 NPR	764	19th	610.4	25

After crops have been dealt with, the next step for households is to check whether their referent needs to be updated. The conditions set out earlier for selecting the referent determine whether this is the case (see *E1.2*). Following this, the households check whether the finance controller of each of their members needs updating. Again, the conditions set out earlier for determining the finance controller of villagers determine whether this is the case (see *E1.1*). After this, should the time-step correspond to the first day of a month, households that are designated as being in receipt of a remittance (see *I11*) will receive the said remittance. This is worth NPR 10,000 per month. Next, households check whether any of their members have met the conditions necessary to trigger household fission and then whether their circumstances have changed such that they need to buy or sell livestock and/or poultry (see *S9* and *S10*). Finally, households assess the state of their finances in light of the income and/or outgoings that have taken place earlier in the time-step (see *S11*). As part of this last process, the household will determine how many portions of meat that those with their household as their finance controller can afford to eat each week. Meat is modelled as it represents the main luxury expenditure outside of festival times. Certain simplifications in the way that households and crops have been modelled are discussed in *Chapter 8*.

P8. Polytunnels. Polytunnels are used to grow tomatoes. In the model, they undergo maintenance on the 46th day of the year. When this happens, households incur a cost of NPR 700. Planting then occurs on the 98th day of the year. Seeds cost NPR 100 per tunnel, while pesticide and fertiliser collectively cost NPR 770 per tunnel. Harvesting occurs fortnightly from the 213th day of the year until 44th day of the next year. Each fortnightly harvest is worth NPR 4,140 per tunnel.

S. Sub-Models

S1. To update career. The stochastic flow diagrams shown in *Figure 6.2* and *Figure 6.3* illustrate the life stages that the villagers in the model progress through as they age. They are based on the contemporary expectations of the villagers in Namsa as discussed in the focus groups. The probabilities outlined in the diagram represent the best guesses of the young persons' and typical life focus groups, with their choices being informed by recent community experience.

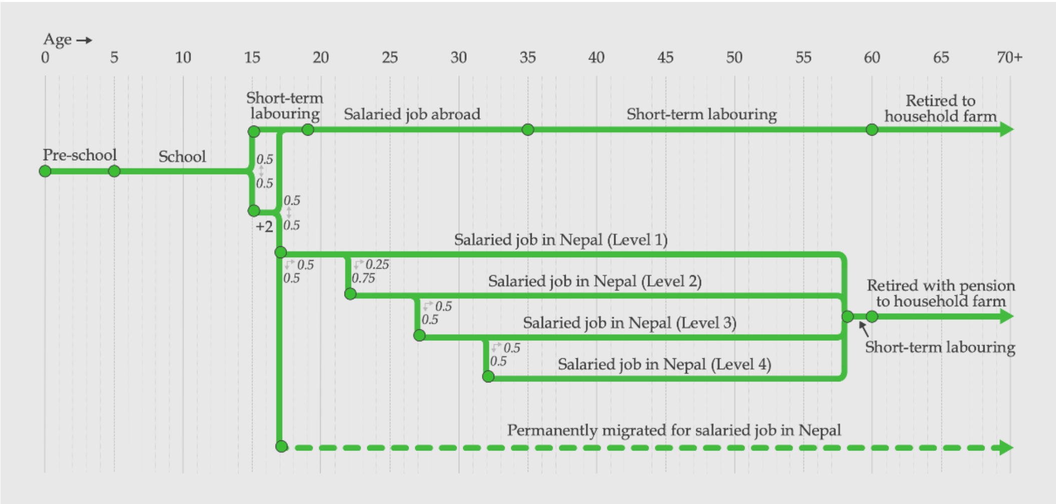

Figure 6.2. Stochastic flow diagram showing the range of potential life-courses of male villagers. Nodes represent change points, while arrows show the probability of travel along different branches.

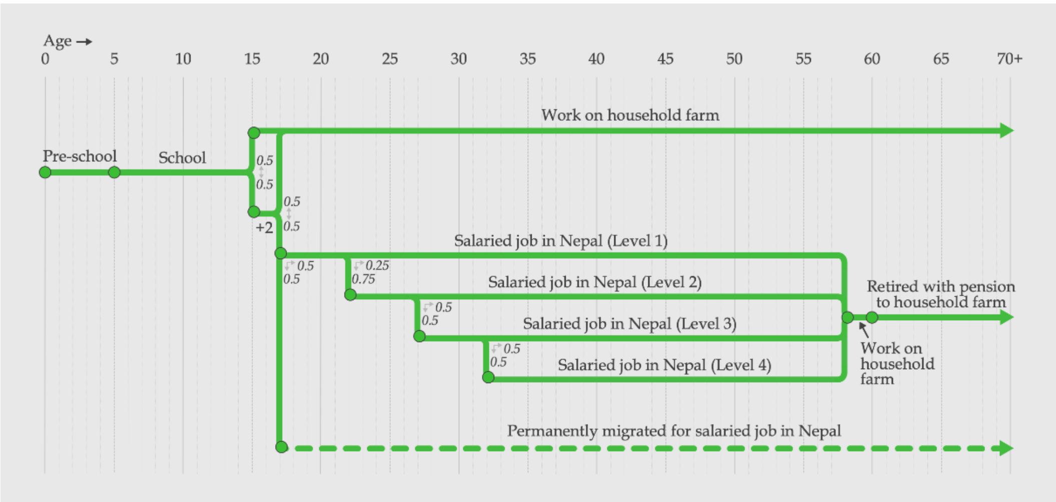

Figure 6.3. Stochastic flow diagram showing the range of potential life-courses of female villagers. Nodes represent change points, while arrows show the probability of travel along different branches.

In most cases, the life-course change points in the model fall on specific birthdays.[50] However, education represents an exception. For a villager to begin or complete school, or to begin or complete +2, they must meet the age condition shown in the flow diagram on the 100th days of the year – the approximate start of the Nepalese school calendar. When villagers complete school or +2, their educational attainment variable is updated to reflect this. Similarly, when villagers transition to a new stage in their life-course, their career variable is updated to reflect this.

S2. To calculate food expenses. The basic daily food requirement of an adult female household member is set out in *Table 6.5*. These values were determined during the 2017 visit through consultation with two of the women who cook for their families on a daily basis. They measured out combinations of ingredients that they adjudged to constitute a typical meal for one adult female. These ingredients were then weighed. Variation in meal types over the course of a typical year is taken into account in the figures. In the case of non-adult females, each foodstuff value in *Table 6.5* is multiplied by the applicable conversion value set out in *Table 6.6*. These conversion values are based on data from the Ministry of Agricultural Development (2012) on age-gender consumption differences. Household members who have salaried jobs abroad or who have emigrated do not incur food expenses in the model. Household members who are engaged in short-term labouring have their food needs reduced by a half on the days that they take up such opportunities. Similarly, household members who have salaried jobs in Nepal or who attend school or college have their food needs reduced by half on the days that they work/study[51] because they typically consume one of their main meals outside of the village on these days. In addition to their regular food consumption, villagers may consume up to three portions of meat per week (see *S11*). The particular number depends on the weekly meat consumption variable of their finance controller. Meat consumption is paid for each Sunday. A notable assumption is that market prices for both meat and other foodstuffs will not fluctuate over time. This simplification was made to avoid over complicating the

[50] This is a simplification, in reality the moment that villagers' transition between career pathways is much more varied.

[51] i.e. Sunday to Friday, except on festival days.

model dynamics – the desired focus of the model at this stage is on the stressors outlined in *Sc*, of which food price fluctuations is not one.

Table 6.5. Daily food requirements of an adult female villagers. These values represent daily averages, thus variability over time is accounted for but not explicitly represented.

Foodstuff	Quantity required (kg / day)	Market price (NPR)
Maize	0.026	0.65
Millet	0.026	0.494
Wheat	0.016	0.352
Rice	0.304	6.08
Potato	0.100	2.2
Other foodstuffs (excl. meat)	-	52

Table 6.6. Pre-meat food consumption needs of various age-gender groups relative to a representative adult woman. The need ratios are derived from the recommended calorific consumption figures for each age-gender group (Ministry of Agriculture Development, 2012).

Female		Male	
Age	Food consumption relative to an adult woman	Age	Food consumption relative to an adult woman
16+	1	16+	1.29
13-15	0.93	13-15	1.10
10-12	0.89	10-12	0.98
7-9	0.88	7-9	0.88
4-6	0.76	4-6	0.76
1-3	0.56	1-3	0.56
0	0.37	0	0.37

S3. To die. When a villager is scheduled to die, they ask their partner – should they have one – to set their widowed status to true.[52] If their partner has a future birth scheduled, this is cancelled unless it is set to occur within next nine months. Next, any cash or debts the villager has are transferred to their finance controller, unless they are their own finance controller, in which case their wife (or household, should they not have a wife) will inherit any such cash or debts. Following this, the villager's household incurs funeral expenses of NPR 200,000[53] and the villager will cease to exist. The expenses figure is based on conversations that the wiki authors had with two households that had gone through the funeral process relatively recently. Occasionally, children may be orphaned as a result of a death. If they have paternal grandparents, they will be adopted by those grandparents.

[52] For simplicity, it is assumed that widows and widowers do not remarry.

[53] At the fieldsite, we found that the sum spent on funerals depends on the affluence of the household and the circumstances of the deceased. Expenditure can be as high as NPR 400,000 in the case of some of the wealthier households. For simplicity, however, we assume a standard expenditure of NPR 200,000. Note that households will often need to take out loans to cover this cost.

Otherwise, they are assumed to be adopted by their maternal grandparents which means they will leave the village and cease to exist in the model. If the deceased was a male finance controller, his wife and children (should he have any) are assumed to move to his wife's village and therefore cease to exist. If the deceased was the sole member of their household, their house, fields, and animals will also cease to exist.

S4. To marry. When a female villager marries, she will leave the village and cease to exist in the model. In addition to this, her parents will incur an NPR 100,000 expense – the cost for them of providing a dowry. When a male villager who has permanently migrated marries, his parents will similarly incur an NPR 100,000 expense. His role in proceedings will then also be over. When any other male villager marries, a new female villager is created to be his wife. Her current age, her destined age of death, her educational attainment, and her career will be determined using the same methods as those employed in villager initialisation (see *I1*, *I2*, *I3* and *I6*). Her household will be the same as her husband's household. Her desired number of children will be stochastically determined with the value being drawn from one of the two fertility scenario distributions (see *Sc2*). The timing of her first child's birth will similarly be stochastically determined with the value being drawn from the distribution shown in *Figure 6.4*. This distribution is based on data gathered by Karkee and Lee (2016). The marriage ceremonies themselves are assumed to be cost neutral for the households involved as gifts from the guests tend to offset the costs. However, a transfer of wealth from the parents of the bride and groom to the new couple does take place. In the model, the groom's parents (if they are alive) and the bride's parents both gift the newlyweds NPR 100,000. This figure represents a typical value according to the wiki authors – it varies somewhat in reality.

S5. To give birth. When a villager gives birth, a new villager is created. Its age is set to zero, its education is set to pre-school. Its parents are set to the villager who has given birth and to the partner of that villager. Its gender is randomly determined with an equal chance of it being either male or female. Its destined age of marriage is determined by drawing a value at random from the gender appropriate marriage age probability distributions that are associated with *Figure*

6.5. These probability distributions were derived from the Nepal Demographic and Health Survey (MHP, 2012b). The child's destined age of death is similarly determined by drawing a value at random from the gender appropriate mortality age probability distribution that is associated with *Figure 6.6*. The mortality probability distributions were derived from the 2015 life table for Nepal (WHO, 2016). Once the new villager has been initialised, its parents update their list of children to include the new villager. If the mother's child count is still below her desired number of children, another birth will be scheduled. The days till this birth will be stochastically determined with the value being drawn from the distribution shown in *Figure 6.7*. These latter distributions are based on field data gathered by Karkee and Lee (2016).

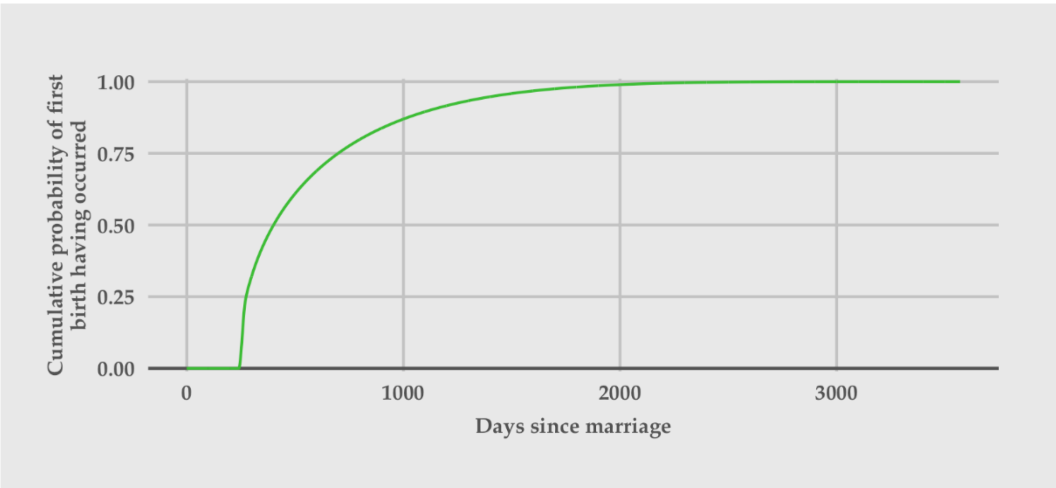

Figure 6.4. The cumulative probability of first births having taken place with time from marriage. The curve is fitted to values set out in Table 1 of Karkee and Lee (2016) for Kaski district in the Mid-Hills of Nepal.

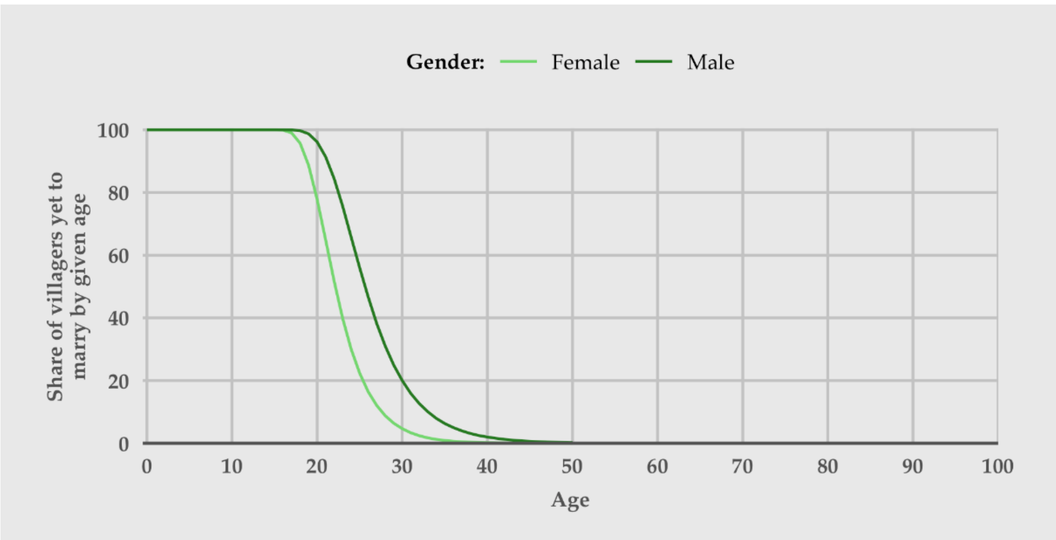

Figure 6.5. Share of villagers who are yet to marry by age.

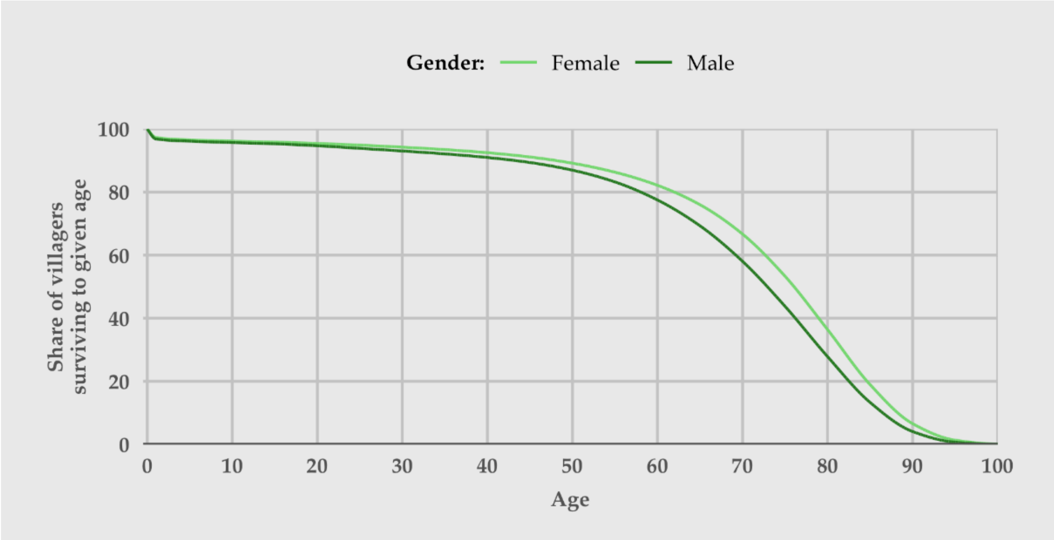

Figure 6.6. Share of villagers surviving to successive ages in the model.

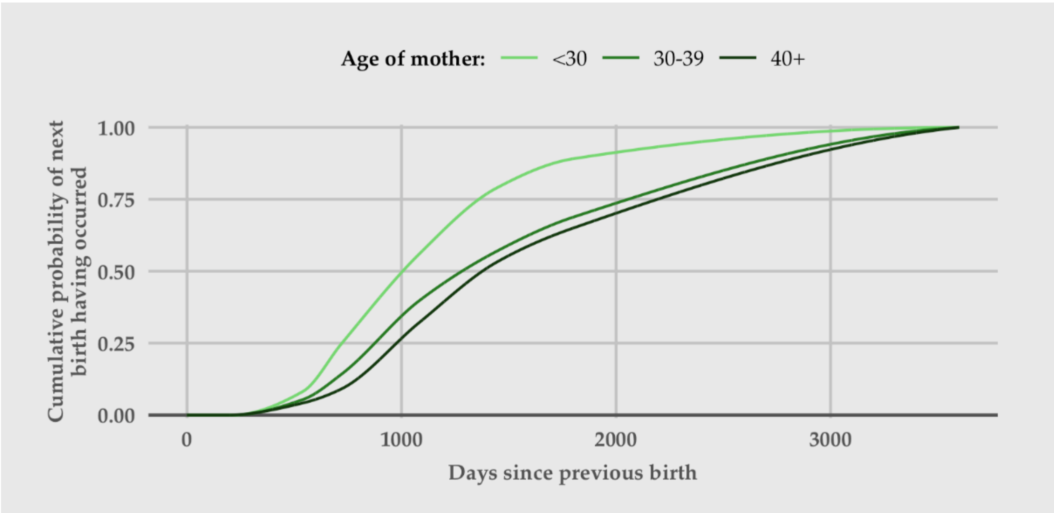

Figure 6.7. The cumulative probability of a birth taking place with time from the previous birth for mothers who are yet to reach their desired number of children. The curves are fitted to values set out in Table 2 of Karkee and Lee (2016) for Kaski district in the Mid-Hills of Nepal.

S6. To update crop strategy. This is a multi-step process. Firstly, households conservatively update their forecast of future grain needs, which means assessing the expected grain consumption of household members, livestock, and poultry for the year ahead (see *P2-6* and *S2*). Secondly, they forecast per-field yields for the coming year for each crop. This is done by applying exponential smoothing to yield data from the previous ten years.[54] Following this, an estimated minimum number of fields that need to be allocated to maize, millet, and wheat in order to

[54] A smoothing constant of 0.25 was used.

fulfil the household's grain needs during the forthcoming year can be calculated.[55] Next, the remaining fields – minus the specialist paddy fields – will be divided between potato, cabbage, and cauliflower production using a fixed ratio of 20:9:3. This ratio represents the standard ratio for cash crops as revealed by the household survey. Fields are non-divisible so, when rounding, potato is prioritised over cabbage and cauliflower, and cabbage is prioritised over cauliflower. Paddy fields are always allocated to rice production. The number of fields that are allocated to each crop during this process represents the household's current crop strategy. The way that crop strategies are modelled is one of the bigger simplifications in the ABM. The processes outlined above constitute a rough generalisation of household behaviour when it comes to crops. In the actual village – as discussed in *Chapter 5* – crop mix decisions were made less deterministically, with the decision process differing slightly between households. The simplifications made here are discussed further in *Chapter 8*.

S7. To plant crops. When planting occurs, the status of the chosen fields is updated to reflect their new usage. Households then incur a cost equal to the seeds required per half ropani for that crop, multiplied by the current market price of the crop, multiplied by the number of fields to be grown, plus the per half ropani cost of fertiliser, multiplied by the number of fields to be grown (these values are shown in *Table 6.4*). Cabbage and cauliflower represent slight exceptions to this rule as cabbage and cauliflower seeds have a fixed price of NPR 300 per ropani. Households without male cattle or buffalo will also incur a cost of NPR 425 per field for hiring oxen to plough their land.[56]

S8. To harvest crops. If the current day is a harvesting day, households receive income from the sale of the relevant crop. The income is equal to the market price of the crop, multiplied by their total crop yield. Market prices are fixed in the model at the rates shown in *Table 6.4*, but yields have a degree of variability (see *Sc3*). For households without male cattle or buffalo, harvests also result in an oxen

[55] It is assumed that households try to grow all of their own maize, millet, and wheat as was typically the case in Namsa, rather than relying on markets.

[56] It is assumed that households with just one draft animal are able to agree a reciprocal deal with other households with one draft animal to pool their animals as required, thereby avoiding the need to pay for additional animal hire.

hire cost of NPR 425 per field that the relevant crop is planted in. In the actual village, households will often exchange labour when engaging in agricultural tasks. Sometimes this involves money exchanging hands, but I have decided not to explicitly simulate the hiring of agricultural labour in this version of the model as it would require a number of additional assumptions to be made. Another notable simplification in this part of the model is the assumption that harvests are always sold in their entirety. In Namsa, only the cash crops are typically sold. However, by selling harvests in the model and then buying produce as required, management of household food stocks is greatly simplified. It is assumed that the grain (i.e. the non-cash crop produce) is both sold and bought at the fixed market price given in *Table 6.4*, so households are typically not financially advantaged or disadvantaged by this buy-back model.

S9. To perform household fission. Prior to the earthquake, when there was more than one son in a household, the elder son(s) traditionally claimed a share of their family's land and built their own home around the time that they married and had their first child. However, post-earthquake, the cost of construction jumped significantly, forcing a delay in household fission.[57] In the model, it is assumed that the elder sons of the referent who have not permanently migrated will still build new homes on the portion of the family's land that they are entitled to inherit, but only after (a) they have married and (b) they have enough money to afford to build the home. It is assumed that the new home will cost NPR 625,000. This is a mid-level figure for what households were forecasting new homes to cost when we returned in 2017. As soon as the couple collectively have this sum of money, plus a buffer of NPR 35,000, they will establish a new household. This means, firstly, claiming the share of the parent household's land that the son is entitled to. This entitlement is calculated using the following equation, with the result being rounded to the nearest half ropani:

$$E = \frac{F}{S + 1}$$

[57] In Namsa, we saw an increase in the rate of fission following the earthquake as young people who had been living with parents/parents-in-law would often build temporary shelters that were separate from their parent's/parents-in-law's temporary shelter. However, they were not entitled themselves to reconstruction grants so once homes were rebuilt, they tended to move back in with their parents/parents-in-law.

Here, E is the departing son's field entitlement, F is the parent household's current field count, and S is the number of sons the referent has who are still members of the household at that moment in time (this includes the departing son). If the entitlement is below six ropani, the son will migrate with his wife and children instead of forming a new household as the entitlement would be insufficient for an economically viable farm. If the entitlement is six ropani or more, the son will immediately claim any fields from the parent household that are not currently in use and will progressively claim additional fields from his parent's household as they are harvested until he has his full entitlement. In the model, it is assumed that the parent households will always retain any paddy fields that they own, so only regular fields will be transferred. The members of the new household will be the departing son, his wife, plus any children they may have. The household's cash stock will be set to the couple's remaining personal cash stock after the cost of building the new home is deducted. The household will purchase poultry and livestock using the method outlined in *S10*. The youngest remaining son in a household will ultimately inherit his parents' home and remaining land unless he chooses to migrate. Consequently, he will not need to engage in household fission himself.

S10. To determine animal ownership. During the decision-making focus group, the main factor determining livestock and poultry ownership was said to be the number of adults available to engage in animal husbandry.[58] Consequently, in the model, animal ownership is deterministically linked to the number of adult household members (>18 years old), as shown in *Figure 6.8*. The relationship model used for each type of animal is based on linear regressions which were estimated from the Namsa data. Importantly, there are a handful of cases in respect to determining bovine ownership in which exceptions are made. If households have less than 5.5 ropani, they are deemed incapable of supporting any bovine animals as they will not be able to produce sufficient crop fodder to support any

[58] This is largely because of the time demands and physical demands that animal rearing entails. Additional factors that shape animal ownership were said to be land sufficiency (i.e. whether the household has enough land to consistently supply the necessary fodder from its own farm), the physical strength, knowledge, and preferences of household members, and broader decisions around the household's livelihood strategy. As these factors are less readily quantified within the model, I focus on adult numbers alone.

cattle or buffalo. For related reasons, households with 5.5 to 10.5 ropani will have their potential bovine ownership capped at one, households with 11 to 16 ropani will be capped at two, and households with 16.5 to 21.5 ropani will be capped at three. These rules are based on discussions in the resource flows focus group, although they represent a simplification of reality. Poultry and livestock ownership are less deterministically defined in the actual village, with animal preferences and strategies varying somewhat, as was discussed in *Chapter 5*.

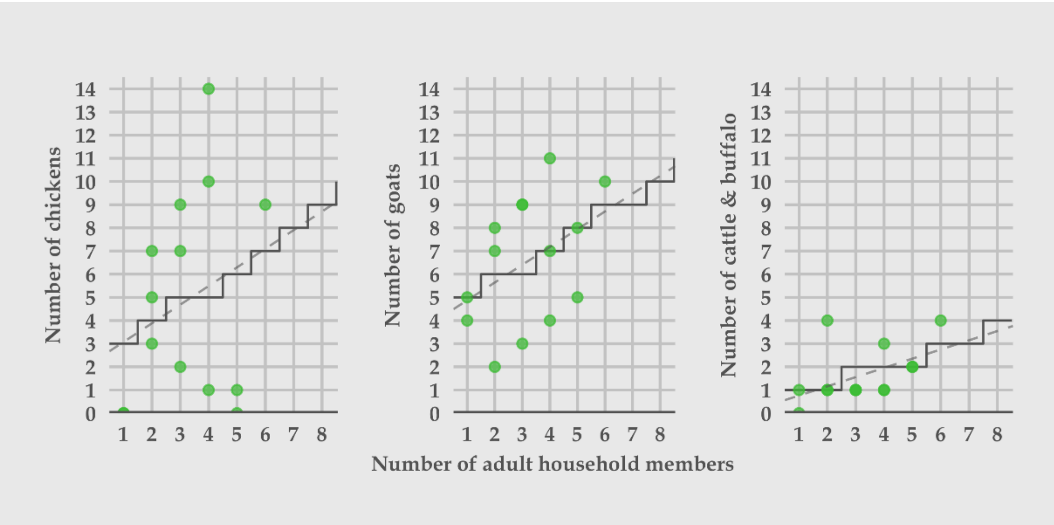

Figure 6.8. The stepped line shows the deterministic relationship between the number of adult members a household has and the number of each animal type it owns. The green points show the actual data from Namsa, while the dashed line shows the linear regression line.

When the number of animals a household has is below the number it should have given its size and land, the household will purchase additional animals to correct the disparity. Chickens are bought when 14 days old at a cost of NPR 400. Their gender is uniformly randomly assigned. Goats are bought when 112 days old at a cost of NPR 5,000 and also have their gender uniformly randomly assigned. If the new animal is to be a bovine, it will be bought when 548 days old at a cost of NPR 3,000 if it is an ox or cow, or NPR 10,000 if it is a buffalo. The breed is stochastically determined with two fifths of bovine designated buffalo, while the remainder are designated cattle. If the household does not already have buffalo or cattle, the animal will be designated female, otherwise it will be designated male. These rules approximate the livestock gender and breed preferences observed in the Namsa survey data. The purchase cost and age values are based on those reported by the wiki authors. If the number of animals a household has is above rather than below the number it should have given its size and land, the household will instead sell animals to correct the disparity. Animals are sold in order of age, from the youngest to the oldest. The money the household receives when selling an animal depends on the animal's breed and age. It is assumed that an animal's worth increases linearly between the time it is purchased and the time it reaches slaughter age.

S11. To assess finances. Once all income and outgoings have been determined for the households and villagers, finance controllers take stock of the impact the transactions have had on their cash situation. If the transactions during the current time-step have resulted in a finance controller having a negative cash balance, the controller will typically need to take out a loan to cover the shortfall.[59] This loan is added to the sum of any existing debt the controller may already have. An exception is made if the finance controller is a household and if that household has another finance controller among its members (i.e. a financially independent son). In such cases the member will cover the household's shortfall if he has sufficient cash, thus helping them avoid accumulating debt. This kind of intra-familial support is fairly typical in Namsa according to the decision-making focus group. Next, if a household has debts, the daily interest due on that debt is calculated and added to the total. The annualised interest rate is set at 20% which is typical for the area according to the wiki authors. Following this, should the time-step correspond to the first day of a month, finance controllers will conservatively forecast their income and expenditures over the coming year, and the effect these will have on their cash situation. This will enable them to assess whether they can afford to make immediate debt repayments (should they have debts) or afford to buy meat during the coming month without getting into a negative cash situation later in the year. Debt repayments are prioritised over the purchase of meat so the feasibility of debt repayments is assessed first. If a household or villager has debt and its cash forecast is in the black for the entirety of the coming year, it will calculate what its cash balance is forecast to be at its lowest. If the household or the villager's debt is less than this amount, it will immediately pay the debt off in full, otherwise it will simply pay down the debt by the forecast minimum cash balance.

[59] This results in their cash balance being reset to zero.

In the scenarios in which earthquakes occur, households will be issued with reconstruction loans which are treated separately from any other debt they may have. The repayment of a reconstruction loan is only contemplated when households are free of other debt. Repayments are made in monthly instalments, each of which amounts to one sixtieth of the original loan. Households only make these monthly repayments when their forecasts suggest they can afford to do so without getting into a negative cash situation later in the year. The reconstruction loans are interest free. If a finance controller has cash remaining after paying off any debts it may have had and after meeting any loan repayment obligations, it will consider how many portions of meat it can afford to buy for its dependents each week for the coming year while still meeting any reconstruction loan repayment obligations it may have. The cost of providing meat to a villager is NPR 102 multiplied by the villager's food consumption multiplier (see *Table 6.6*). Up to three portions of meat per week are considered. Once the maximum viable number of portions that the controller can afford has been determined, the controller's weekly meat consumption variable will be set to reflect it. Of course, this representation of how households manage their finances incorporates a number of simplifying assumptions. The reality, which was discussed during the decision-making focus group, can be more complicated and varies somewhat between households. The implications of taking this simplified approach are reflected on in *Chapter 8*.

I. Initialisation

For the model to provide useful insights into the future evolution of villages like Namsa, the initial model conditions need to be realistic. One option would have been to directly replicate the fieldwork village in virtual form. However, there are two significant ethical reasons why this would be inappropriate. Firstly, doing so would pose a privacy threat to the research subjects as, in combination, the individual and household attributes that would be included in the code could potentially lead to their identification by third parties (Gkoulalas-Divanis *et al.*, 2014). Secondly, the act of simulating the behaviour and life course of actual individuals might reasonably be perceived as infringing on the dignity of the research subjects. For example, few of the villagers would, presumably, appreciate their deaths being simulated. For these reasons, it is necessary to either obfuscate the empirical data prior to its use or to use synthetic datasets in the model in lieu of the empirical data.

There are a number of obfuscation techniques available such as randomization, data swapping, and data desensitisation[60] (Bakken *et al.*, 2004). However, their use in this case would be complicated by the existence of numerous dependencies between data points and the need to retain data granularity and a consistently high degree of verisimilitude. Furthermore, most obfuscation techniques focus on details rather than structures, so they could potentially leave signature patterns within datasets that could still enable re-identification.

The alternative approach, population synthesis, has seen a flurry of interest in recent years as it represents a key stage in the spatial microsimulation process (Lovelace and Dumont, 2016). Typically, spatial microsimulation requires a population of synthetic individuals be generated in instances where aggregate statistics are available, but individual level data is restricted to a subset of the real population.[61] While there are a range of methods available for population synthesis, most of them essentially involve combining the aggregate information with the individual level data that is available to construct a synthetic population which approximates the "correlation structure of the true population" (Barthelemy and Toint, 2013, p.266). The strengths and weaknesses of each method of population synthesis can, however, differ substantially.[62] Importantly in our case, only a fraction of the techniques perform well in creating realistic household groupings of synthetic individuals. One such example is given by Gargiulo *et al.* (2010) who set out a sample-free method for generating a synthetic population organised in households. Their approach respects a variety of statistical constraints such as "distribution of household types, sizes, age of household head, difference of age between partners and among parents and children" (Gargiulo *et*

[60] An example of data desensitisation is lowering data item accuracy in a systematic way (Bakken *et al*. 2004).
[61] Note that in contrast to most uses of spatial microsimulation, we start with disaggregated data for the entire population. We draw on the approach for different reasons to those that it is typically employed for.
[62] See Müller and Axhausen (2011) and Lovelace and Dumont (2016) for discussions of the relative merits of various approaches.

al., 2010) – all of which are a requirement for the model set out here. However, like most population synthesis methods, the approach used by Gargiulo *et al.* (2010) assumes a significantly larger initial dataset can be drawn upon than the one available in our case and it was also designed with the generation of rather larger populations in mind than the one we require. Unfortunately, their method does not downscale particularly well when it comes to the use of small input datasets and the need for small population outputs. However, approaches such as that of Gargiulo *et al*. (2010) do offer a framework from which we can take inspiration.

I1. Population synthesis. Given the limitations of existing methods of population synthesis, it has been necessary to design a bespoke approach – an approach that can generate realistic households composed of realistic individuals, and that can approximate the composition of household types seen at the fieldsite using just the data I have available. Rather than generating a population of individuals and then allocating them to households (the approach typically used), I determine a set of household types and then generate individual household members iteratively to suit the types of household created. The main steps are as follows:

1. The number of households that should be generated is specified. For the purposes of this thesis, this will always be 14 – the number of households that resided in Namsa at the time of the fieldwork.
2. Each of the households to be generated is assigned a household type from the options shown in *Figure 6.9*. Assignment is done through the use of stochastic universal sampling (SUS) to ensure that a minimum spread of different household types is chosen while still allowing for a degree of variability in each model run. The probability of each household type, $P(t)$, being selected is proportionate to the observed occurrence of that household type during the main fieldwork phase in 2015.
3. The next sequence of steps involves populating each household in turn with members. This process starts by selecting the age of the household's referent individual, a_r. These are the individuals shown in dark green in *Figure 6.9*. The age is selected using a simple uniform random draw from the set of observed ages of the equivalent individuals in the equivalent household types in Namsa, $P(a_r|t)$. A small amount of noise is then added or subtracted from

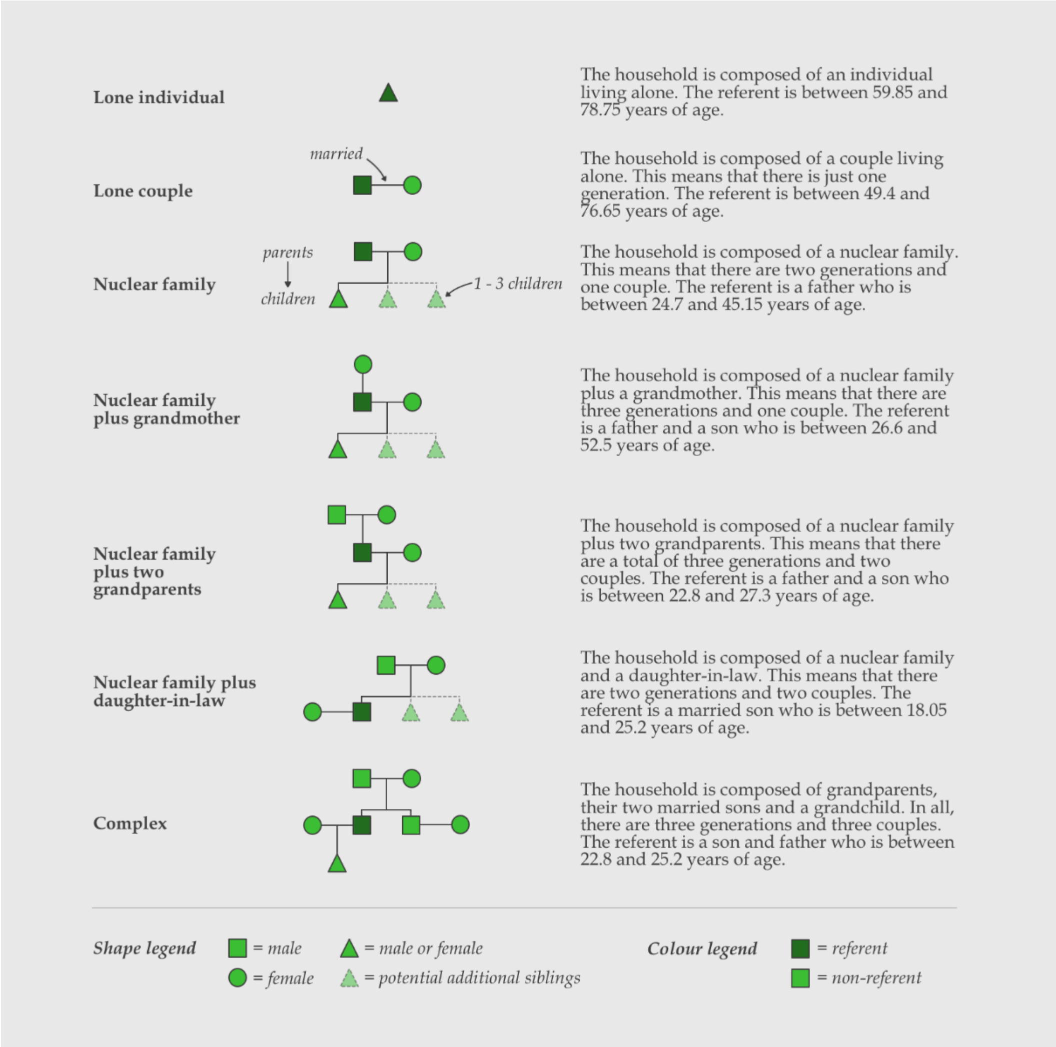

Figure 6.9. The seven basic household structures observed in Namsa in 2015. They form the basic household types that are generated in the population synthesis process. This data comes from the household surveys.

this figure (±5%). This ensures that referents will not all share the same birthday and it adds diversity to the potential outcomes that goes beyond the observed referent age values. Also determined at this point is the gender of the referent. If t is not a lone individual, the referent is always male. However, if t is a lone individual, the gender is instead randomly determined – the probability of the referent being male or female is assumed to be equal. In the case of lone individual household types, the household will be fully populated at this point so the process of populating the next household in the list will then commence. If the household is not a lone individual, the next stage of the process commences.

4. The next step is to select the age of the referent's partner, a_p. This involves adding the result of a simple uniform random draw from the set of observed age differences between husbands and their spouses, to the previously selected a_r value. Importantly, any of the observed age differences that would result in the partner being younger than 18 years-old[63] are excluded from consideration and a small amount of noise (equivalent to ±0.5 years-of-age) is added to each observed value before the draw is made. The noise is applied so that the birthday of the partner will usually differ from that of the referent. The noise value is kept small so as not to radically alter the initially determined value. The gender of the partner is then set to female. After this, the number of children the couple will have during their lifetime is decided probabilistically according to $P(c|a_p)$. These probabilities are again based on the survey data from Namsa. If the household is to be a lone couple, the process of populating the next household in the list will then commence. For the remaining household types, the process continues.
5. If the household type is not a nuclear family plus daughter-in-law, the age and gender of the referent's current children is decided, and the provisional date of the next birth is selected if the current number of children is not equal to the value of the lifetime number of children that was determined in the previous step. This process involves first deciding the age of the eldest child probabilistically based on $P\left(a_{c1}\middle|a_p\right)$, and then selecting the birth interval to each subsequent child probabilistically based on $P(birthInt)$. Both of these probabilities are again based on the data gathered during the surveys. If an interval yields a future date, that value will represent the provisional date of the next birth. As the birth interval values are not integer years, it is not necessary to add noise to the results. Following these steps, the gender of each child that has been born is randomly determined – the probability of each child being male or female is assumed to be equal. If the household is to be a nuclear family, the process of populating the next household in the list will then commence. For the remaining household types, the process continues.

[63] This was the legal age of marriage at the time the model was designed. The legal age of marriage has since been raised to 20. However, the legal marriage age is not strictly observed in Nepal so this change in law is not necessarily all that problematic.

6. The next step is to select the age of the referent's mother, a_m. This involves adding the result of a simple uniform random draw from the set of observed age differences between referents and their mothers, to the a_r value. Again, a small amount of noise (equivalent to ±0.5 years-of-age) is added to the result. The gender of the referent's mother is then set to female. If the household is to be a nuclear household plus grandmother, the process of populating the next household in the list will then commence. For the remaining household types, the process continues.
7. Next, the age of the referent's father, a_f, is determined. A simple uniform random draw is made from the set of observed age differences between referents' mothers and referents' fathers with the chosen value then added to a_m. A small amount of noise (equivalent to ±0.5 years-of-age) is again added. The gender of the referent's father is set to male. If the household is to be a nuclear household plus grandparents, the process of populating the next household in the list will then commence. For the remaining household types, the process continues.
8. If the household is a nuclear household plus daughter-in-law, the referent will not have children, but he may still be living with siblings. The number of children the referent's parents have is decided probabilistically according to $P(c|a_m)$. This probability is again derived from the household surveys. As the referent is the only one of the siblings who will be married at the initialisation point, he is assumed to be the eldest. The interval between each sibling in age is also determined probabilistically by repeat picking based on $P(birthInt)$. Following these steps, the gender of each sibling other than the referent is uniformly randomly determined. After this, the process of populating the next household in the list will commence.
9. At this point, just one household type remains to be completed: the *complex* household. In this instance, the age of the referent's brother, a_b, is chosen next based on $P(birthInt)$. As reasonable age values for a_b are bounded in this case by the need for both brothers to be relatively close in age (less than 3 years), only a subset of the potential birth intervals is included in the possibility set. The age difference which is selected is added to a_r. Next, the age of the brother's wife, a_{sil}, is chosen by selecting a value using the same process as

that used for determining the age of the referent's partner. The gender of the referent's brother is set to male and the gender of the referent's sister-in-law is set to female. After this, process of populating the next household in the list will commence.

This basic flow is repeated until all of the households have been populated. This bespoke approach allows creation of virtual villages that should be qualitatively similar to Namsa in terms of population and household structure, while preserving the anonymity of the research subjects. It also means that actual individuals are not simulated, so it addresses the core ethical concerns mentioned earlier. Furthermore, it is well suited to the data available and can create small populations without issue. There are, however, certain limitations to the approach. Firstly, the archetypal households are limited to those observed at the fieldsite in 2015 and, secondly, the reference distributions that inform the probabilistic selections are based on small samples. This means that possible outcomes are always quite strongly tethered to the particularities observed in Namsa.

I2. Initialise villager educational attainment. Villagers who are less than 2,090 days old will be in pre-school at the time of model initialisation as they will have been less than five years old when the current school year started. Villagers who are older than 2,090 days but younger than 5,740 days will be in school as they will have been between five and 15 years old when the current school year started. Villagers who are older than 5,740 days but younger than 6,570 days will either be undertaking their +2 or will have left the education system as they will have been between 15 and 18 years old when the current school year started. Both possibilities are equally likely. Of the villagers who are older than 6,570 days, but under 28 years-of-age, by default a quarter will have attained +2 qualifications, a quarter will have left education after completing their SLC, and the remaining half will have left school before attaining any qualifications. Villagers who are over 28 years-of-age but under 45 years-of-age will have a 25% chance of having attained their SLC. The remainder – along with villagers who are over 45 years-of-age – will have left school before attaining any qualification. These rules have been derived from the data on educational attainment that was set out in *Chapter 5* and from discussions during the typical life and young persons' focus groups.

I3. Initialise villager career. Villagers who have completed their education will be allocated to a career pathway at initialisation. The particular career pathway that is selected for a villager is determined using the same principles employed in *S1*, with the villager's gender, age, and educational attainment all being taken into account.

I4. Initialise villager age of marriage. The marriage age of those who are single at the time of model initialisation is determined by drawing a value at random (with uniform probability) from the viable values[64] in the gender appropriate marriage age probability distributions that are associated with *Figure 6.5*. A similar process is used for women who are already married at initialisation, except the age of their eldest child (should they have one) is taken into account in determining what is a viable value as it is assumed that women will be married prior to having their first child. The marriage age of husbands is then determined based on the values assigned to the women.

I5. Initialise villager fertility. The desired child count of married women who are under the age of 50 is also determined at initialisation. The process used to select this value is the same as the one outlined in *S4*, except it takes into account the number of children the women already have, the time since they had their last child, and the time since they married. Specifically, the number of children that a woman already has determines her minimum desired fertility; women who have been married more than 9.78 years without having a child are assumed to desire no children; and women whose last child was born 9.86 years ago are assumed to desire no more children. The choice of these values is based on data from the Nepal Demographic and Health Survey (MHP, 2012b). Women who desire more children than they currently have will also have the timing of their next birth determined at initialisation. This is done using the same method as that outlined in *S4* for women who are yet to have a child, and *S5* for women who already have at least one child, except the viable values that are drawn from are constrained by the time that has elapsed since the women were deemed to have last given birth or married.

[64] Viable values are those that are greater than a villager's current age.

I6. Initialise villager age of death. The age at which the newly initialised villagers are set to die is determined by drawing a value at random (with uniform probability) from the viable values[65] in the gender appropriate mortality age probability distributions that are associated with *Figure 6.6*.

I7. Initialise household fields. The number of fields a household is assigned is determined using a stochastic function that takes into account the number of adults in the household. The function is based on a linear regression model which was fitted to data from the Namsa household surveys. Noise terms derived from the standard error values of the regression model are added to the function to mimic the observed variability between households. The function is as follows:

$$r = 1.8854 + (2.0284 * a) + \eta_1 + \eta_2$$

Here, $\eta_1 \sim N(0, 1.6715)$, $\eta_2 \sim N(0.4728)$, r being the number of ropani, and a being the number of adults in the household. Values generated by the function are rounded to the nearest half ropani as a half ropani is the standard unit of land used in the model. A floor of 5.5 ropani is enforced as this was said to be the minimum viable size of a functional farm.

I8. Initialise household paddy fields. Two, three, or four of the fields that are assigned to households with 16+ ropani of land will be deemed suitable for rice cultivation when the model is initialised. The precise number of fields allocated is randomly determined with each option being equally likely.

I9. Initialise household polytunnels. Three uniformly randomly chosen households who have at least two adults under the age of 60 will be allocated polytunnels. The particular number of polytunnels each household is allocated is uniformly randomly determined but will be either one, two, or three. These rules are designed to allocate polytunnels to the kinds of households that had been targeted for support by JICA in the actual village.

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[65] As with the initialisation of marriage age, viable values are those that are greater than a villager's current age.

I10. Initialise household animals. The number and gender of the animals that each household has at initialisation is determined using the same deterministic method as that outlined in *S10*. However, rather than the animals being assigned the default age values for new livestock and poultry, their initialisation ages are uniformly randomly determined out of the viable age values.

I11. Initialise finances. Finance controllers have their finances initialised using a two-step process. Firstly, they conservatively forecast their income and outgoings for the forthcoming year, while assuming meat consumption of two portions per week and the realisation of expected crop yields (the latter being of relevance only to household). Based on this assessment, the amount of initial cash that they require to meet their consumption and livelihood needs during the coming year without going into debt can be determined. They are then allocated this sum. In addition to this, households may be allocated historical savings or debts. This is done by uniformly randomly assigning each household the net finances of one of the households in Namsa (as established in the household surveys), using a sampling without replacement approach. Two households are also assigned a monthly remittance income of NPR 10,000. Finance controllers who are villagers will, meanwhile, be allocated historical savings that take into account their estimated earnings and expenditures since they left education. This is important as it can affect the timing of household fission.

I12. Initialise past yields. Ten years of historical crop yield data is generated at initialisation to enable the crop strategy selection procedure to function. This is done by repeating ten times for each crop the procedure that is outlined in *Sc3* for stochastically determining a given crop's yield.

I13. Initialise future yields. For simplicity, the yield of each crop for each simulation year is predetermined. This is done in the same way as the above procedure, but for fifteen years' worth of yields instead of ten (simulations are fifteen years long).

I14. Initialise crop status. The initial crop strategy of households is determined using the same method as that outlined in *S6*. Wheat, cabbages, and cauliflower are scheduled to be planted at the time the model starts so households assign the applicable number of fields to each of these crop types, following essentially the same process as that set out in *S7*.

Sc. Scenarios

In this iteration of the model, I focus on assessing the potential impact of the 2015 earthquakes, changing fertility rates, and increasing crop yield variability on household finances and village demographics. Two scenario pathways have been crafted for each of these stressor types. As explained below, each pathway embodies a certain set of assumptions about how that particular stressor will play out. Each model run involves simulating one of the earthquake pathways, one of the fertility pathways, and one of the crop variability pathways. This means that there are eight potential pathway combinations in all. These particular stressors have been chosen because: (a) they are representative of the contemporary challenges that many mountain communities face; (b) they were particularly pertinent to the villagers in Namsa at the time of the fieldwork; and (c) they are emblematic of the three main categories of stressor that were identified in *Chapter 2*.[66] Other stressors also fulfilled these criteria – food price fluctuations and changing labour market opportunities, for example. However, the trajectory of these latter stressors is highly uncertain, so they are not being considered at this stage.

Sc1. Earthquake scenarios. The first earthquake pathway is an effort to mimic the impact of the 2015 earthquakes which struck Namsa towards the end of the main fieldwork spell, shortly after the baseline data – which the initial model conditions are generated from – was collected. The details of the scenario are based on the experiences reported by the villagers themselves during the follow up fieldwork in early 2017. Middling values are used where households disagreed about the degree of impact or where experiences differed. The scenario details are as follows:

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[66] Namely (a) climatic and meteorological stressors; (b) seismic, geomorphological and ecological stressors; and (c) economic and social stressors

- Five percent of livestock die as a result of collapsed shelters and stress. Households are not able to sell these deceased animals due to the chaotic circumstances and loss of access to local markets due to landslides blocking the highway.[67]
- There is a fifty percent chance of individuals who live alone leaving the village to reside permanently with family members elsewhere in Nepal. There is also a fifty percent chance of households that are composed of two adults emigrating permanently if one of those adults has a salaried job. When a household leaves the virtual village, their house, fields, and animals cease to exist.
- The yield of the crops that are in the ground between 25 April and 12 June (one month after the 7.3 M_w aftershock) is 30% below what it would otherwise have been due to terrace collapses, soil movements, damage to the village irrigation system, and a reduction in the time that villagers can dedicate to agricultural activities.
- The standard cash crop yield permanently declines by 15% as a result of the reduced irrigation capacity of the village following the damage caused to the village irrigation system which the households are unable to repair.
- Off-farm labouring stops for three months, as villagers focus on dealing with the challenges on their own farm and because of the regional economic disruption. However, once this three-month period is over, off-farm labouring opportunities increase by 50% above the baseline rate for twenty-four months as the recovery and reconstruction processes get underway.
- On 25 October 2016, eighteen months after the main shock, households take out reconstruction loans to fund the rebuilding of their houses. The size of the loan depends on the number of members the household has at that moment in time. Households of one or two members are issued with a loan of NPR 300,000. This rises to NPR 425,000 for households with three to four member, NPR 550,000 for households with five to six members, and NPR 675,000 for households with seven or more members. The role of reconstruction grants is

[67] Human mortality is assumed to be zero in the model. While one person died in a neighbouring village, none of the Namsa villagers died, and the earthquake mortality rate for Dolakha district was just 0.09% (OCHA Nepal, 2015).

reflected in the chosen loan sizes. Details of the loan repayment process are given in *S11*.

The second earthquake scenario is a counterfactual in which the earthquakes do not happen and therefore the impacts listed above are not realised. This alternative pathway provides a baseline against which the consequences of the earthquakes for household finances and village demographics can be gauged.

Sc2. Fertility scenarios. The first fertility scenario assumes an average fertility rate of 1.6 children per woman, while the second assumes the slightly higher rate of 2.1 children per woman. *Figure 6.10* shows how these headline fertility rates translate into probabilities for particular numbers of children in each case. Both of the fertility rates can be considered equally plausible for Namsa over the short- to medium-term based on the discussions during the young persons' focus group and recent demographic reporting for Nepal (MHP, 2012a). Those who attended the focus group – who will represent the next generation of parents – spoke of a clear preference for either one or two children. Taken at face value, this would suggest that a fertility rate of more than one but less than two should be expected. However, a 2014 study estimated that 26.1% of births in the Central development region of Nepal (in which Namsa is located) were unplanned (Puri *et al*., 2016). For this reason, it is assumed that the actual fertility rate is likely to be somewhat above the intended rate. Based on this logic, the chosen fertility rates represent reasonable 'high' and 'low' scenarios. Notably, the 1.6 rate is equal to the current urban fertility rate, while the 2.1 rate is the Nepalese government's long-term national target (KC *et al*., 2016).

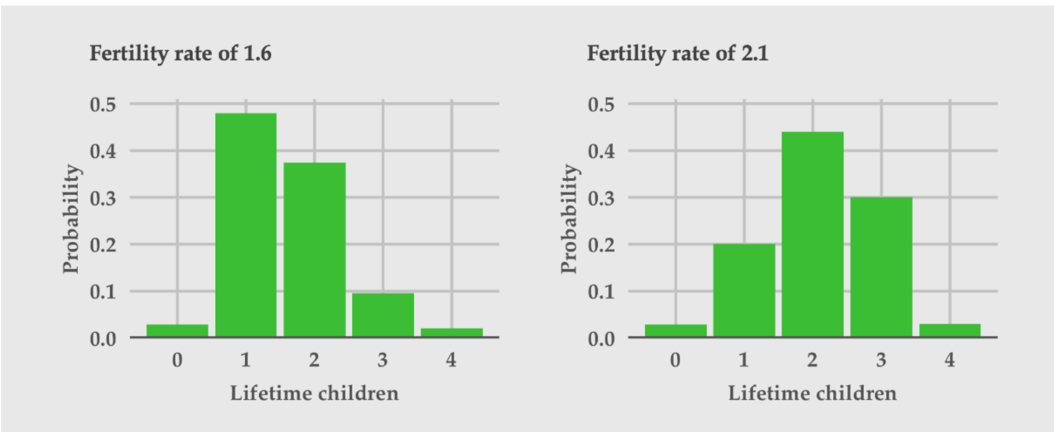

Figure 6.10. The two fertility rate scenarios decomposed probabilistically by lifetime children.

Sc3. Crop variability scenarios. The first crop variability scenario assumes a continuation of the status quo in terms of inter-annual yield variability, while the second scenario assumes a slightly higher degree of inter-annual yield variability than is currently reported. This latter scenario is intended to represent the potential consequences of climate change and the increasing threat of pests and diseases for agriculture.[68] In the model, each crop has a standard (mode) yield as shown in *Table 6.4*. When a crop is due to be harvested, this standard yield is multiplied by a number drawn randomly from a crop yield probability function to determine the actual yield. The crop yield probability function that is used depends on the crop type and the scenario that is being simulated. There are four crop yield probability functions in all, each of which is based on a beta function that is calibrated to result in a specific half-yield recurrence interval (see *Figure 6.11*). Half-yield frequencies are used as the concept was readily understood during discussions with the villagers in the community history focus group. For simplicity, all of the traditional subsistence crops (maize, millet, wheat, and rice) are assumed to have the same degree of variability in any given run and all of the cash crops (potato, cabbage, cauliflower) are assumed to have the same degree of variability in any given run.[69] However, the actual yield of a crop in any given year is independent of the yield

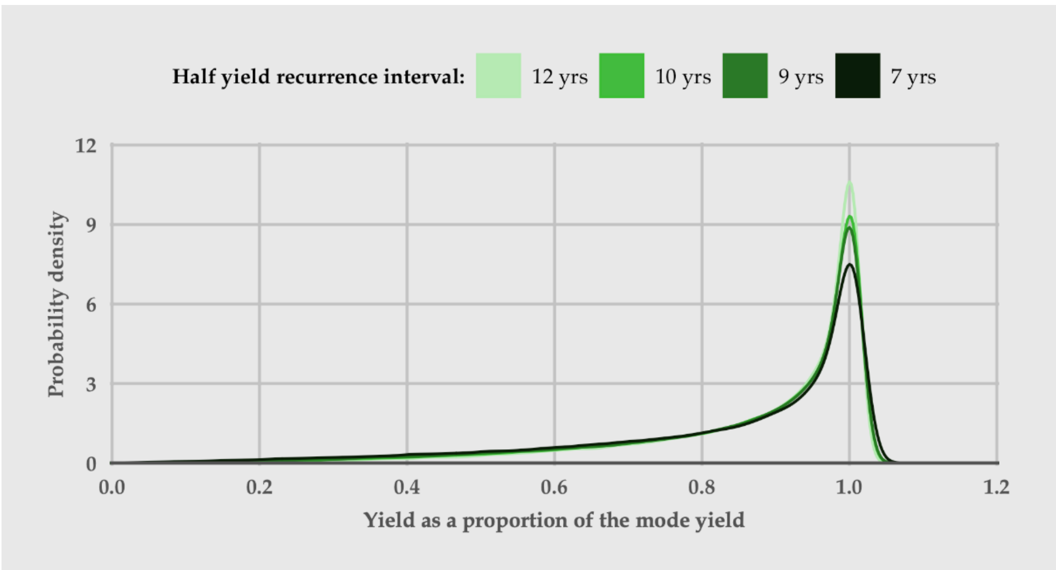

Figure 6.11. The four crop yield probability curves that are used in the model.

[68] The three-year difference in half-yield frequency is an arbitrarily chosen figure.
[69] This is a simplification as there are known to be distinctions within the categories. However, difficulties obtaining agreed values for each crop during the focus group discussions meant that it is necessary to use the more general group values for which more clear agreement was attained.

of the other crops. For subsistence crops, the status quo half-yield recurrence interval is 12-years, dropping to 9-years for the alternative scenario. For cash crops, the status quo half-yield recurrence interval is 10-years, dropping to 7-years for the alternative scenario.

6.2 Parameterisation and calibration

The majority of the parameter values that are set out in the ODD protocol are directly informed by evidence gathered during the fieldwork (e.g. food prices, crop yield fluctuations, wages) or by information from third party datasets (e.g. the birth, marriage, and mortality probabilities). However, in the case of other living expenses and short-term labouring demand, it was not possible to directly identify suitable parameter values for use at daily timesteps. This was due to considerable temporal variability, a lack of consensus during discussions, the diverse nature of the expenditure types making recall difficult in the case of other living expenses, and a lack of relevant third-party data. That said, the household surveys did provide annual estimates of living expenses and income from short-term labouring, and the standard daily wage rate for short-term labouring is known. In combination, this information enabled both parameters to be estimated 'inversely' through a calibration process. This was done by conducting a series of one-year experimental model runs in which the two parameters were adjusted until the average simulated annual income from short-term labouring and average simulated annual other living expenses approximated the figures that were reported in Namsa.

6.3 Determining the necessary number of replicates

Given the stochastic nature of the model, it is necessary to conduct multiple runs for each scenario in order to determine what constitutes typical outcomes and to gauge variability (Lee *et al.*, 2015). Following Lee *et al.* (2015) and Broeke *et al.* (2016), I looked at how the coefficient of variation of various metrics changes with the number of runs – see *Figure 6.12*. In each case, the coefficient of variation largely stabilises after 200 runs. Consequently, this number was considered the minimum number of replicates necessary for the analysis which follows.

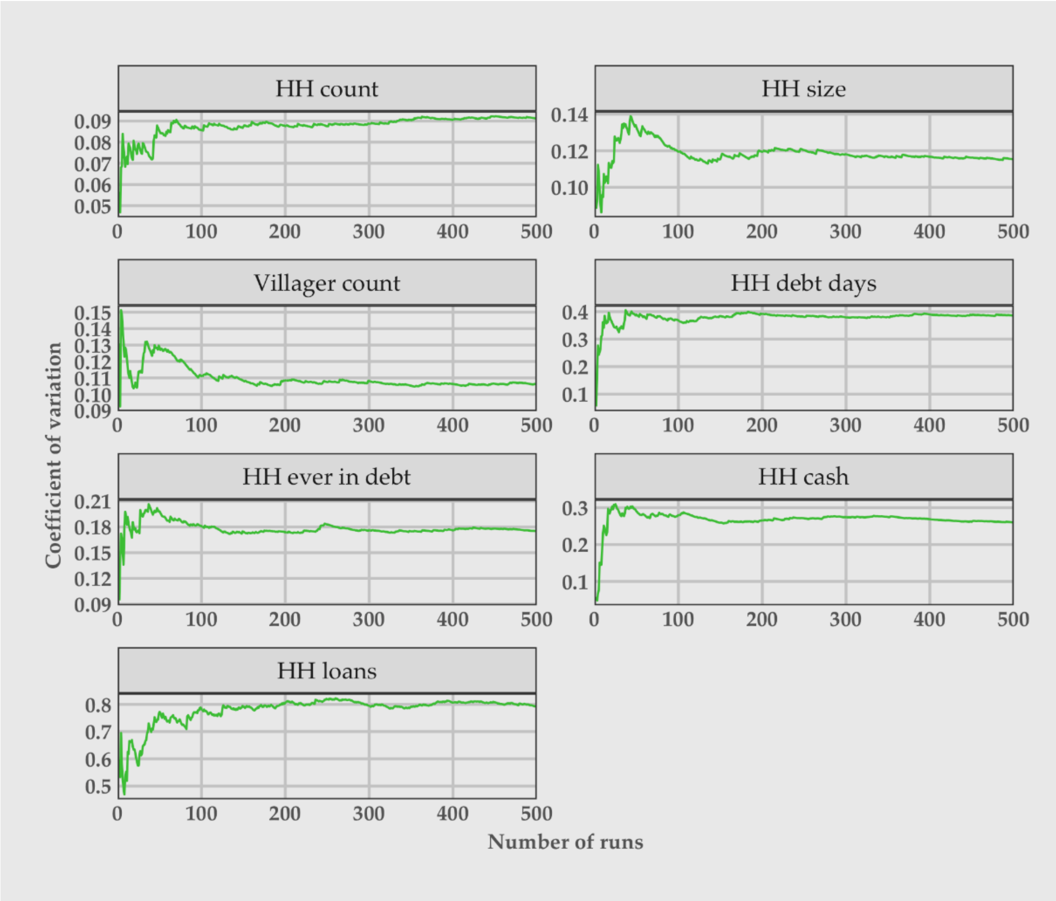

Figure 6.12. Coefficient of variation of various metrics for increasing numbers of runs in the no-earthquake, low crop variability, 2.1 fertility rate scenario with parameters set to their default values.

6.4 Validation

Model validation is the "process of ensuring that there is a correspondence between the implemented model and reality" (Wilensky and Rand, 2015). It refers to the establishment of legitimacy in respect to the model design and parameterisation decisions (Oreskes *et al*., 1994). Within the field of agent-based modelling, two broad approaches to validation can be discerned: empirical validation and stakeholder validation. Empirical validation involves assessing how well data produced by a model corresponds to real-world empirical data. This is the most popular approach to validation in the literature and is the "traditional yardstick for establishing confidence in models" (Polhill and Salt, 2017). However, as Polhill and Salt (2017) note, this often requires an unfeasible amount of data if it is to be done effectively. It is particularly problematic in cases such as this, where a system has many potential evolutionary pathways, but only one can ever be observed. Stakeholder validation, meanwhile, involves the subjects of the model (or other third-party experts) providing feedback on the appropriateness and accuracy of design decisions (Moss, 2008; Hassan *et al.*, 2013). In respect to this study, stakeholder validation is more straightforward than empirical validation, but ultimately is reliant on the quality of the judgements that are made by those who are engaged in the validation process.

Here, I have drawn upon a combination of empirical validation methods and qualitative validation methods to assess the appropriateness of the model, recognising the respective strengths and drawbacks of each approach. In respect to empirical validation, I conducted four-hundred one-year-long model runs for the no-earthquake, low crop variability scenarios in an effort to approximate the conditions in the year leading up to the fieldwork. I then calculated the total income and expenditure of the village in each replicate, breaking this down by income and expenditure type. Next, I compared the mean and the range of the values produced in this simulated data to the household survey data for the same categories of income and expenditure as shown in *Figure 6.13*. Before this was done, however, the two datasets were adjusted to account for certain differences in how the model operates compared to real-life. Specifically: (a) Subsistence crops are by and large not monetised in the actual village, so their sale and purchase values are removed from the income and expenditure data in the simulation results; (b) In the model, households are assumed to buy all of their new animals from third parties, while selling all of their new-born animals. In reality, households breed a majority of their own animals so therefore spend less on animals and receive less for animals than the model suggests. To adjust for this, two-thirds of the spending on new animals in the model data is deducted from livestock income (which includes animal sales), with livestock expenditure in turn reduced by two thirds; (c) In reality, households will often consume meat from animals reared within the village rather than purchasing their meat solely from markets as the model assumes. To adjust for this, two-thirds of meat expenditure is deducted from food expenditure and livestock income; (d) Finally, in the actual village, there is a household that owns a grain mill which means it has unusually high business income and livelihood expenditures relative to the other households. It also has anomalous educational expenditure. As the mill is not simulated in the model, these anomalously high income and expenditure values have been corrected for in the benchmark empirical data through the use of mean substitution. In the case of business income and livelihood expenditure, the substitute value was based on the mean per adult business income and livelihood expenditure of other households (i.e. NPR 1,987 and NPR 7,671 per adult respectively). In the case of educational expenditure, the substitute value was based on the mean per child educational expenditure of the other households (i.e. NPR 12,000 per child).

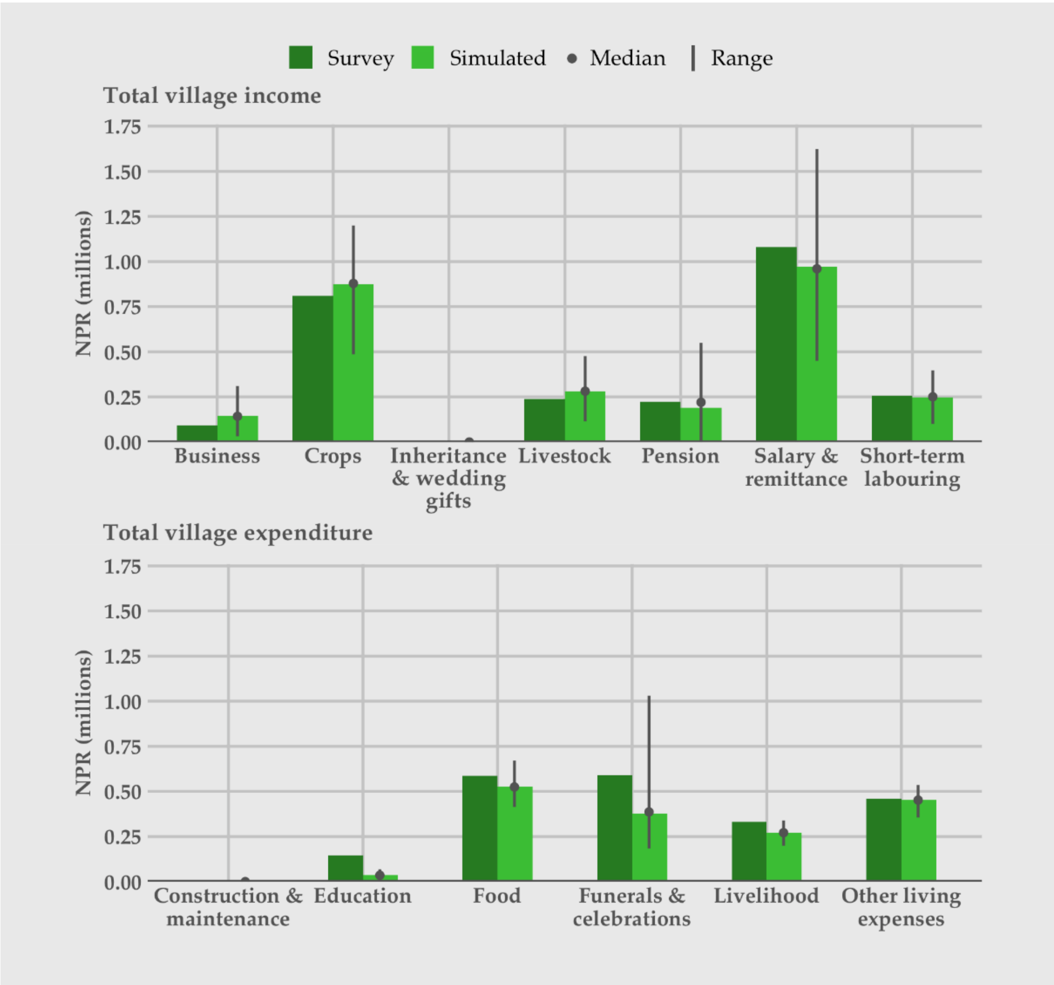

Figure 6.13. Comparison of surveyed and simulated total village income and expenditure disaggregated by type. Four hundred simulations were conducted in all – 200 with a fertility rate of 1.6 and 200 with a fertility rate of 2.1.

That the survey data points fall within the range of simulated outcomes in most income and expenditure categories is a positive sign.[70] That said, it is hardly surprising in the case of the short-term labouring and other living expenses categories as they were calibrated to the survey data. It was, however, less inevitable in the case of the other categories as the parameters that underlie them were by and large not derived from the annual income and expenses data gathered during the household survey. The values do not exactly coincide and there is substantial variability in a number of the simulated categories, but this is to be expected given the stochastic nature of many of the processes (Schmidt, 2000). The only category where the simulated outcomes do not overlap with the survey derived value is education costs. The simulated education values undershoot the reported value by a large margin[71] – NPR 108,984. The reason for this discrepancy is not, however, clear. It could reflect a problem with the survey data, or an issue with the model design and the parameters which were informed by the wiki. Further fieldwork would be needed for the cause to be established. Whether this comparison of values is of much value is debatable given the number of strong assumptions that were necessary to make the two data sets comparable and the substantial variability in model outcomes. This makes the efforts that were made to cross verify the data that informed the design of the model, all the more important. Also valuable was the chance to run the initial ideas for the model by some of the villagers on my return visit in 2017, as discussed in *Chapter 4*. This provides confidence that most of the model processes are at least valid "on face" (Wilensky and Rand, 2015). As an additional step, extensive monitoring of individual runs was conducted to check for unreasonable behaviours (Wilensky and Rand, 2015). Where unexpected behaviours were identified, investigations were conducted into their cause and corrections were made where appropriate. The potential implications of uncertainties in the parameter values is explored in the sensitivity analysis detailed below.

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[70] For additional comparison, the Nepal Living Standards Survey of 2010/2011 (CBS, 2011b) placed the nominal average per capita income level in rural areas at NPR 35,923. This includes farm income, non-farm income, remittances, consumption of own-dwelling, own account production income, and other sources. Share of farm income in all household income averaged 28%, while non-farm income constituted 37%, remittance was 17%, and share of own production consumption was 16% (CBS, 2011a, p.39).

[71] This is true even with the survey derived education value corrected for the effect of the mill household's education spending.

6.5 Sensitivity analysis

Sensitivity analysis (SA) explores the response of a model's outputs to plausible changes in input parameters (Railsback and Grimm, 2012; Lee *et al.*, 2015). It is used both to "quantify the uncertainty of the model outcomes that is caused by parameter uncertainties" (Ten Broeke *et al.*, 2016) and to gain insights into model behaviour. Here I use an adapted version of the popular one-parameter-at-a-time (OAT) approach to SA as it is the least computationally demanding of the standard SA methods (Ten Broeke *et al.*, 2016). This is important because the Nepal SIM model is highly computationally demanding. Typically, OAT involves varying one parameter at a time while holding all other parameters at their default baseline values (Lee *et al.*, 2015). This enables the impact of each varied parameter on the outputs to be assessed, thus providing some insight into the sensitivity of each output to that parameter and offering a sense of the relative importance of various model components. Here, I deviate from the standard approach to OAT by varying parameters in thematic groups rather than individually. This is done because the Nepal SIM model involves an unusually large number of parameters which makes it impractical to examine each one in isolation. The impact of the parameter changes will likely be bigger as result of varying them in groups, than if they had been varied in isolation from one another.[72] It is important to bear this in mind when interpreting the outcomes. The thematic groups are shown in *Table 6.7*. Each individual parameter is assigned a default value, C, a feasible upper extreme, C^+, and a feasible lower extreme, C^-.[73] Two hundred simulations were conducted with all of the parameters set to the default C value and then a further 200 simulations were conducted for each parameter group at its C^+ value and then at its C^- value. As there are 11 parameter groups, this yielded 4,600 simulations in all.[74]

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[72] It is unlikely that the parameter changes within any of the groups will mitigate one another – the groups have been designed to avoid this.

[73] These extremes were determined in discussion with the villagers (see *Table 6.2* for details of the data sources). It should be noted that the extremes do not represent the potential extremes of individual real-world case (e.g. someone getting an exceptionally good price for a chicken), but rather the perceived extremes of the village average cases as determined by uncertainty and variability in those values (e.g. chicken prices during a conceivably very good year).

[74] The no-earthquake, low crop variability, 2.1 fertility rate scenario was used for these simulations.

Table 6.7. The thematic parameter groups, the parameters they include, their default baseline values (C), and the variation in the parameters relative to the default values.

Parameter group	Parameters included	C	C-	C+	Percentage change
Animal purchase price	Chicken purchase price	400	320	480	-20 / +20
	Goat purchase price	5,000	4,000	6,000	-20 / +20
	Cattle purchase price	3,000	2,550	3,900	-15 / +30
	Buffalo purchase price	10,000	8,500	13,000	-15 / +30
Animal slaughter price	Chicken slaughter price	1,200	960	1,440	-20 / +20
	Goat slaughter price	7,600	6,080	9,120	-20 / +20
	Female buffalo slaughter price	28,000	19,600	36,400	-30 / +30
	Male buffalo slaughter price	42,000	29,400	54,600	-30 / +30
Career advancement probability	Prob. of doing +2 post-school	.5	.42	.57	-15 / +15
	Prob. of obtaining salaried job if completed +2	.25	.17	.32	-15 / +15
	Prob. of advancing to level II from level I salaried job	.75	.64	.86	-15 / +15
	Prob. of advancing to level III from level II salaried job	.5	.43	.58	-15 / +15
	Prob. of advancing to level IV from level III salaried job	.5	.43	.58	-15 / +15
Cash crop price	Potato price per kg	22	18	26	-20 / +20
	Cabbage price per kg	18	14	22	-20 / +20
	Cauliflower price per kg	25	20	30	-20 / +20
Cottage industry income	Daily milk income from cow for one-person household	135	115	155	-15 / +15
	Daily milk income from cow for two-person household	90	77	104	-15 / +15
	Daily milk income from buffalo for one-person household	225	191	259	-15 / +15
	Daily milk income from buffalo for two-person household	150	128	173	-15 / +15
	Tomato sale income per harvest	4,140	3,312	4,968	-20 / +20
Day-to-day expenses	Other living expenses	27	22	32	-20 / +20
	Other food expenses	52	42	62	-20 / +20
Educational expenses	Monthly school expenses	400	200	800	-50 / +50
	Monthly +2 expenses	800	400	1,600	-50 / +50
Festival, funeral & wedding costs	Festival expenses	200	160	240	-20 / +20
	Wedding gift	100,000	80,000	120,000	-20 / +20
	Funeral cost	200,000	160,000	240,000	-20 / +20
Salaried job abroad	Monthly foreign job salary	10,000	9,000	12,000	-10 / +20
Salaried job in Nepal	Monthly level I job salary	12,000	10,800	13,200	-10 / +10
	Monthly level II job salary	15,000	13,500	16,500	-10 / +10
	Monthly level III job salary	20,000	18,000	22,000	-10 / +10
	Monthly level IV job salary	25,000	22,500	27,500	-10 / +10
Short-term labouring	Daily labouring wage	500	450	600	-10 / +20
	Daily short-term labouring probability	0.19	0.15	0.23	-20 / +20

Eight summary statistics were calculated for each simulation once the runs were completed: (a) the total households in the village at the end of the simulation; (b) the average household size at the end of the simulation; (c) the villager count at the end of the simulation; (d) the combined number of days that households spent in debt over the course of the simulation; (e) the total number of households who were in debt at some point during the simulation; (f) total household cash at the end of the simulation; (g) total household loans at the end of the simulation; (h) the Gini Index for the village at the end of the simulation.[75] The impact of using each parameter group's C^+ and C^- values on these statistics is shown in *Table 6.8* as a percentage change relative to the baseline simulations. The instances where the change was statistically significant are highlighted.

Table 6.8. Change in each statistic relative to the baseline simulations when a parameter sets C^+ *and* C^- *values are used. The bracketed number is the Mann–Whitney U test score. The statistically significant results are coloured. Green showed a positive change, while blue shows a negative change. HH = household.*

	Animal purchase price		**Animal slaughter price**		**Career advancement probability**		**Cash crop price**	
	C^-	C^+	C^-	C^+	C^-	C^+	C^-	C^+
HH count	-0.19% (.8329)	-0.23% (.8133)	-0.04% (.9982)	-0.04% (.9964)	-0.19% (.8345)	-0.04% (.9745)	-0.04% (.9964)	-0.15% (.8916)
HH size	+0.22% (.8277)	+0.51% (.6976)	+0.25% (.9001)	+0.28% (.9858)	+0.15% (.8707)	+0.17% (.8721)	+0.08% (.9523)	+0.16% (.9796)
Villager count	+0.14% (.9264)	+0.33% (.7231)	+0.23% (.8447)	+0.15% (.9830)	+0.51% (.5987)	-0.42% (.7034)	+0.38% (.7903)	+0.33% (.6915)
HH debt days	+3.70% (.3096)	-3.57% (.4337)	**+12.02% (.0050)**	**-11.53% (.0035)**	-0.58% (.8909)	+0.04% (.9283)	**+10.21% (.0152)**	**-10.53% (.0055)**
HH ever in debt	+1.43% (.4003)	-1.12% (.5653)	+3.43% (.0734)	-2.55% (.1608)	-0.56% (.7997)	0.00% (.9661)	+1.37% (.4504)	-1.50% (.4737)
HH cash	-1.79% (.6226)	+1.85% (.3938)	-4.87% (.0903)	**+5.79% (.0193)**	-1.76% (.5828)	+1.86% (.4209)	**-5.88% (.0364)**	**+5.11% (.0400)**
HH loans	+5.57% (.4137)	-2.99% (.5604)	**+24.68% (.0037)**	**-21.21% (.0056)**	+2.15% (.7869)	-2.06% (.8123)	**+19.72% (.0219)**	-13.30% (.0602)
HH finance inequality	-2.82% (.3534)	+19.24% (.4917)	**+24.49% (.0076)**	**-33.61% (.0023)**	+3.07% (.7093)	-18.51% (.6965)	**-12.32% (.0181)**	**-27.98% (.0207)**

	Cottage industry income		**Day-to-day expenses**		**Educational expenses**		**Festival, funeral & wedding costs**	
	C^-	C^+	C^-	C^+	C^-	C^+	C^-	C^+
HH count	-0.04% (.9899)	-0.15% (.8312)	-0.12% (.9015)	-0.23% (.8274)	-0.04% (.9756)	-0.27% (.7410)	+0.04% (.9449)	-0.04% (.9809)
HH size	+0.32% (.8882)	+0.66% (.6450)	+0.35% (.7643)	+0.39% (.8183)	+0.26% (.7719)	+0.39% (.8059)	+0.13% (.9703)	+0.51% (.6948)
Villager count	+0.29% (.8282)	+0.43% (.7496)	+0.42% (.6699)	+0.15% (.9079)	+0.09% (.9969)	+0.09% (.7946)	+0.14% (.9361)	+0.33% (.7528)
HH debt days	+3.97% (.3522)	-1.57% (.6949)	**-20.03% (<.0001)**	**+20.49% (<.0001)**	-4.74% (.2223)	**+8.92% (.0355)**	**-12.1% (.0017)**	**+12.67% (.0025)**
HH ever in debt	+1.50% (.3339)	-0.56% (.7896)	**-5.42% (.0029)**	**+5.98% (.0013)**	-1.50% (.4399)	+2.06% (.2477)	**-4.05% (.0352)**	**+3.93% (.0256)**
HH cash	**-7.63% (.0028)**	**+7.24% (.0067)**	**+9.85% (.0001)**	**-10.12% (.0001)**	+0.84% (.6411)	-3.61% (.1999)	**+5.36% (.0220)**	**-4.26% (.1088)**
HH loans	+2.42% (.8127)	+0.64% (.9693)	**-38.09% (<.0001)**	**+52.17% (<.0001)**	-10.86% (.2125)	**+25.18% (.0064)**	**-24.24% (.0010)**	**+33.33% (.0002)**
HH finance inequality	+0.85% (.2226)	-22.89% (.5870)	**-42.19% (<.0001)**	**+26.56% (<.0001)**	-25.71% (.2429)	**+11.78% (.0049)**	**-34.17% (.0007)**	**+764.11% (.0006)**

[75] This was calculated for households and is a very crude measure of inequality as it does not take into account the different demographic circumstances of each household or non-monetary wealth of the households.

	Foreign salary		Nepal salary		Short-term labouring	
	C-	C+	C-	C+	C-	C+
HH count	-0.04% (.9079)	-0.15% (.8917)	-0.08% (.9295)	0.00% (.9803)	-0.12% (.8963)	-0.04% (.9756)
HH size	+0.24% (.8189)	+0.57% (.6818)	+0.40% (.8940)	-0.17% (.8766)	+0.30% (.8298)	+0.31% (.8738)
Villager count	+0.49% (.7028)	+0.35% (.7896)	+0.17% (.8039)	-0.05% (.9655)	+0.13% (.9948)	+0.24% (.9062)
HH debt days	+3.65% (.3256)	-6.43% (.1037)	+0.63% (.9204)	-0.62% (.8865)	+3.86% (.3325)	-7.51% (.0623)
HH ever in debt	+2.12% (.2325)	**-3.80% (.0362)**	+0.37% (.8472)	-0.19% (.9549)	+0.37% (.7614)	-1.50% (.3919)
HH cash	-3.83% (.1609)	**+8.52% (.0012)**	-4.51% (.1125)	+4.50% (.0962)	-1.10% (.7621)	+2.97% (.1927)
HH loans	+6.57% (.4267)	-8.72% (.2583)	+0.50% (.9019)	-0.97% (.9064)	+10.68% (.2032)	**-15.77% (.0344)**
HH finance inequality	-4.91% (.2350)	**-29.44% (.0175)**	-11.63% (.6761)	-20.33% (.6879)	+69.52% (.1886)	-28.24% (.0359)

The results of the SA show that the demographic outcomes of the model are by and large insensitive to changes in the parameters that are set out in *Table 6.7*. This is not overly surprising as the demographic components of the model are largely (though not completely) isolated from the model mechanisms in which these parameters play a role. The economic processes in the model are, by contrast, much more closely associated with these parameters. Unsurprisingly, therefore, several of the parameter groups do appear to play a significant role in conditioning economic outcomes. The uncertainty/variability in the day-to-day expenses parameters has the greatest impact on the economic outcomes of any of the parameter groups, possibly because these expenses are applicable to all villagers on all of the timesteps. The uncertainty/variability in animal slaughter prices, cash crop prices, and event costs, meanwhile, has roughly half the effect on household cash and household debt days of the day-to-day expenses group. Cottage industry income and short-term labouring are the other two parameter groups which have statistically significant effects on the outcomes considered.

Unsurprisingly, the household loans, debt days, and experience of debt metrics tend to increase and decrease together, with household cash going in the opposite direction. However, the strength of the relationship between the metrics appears to differ from one parameter group to another. This suggests that they affect village economics in somewhat different ways. The shifts that are seen in household Gini coefficient between the parameter groups lends further weight to this idea. Another important observation is that the magnitude of the changes tends to be substantially greater in the case of household loans and the Gini coefficient than in the case of the other metrics. This is the result of certain households becoming trapped in debt spirals whereby the high rate of interest on debts magnifies any initial financial problems they may have had, pulling them deeper and deeper into the red in a non-linear fashion. By contrast, such feedbacks do not play a prominent role in the other metrics.

An important limitation of this SA is that it does not consider interaction effects between parameter groups (Ten Broeke *et al.*, 2016). Ideally, this will be addressed in future research. However, the SA nevertheless provides an important insight into how the model functions and which parameter groups are particularly influential.

6.6 Concluding remarks

In this chapter, details have been set out of the agent-based model that has been developed for this thesis and a number of stressor scenarios have been developed for simulation within it. The design of the model has been informed by the fieldwork that was discussed in *Chapter 4* and *Chapter 5*. Meanwhile, the choice and design of the scenarios has been informed by both the fieldwork and the literature that was reviewed in *Chapter 2* and *Chapter 3*. Details of the calibration and validation process have also been presented, as have the limitations of the latter. The chapter has concluded with the results of a sensitivity analysis. This is a particularly important part of the modelling process as it gives a sense of how robust the results are to uncertainties in the model parameters and processes. It revealed that demographic outcomes are relatively insensitive to the known uncertainties, but financial outcomes are somewhat less robust – something that needs to be borne in mind. That said, the model is not intended to be perfectly predictive, rather it is meant as an aid to thought and scientific exploration, so the fact that it is not wholly robust to uncertainties should not necessarily be viewed as a problem. In the next chapter, the results of the simulations are presented.

Chapter 7: Results

Demographic impact of scenarios on the village | Economic impact of scenarios on the village | Role of context in shaping stressor impact | Role of household attributes in determining vulnerability to stressors

In this chapter, the results of the simulations are set out, with both village- and household-level outcomes considered. The chapter is divided into three main parts. Each part deals with one of the specific questions set out in the *Chapter 1* objectives (see below). The first part looks at the effect of the various scenarios on (a) the demographic trajectory of the village and (b) the financial trajectory of households. The second looks at the role of context in shaping the impact of stressors. The third looks at the attributes that determine the capacity of households to financially cope with stressors. The implications of the results that are presented in this chapter are then discussed in *Chapter 8*.

Objective 3. To conduct simulation runs for a number of future stressor scenarios for the period 2015-2030, examining the impacts on village demographics and household finances. In particular, the following questions are addressed:

a. How do the various stressor scenarios affect the financial trajectory of households and the demographic trajectory of the village?
b. To what extent does the impact that a stressor has on household finances depend on the context in which it occurs?
c. What are the main attributes that determine the capacity of households to financially cope with stressors?

In analysing the results, I draw on frequentist statistical hypothesis tests, among other things. This is in keeping with the kind of approach that is commonly used to study field and lab data. However, the use of such tests in relation to simulation model results comes with a number of caveats that should be borne in mind. The first issue is that as a result of large numbers of simulation runs being conducted, p-values are typically going to be small, regardless of effect size (White *et al.*, 2014). Given this, it is important not to conflate statistical significance with socio-ecological importance. The second issue is that in the context of modelling studies such as this, hypothesis testing is often needless as the existence or absence of relationships between independent and dependent variables is *usually* determinable *a priori*, arguably "invalidating the premise of the test" (White *et al.*, 2014, p.385). That said, what is *usually* the case, is not *always* the case. The complicated nature of the Nepal SIM model makes it more difficult than it would normally be to conclusively establish the presence or absence of certain relationships. That means that the use of frequentist statistical hypothesis tests is valuable despite the associated caveats.

7.1 Demographic impact of scenarios on the village

The demographics of the village in 2030 are set out in *Figure 7.1* and *Figure 7.2* for each of the eight combinations of stressors that were simulated. To enable statistical comparison, three-way between-groups ANOVA tests were performed on each of the metrics.[76] In the tests, the metrics represented the dependent variables, while the earthquake, fertility rate, and crop variability scenarios constituted the independent variables. The first chart (*Figure 7.1a*) shows that the number of households at the end of the simulation is typically less than the 14 households that were generated at initialisation. The earthquake's occurrence had a statistically significant impact, $F = 124.72$, $p < 0.01$, with earthquake affected simulations ending with a lower mean household count ($M = 12.38$, $SD = 1.08$) than the simulations in which earthquakes did not occur ($M = 12.77$, $SD = 1.16$).

[76] Levene's test for equality of variances was performed in each case to ensure that it was acceptable to proceed with the ANOVA. No violations were found, $F\ (7, 3992) \leq 2.00$, $p \geq 0.052$.

Fertility rates and crop variability did not have a statistically significant impact on the ultimate household count, $F \leq 0.072$, $p \geq 0.78$.

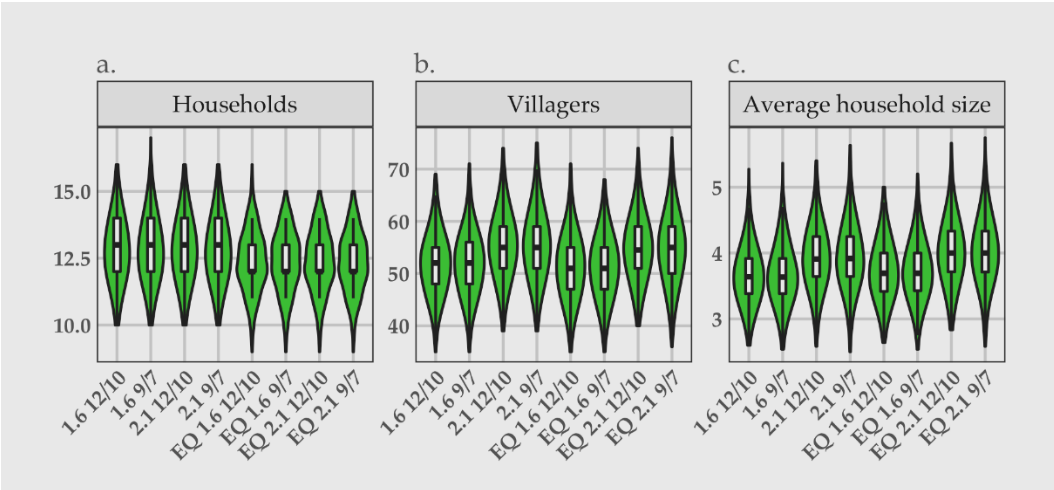

Figure 7.1. Violin plots showing the number of (a) households, (b) number of villagers, and (c) the average household size at the end of the simulations for the eight scenarios. EQ stands for earthquake; 1.6 and 2.1 stands for the average fertility rate; 12/10 and 9/7 stand for the half yield crop variability rate with the first number representing the rate for subsistence crops and the latter number representing the rate for cash crops.

The final villager count, meanwhile, exhibits signs of being affected by differences in both the earthquake scenario, $F = 9.68$, $p < 0.01$, and the fertility rate, $F = 357.07$, $p < 0.01$, but not by crop variability, $F = 0.133$, $p = 0.72$ (see *Figure 7.1b*). The occurrence of the earthquake reduces the average villager count ($M = 53.04$, $SD = 6.11$) by 0.58 people relative to the simulations in which the earthquake did not occur ($M = 53.62$, $SD = 6.09$), while the higher fertility rate increases the villager count ($M = 55.08$, $SD = 6.06$) by 3.50 relative to the lower fertility rate ($M = 51.58$, $SD = 5.64$). For each scenario combination, the average 2030 villager count represents a decrease on the average initial villager count of 57.57 – the mean decline in population ranges between 2.13 and 6.28 people.

The third chart (*Figure 7.1c*) shows the average household size in 2030 for each scenario combination. As with the villager count, both the earthquake, $F = 25.97$, $p < 0.01$, and the fertility rate, $F = 410.11$, $p < 0.01$, had a statistically significant impact, but crop variability did not, $F = 0.26$, $p = 0.61$. The earthquake affected simulations resulted in a marginally higher mean household size ($M = 3.87$, $SD = 0.47$) than the simulations in which earthquakes did not occur ($M = 3.80$, $SD = 0.46$). The higher fertility rate, meanwhile, led to a higher average household size ($M =$

3.98, *SD* = 0.47) than the lower fertility rate (*M* = 3.70, *SD* = 0.42). This latter figure is similar to the average household size at initialisation (*M* = 3.71), while the former figure represents a notable increase.

Figure 7.2 shows the number of under-18s, number of working age individuals, and number of over-60s in the village in 2030. The different fertility rates have a clearly discernible effect on the number of under-18s in 2030, $F = 1146.90$, $p < 0.01$, but the earthquake and crop variability scenarios do not, $F \leq 0.85$, $p \geq 0.36$ (see *Figure 7.2a*). Relative to the number of under-18s at initialisation (*M* = 14.69), the average number of under-18s for the lower fertility rate (*M* = 11.51, *SD* = 3.07) represents a reasonably substantial drop. By contrast, the higher fertility rate leads to a slight increase relative to 2015 (*M* = 15.04, *SD* = 3.51). The number of working age adults (see *Figure 7.2b*) is much more consistent between the different stressor combinations, with none of the scenarios having a statistically significant effect, $F \leq 1.809$, $p \geq 0.18$. The average adult count of 28.42 (*SD* = 3.62) in 2030 constitutes a drop of 5.27 relative to the 2015 average (*M* = 33.69). In contrast, the mean number of over-60s in 2030 (*M* = 11.63, *SD* = 2.54; see *Figure 7.2c*) was slightly up on the 2015 average (*M* = 9.2). Once again, fertility rates and crop variability were found not to have a statistically significant impact, $F < 0.01$, $p \geq 0.93$, but the earthquake scenario did have a slight effect, $F = 16.41$, $p < 0.01$. The over-60s count was marginally lower at the end of the simulations in which the earthquake did occur (*M* = 11.47, *SD* = 2.51), relative to the simulations in which it did not (*M* = 11.80, *SD* = 2.56).

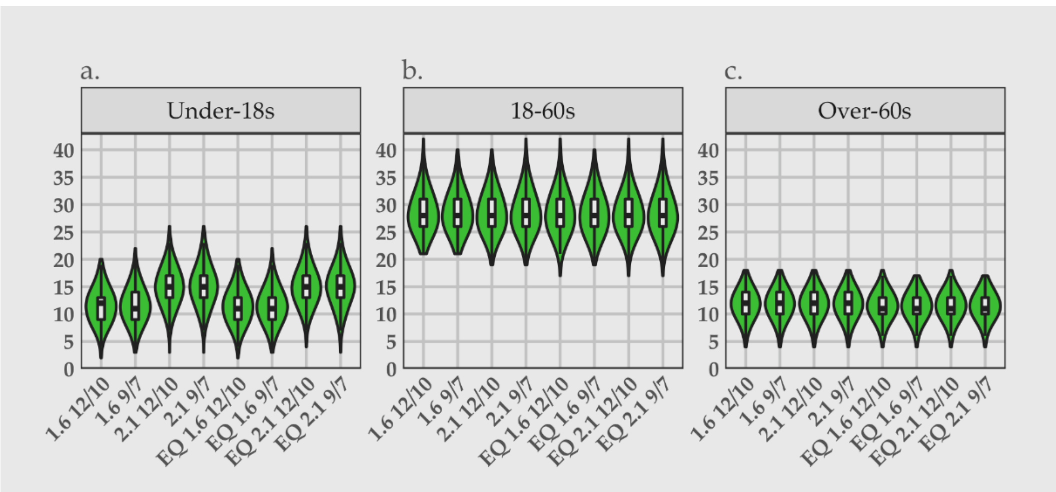

Figure 7.2. Violin plots showing the number of (a) under-18s, (b) 18-60s, and (c) over-60s in the village at the end of the simulations for the eight scenarios.

The change in the demographic structure of the village during the simulations can be more richly understood by looking at the population pyramids in *Figure 7.3*. Particularly noticeable is the increase in villager numbers within the eldest age cohorts and the decline in men who are working abroad as members of the initial 25-29 years old cohort return to the village. There is also a substantial decline in the size of the youngest couple of cohorts. In the mid- to late-2030s, many of those who were in the youngest cohort at the start of the simulations will be of working age and thus the village may be set to experience a demographic dividend which is not captured in the timeframe considered within the simulations.

Figure 7.3. Population pyramids showing the average initial demographic structure of the village and the demographic structure of the village in 2030 for each of the fertility rates that were modelled. The grey bars show men who are working abroad.

7.2 Economic impact of scenarios on the village

In this section, I examine the impact of the eight combinations of stressors on a range of household- and village-level economic metrics. By looking at the economic impact of the stressors from a variety of (sometimes subtly) different angles, I hope to paint a more rounded picture than might otherwise be achieved. To enable statistical comparisons between the stressor combinations, three-way between-groups ANOVA tests were once again performed for the metrics where Levene's test was not violated.

The average income and expenditure of the village over the period of the simulations is set out in *Figure 7.4a* and *Figure 7.4b* respectively. It is apparent that the presence or absence of the earthquake is the main factor differentiating the scenario combinations from one another in the case of both village income, F = 259.95, p = < 0.01, and village expenditure, F = 1094.65, p = < 0.01. The village income in the earthquake affected simulations (*M* = 51,077,056, *SD* = 4,868,408) is typically below that of the simulations in which the earthquakes did not occur (*M* = 53,633,868, *SD* = 5,167,456). At the same time, village expenditure is higher in the earthquake affected simulations (*M* = 45,336,032, *SD* = 2,779,034) than in the earthquake free simulations (*M* = 42,548,361, *SD* = 2,675,482). Crop variability also had a statistically significant effect on village income, F = 13.42, p = < 0.01, but not on village expenditure, F = 1.00, p = < 0.01. Conversely, the fertility rate had a statistically significant effect on village expenditure, F = 196.609, p = < 0.01, but not on village income, F = 0.84, p = 0.36. The practical impact of crop variability on village income was actually very small. The low crop variability scenario led to only marginally higher village income (*M* = 52,645,957, *SD* = 5,210,829) when compared against the high crop variability scenario (*M* = 52,064,967, *SD* = 5,133,486). The impact of fertility rates on village expenditure was somewhat more substantial, although still less than the earthquake. The low fertility scenario typically resulted in lower village expenditure (*M* = 43,351,484, *SD* = 2,979,321) than the high fertility scenario (*M* = 44,532,909, *SD* = 3,032,185). Overall, it can by-and-large be said that the higher the village income, the lower the village expenditure for each scenario combination.

Total household cash and debt (excluding outstanding reconstruction loans) at the end of the simulation for each of the scenario combinations is shown in *Figure 7.4c* and *Figure 7.4d*. Unsurprisingly, the results have similarities with total village income and expenditure. However, in contrast to the other variables, the values are non-normally distributed and they violate Levene's test for equality of variance, F (7, 3992) ≥ 3.17, p > 0.01. Total household cash in 2030 tends to be substantially lower in the earthquake affected simulations (*Med* = 11,035,867, *IQR* = 4,726,395) when compared to the simulations in which the earthquake does not occur (*Med* = 15,288,576, *IQR* = 5,401,133). The paying down of reconstruction loans has a substantial depressive effect on these cash figures. At the same time, total household debt tends to be higher in the earthquake affected simulations (*Med* = 3,196,264, *IQR* = 3,243,371), relative to the earthquake-free simulations (*Med* = 2,376,040, *IQR* = 3,156,432), but the magnitude of the impact is less than it is in the case of household cash. The high fertility rate scenario, meanwhile, leads to slightly lower household cash on average (*Med* = 12,716,753, *IQR* = 5,844,914) than the lower fertility rate (*Med* = 13,478,684, *IQR* = 6,002,207), and slightly higher household debt (*Med* = 3,088,231, *IQR* = 3,422,514) than the lower fertility rate (*Med* = 2,556,437, *IQR* = 3,140,646). Similarly, the high crop variability scenario typically leads to lower household cash (*Med* = 12,888,714, *IQR* = 5,810,738) than the low crop variability scenario (*Med* = 13,307,356, *IQR* = 5,943,896), and slightly higher household debt (*Med* = 2,982,527, *IQR* = 3,403,103) than the low crop variability scenario (*Med* = 2,707,850, *IQR* = 3,162,288).

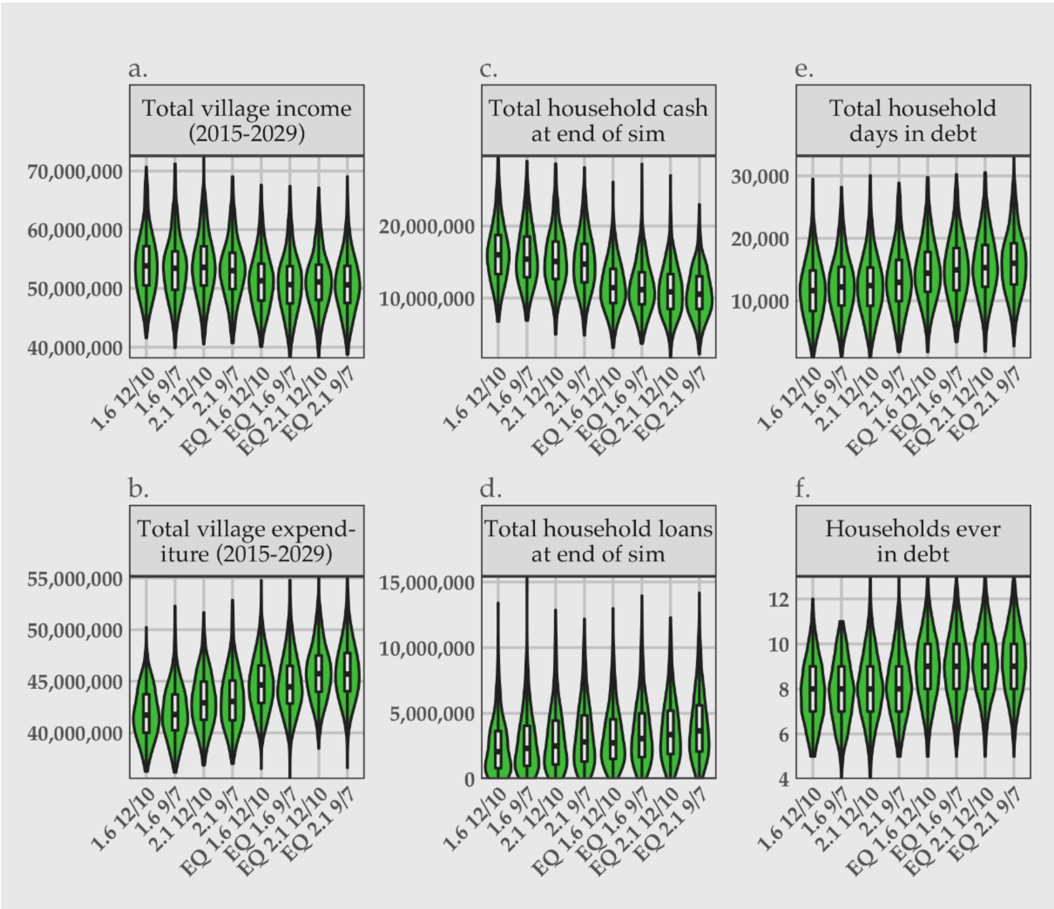

Figure 7.4. Violin plots showing total village income and total village expenditure during the simulations, total household cash and total household loans at the end of the simulations, total days that households spend in debt during the simulations, and the total number of households who are ever in debt during the simulations.

The total household days in debt and the total households ever in debt are shown in *Figure 7.4e* and *Figure 7.4f*. In respect to the former, the data shows that the earthquake scenario, the fertility rate, and the degree of crop variability, each have a statistically significant effect, $F \geq 15.68$, $p < 0.01$. The earthquake has the greatest impact. In the simulations in which it occurs, the average number of household days in debt (M = 15,402.29, SD = 4,976.06) is markedly above that of the simulations in which it did not occur (M = 12,588.01, SD = 4,907.36). The days in debt is also higher when the fertility rate is high (M = 14,410.61, SD = 5,176.53) and when crop variability is high (M = 14,303, SD = 5,131.13), than it is when the fertility rate is low (M = 13,579.69, SD = 5,065.92) and when crop variability is low (M = 13,687.31, SD = 5,127.12). In the case of households ever in debt, the main factor shaping the results is again the presence or absence of the earthquake, F = 540.70, $p < 0.01$. When the earthquake occurs the average number of households that dip into the red (M = 9.06, SD = 1.43) is notably greater than when the earthquake does not occur (M = 8.02, SD = 1.42). The fertility rate also has a statistically significant effect, F = 31.56, p = < 0.01. The high fertility rate led to marginally more households getting into debt (M = 8.67, SD = 1.51) than the low fertility rate did (M = 8.42, SD = 1.51). The effect for crop variability did not reach statistical significance, F = 2.72, p = 0.10. When considering these figures, it is important to note that an average of 4.45 households began the simulations in debt.

While the total household cash and loan statistics in *Figure 7.4c* and *Figure 7.4d* offer a sense of how different scenario combinations perform relative to one another, these headline figures mask intra-village disparities in household outcomes. To understand these disparities in household finances better, *Figure 7.5* presents a break-down of the minimum, first quartile, median, third quartile and maximum net finances of households at the end of the simulations for the eight scenario combinations. The minimum net finance figures tend to represent households who have been caught in debt spirals wherein they are unable to pay-off their loans and are consequently pulled ever further into the red by interest charges. Due to the spiralling nature of these interest charges, the minimum figures (Med = -1,706,491, IQR = 1,919,017) can be quite extreme relative to the other quartiles. The maximum figures (Med = 3,780,874, IQR = 1,641,197) also exhibit a certain run-away characteristic. This is because these figures tend to represent households who have income from salaried jobs. Such households tend to have much greater income than expenditure, so their cash holdings tend to accumulate in a relatively linear fashion save for the effect of other stressors and changes in circumstances. The Q1 data (*Med* = 12,222, *IQR* = 272,373), meanwhile, tends towards the zero line. The median Q1 figures for the non-earthquake scenarios are positive, while the equivalent figures for the earthquake scenarios are negative. Notably, the difference between the highest and lowest Q1 medians is just NPR 238,156. This compares to NPR 500, 307 for the median households and over NPR 600,000 in the case of the minimum, Q3, and maximum households. The reason for the relatively compressed range in values in Q1 is that households who are in debt or at risk of debt reduce their spending on meat and on reconstruction repayments (where applicable) in an effort to remain in the black, thus (in)tending towards the positive side of the zero line. Relative to the equivalent figures at initialisation, the Q1 figures are the least changed.[77] The other figures, by contrast, show relatively large growth, whether downwards, as in the case of the minimum figures, or upwards, as in the case of the median, Q3, and maximum figures.

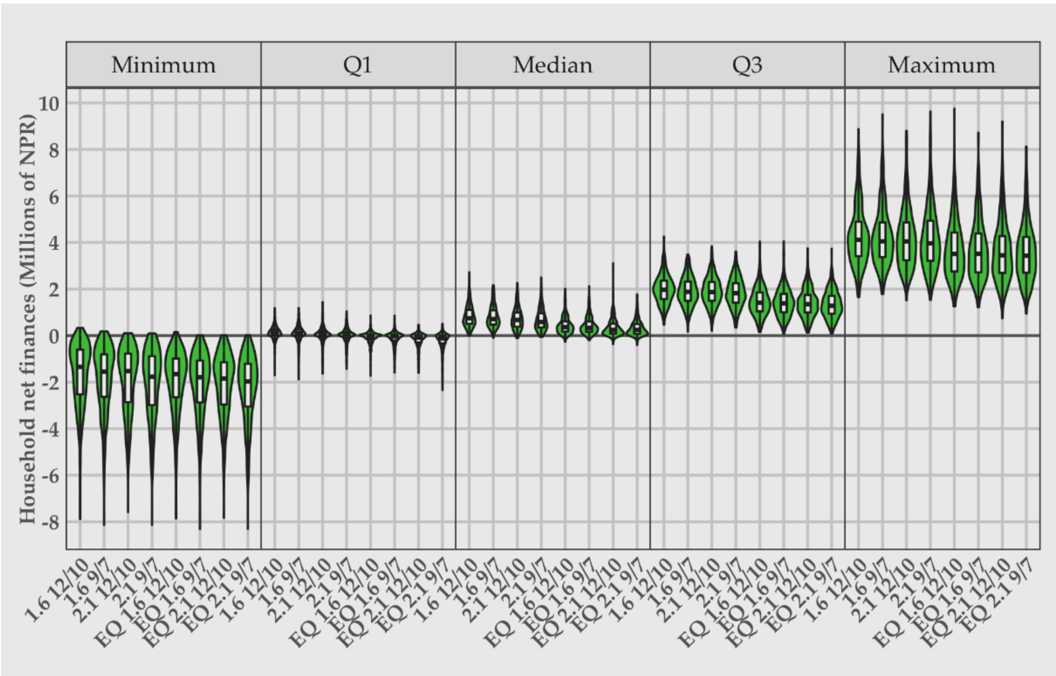

Figure 7.5. Violin plots showing the minimum, first quartile, median, third quartile and maximum net finances of households at the end of the simulations for the eight scenarios.

[77] The average initialisation figures for the quartiles were as follows: Minimum = NPR -138,941; Q1 = NPR -20,574; Median = NPR 40,205; Q3 = NPR 81,808; Maximum = NPR 429,674.

Figure 7.6 offers a further perspective on household net finances, showing their evolution over the course of the simulations. For starters, the timeseries bolster some of the points made in respect to *Figure 7.4*, namely the relatively linear increase in net finances among the highest earning households (although the rate of cash accumulation does occasionally increase as a result of career promotions or additional members engaging in work), the quasi-exponential decrease in net finances among the poorest households, and the tendency of the Q1 households to hug the zero line. Notably, the charts also show vividly the depressive effect of the earthquake on household finances. For the wealthier households, this is particularly the case between 2016 and 2022, while for middle income households the suppression of wealth accumulation is rather longer. This is a result of the households paying back reconstruction loans over the period. Less of an impact is visible among households who are in the red as they defer their repayments. Also apparent is a slight reduction in the rate of cash accumulation towards the latter end of the simulations in the case of the higher fertility scenario combinations relative to the lower fertility scenario combinations. This is most apparent in median household finances. The impact of higher crop variability is also apparent in that it slightly reduces the net earnings of households over the course of the

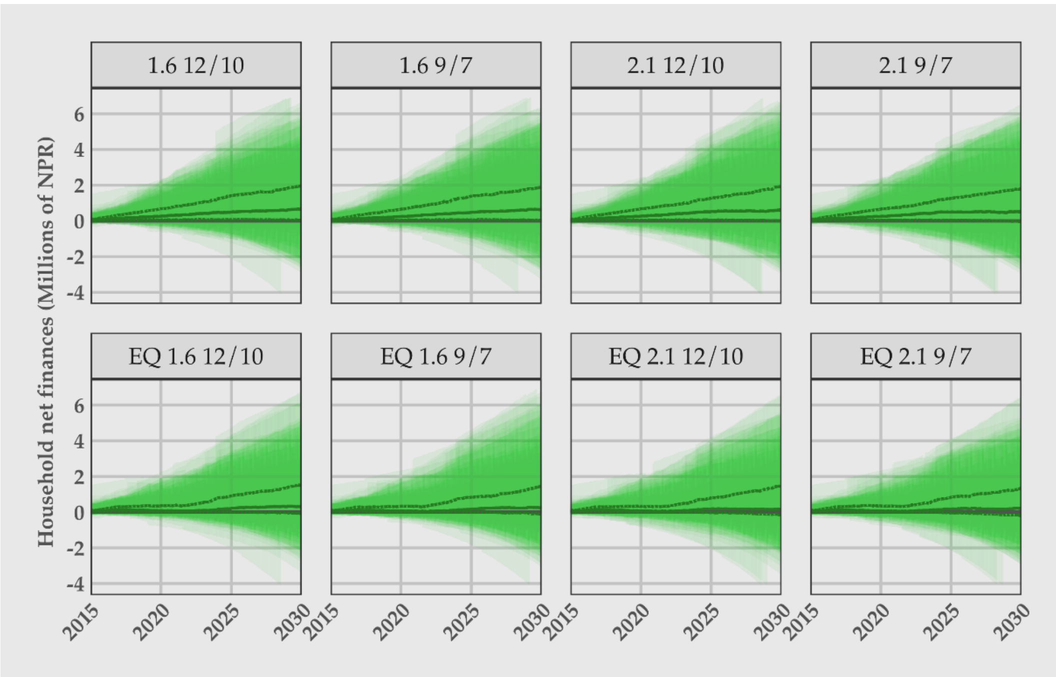

Figure 7.6. Timeseries for the eight scenarios showing household net finance trajectories over time. The dark green dotted lines show the upper and lower quartiles, while the dark green solid line shows the median. The zero line is shown in grey for reference.

simulations. Due to the ensemble nature of the charts, the effect of increased crop variability is smoothed. The effect is more pronounced when viewed at the level of individual simulations.

7.3 Role of context in shaping stressor impact

In this section, the role of context in determining the impact of stressors on households is investigated. This is done firstly by investigating the interaction between earthquakes, fertility rates, and crop variability. After that I assess the frequency of various financially significant events in the twelve months prior to households becoming indebted in order to better understand the role of happenstance in shaping outcomes. Finally, I investigate the importance of temporal context by looking at the timing of entry into debt and the seasonality of household finances.

7.3.1 Interaction between earthquakes, fertility rates, and crop variability

The three-way between-groups ANOVA tests that were performed on the metrics in the preceding sections have the potential to reveal not only main effects, but also interaction effects between the stressors. Interestingly, while main effects were identified for almost all of the metrics, no statistically significant interaction effects were found, $F \leq 1.35$, $p \geq 0.25$.

7.3.2 Other shocks and stressors

While the primary purpose of the model has been to investigate the combined impact of earthquakes, fertility rates, and crop variability on household finances and demographics, a number of other stressors and shocks have been implicitly simulated as well. For example, in addition to births, the demographic processes in the model include ageing and death – both of which can impact households economically. A list of financially negative events which are simulated in the model is set out in *Table 7.1*. To assess the significance of these events as contributors to households getting into financial difficulties, I first identified all occurrences of the events during the lifespan of each simulated household. As the interest is in the significance of the events as contributors to households getting into financial difficulties, I next subset just those occurrences that households experienced while their finances were net positive. I also excluded occurrences that took place while households were fluctuating between being in debt and not being in debt (defined as periods of less than a year in the black). This was done because such circumstances suggest that these households may already have been in financial difficulty before the event of interest occurred, thus making the significance of the event as a contributor to the new debt instance particularly difficult to discern. Finally, I calculated the number of the events which occurred within a year of the affected households entering into debt and the number that did not. This allowed the proportion of event occurrences that preceded debt entry to be calculated.

Table 7.1. Financially significant events ranked according to the percentage of their occurrences that take place within a 12-month period of the affected households entering into debt.

	Event	Frequency		% of occurrences that precede debt
		Preceding debt entry	Not preceding debt entry	
1	Death of HH member	10,181	14,685	40.94
2	Wedding of a HH member	3,871	10,109	27.69
3	An ox or cow has been replaced	1,276	21,405	5.63
4	Cabbage yield down 50% +	20,056	412,299	4.64
5	Cauliflower yield down 50% +	20,042	412,314	4.64
6	Potato yield down 50% +	19,478	415,116	4.48
7	Wheat yield down 50% +	19,257	412,276	4.46
8	Maize yield down 50% +	19,048	416,640	4.37
9	Birth of a HH member	542	12,046	4.31
10	Millet yield down 50% +	18,409	415,461	4.24
11	Rice yield down 50% +	18,396	415,704	4.24
12	An animal's milk production has stopped	2,660	111,418	2.33

The results show that 40.94% of households in the subset data entered into debt within a year of experiencing the death of a member. This suggests that deaths tend to be the most financially potent shock of all the events considered. Weddings also seem to be an important contributor to households getting into financial difficulties with 27.69%of households entering the red less than 12-months after members wed. While the events themselves are cost neutral, they are accompanied by a transfer of wealth and they catalyse changes in the demographic circumstances of the affected households. The figures for the other events are some way off these with the next highest percentage being 5.63%. An important caveat to these results is that alternative thresholds for defining a crop yield shock would have produced different figures in the case of the crops. However, the half yield or lower figure was discussed with the villagers when developing the crop scenarios. Another caveat is that households may well have entered into debt regardless of whether many these events occurred – the figures do not provide evidence of causality, although the fact that the events will have negative financial repercussions means they unquestionably make entry into debt more likely.

7.3.3 Seasonality in household finances and debt entry

Given the temporal variability in agricultural income and expenditure in the model, some seasonal fluctuation in household finances is to be expected. *Figure 7.7* shows the average seasonality of household net finances for households with a single individual and no wage, salary, pension or tomato income. Such households are the most exposed to seasonal fluctuations in agricultural income and expenditures so best reveal temporal vulnerabilities in household finances. The curves, which have been de-trended, show that household finances tend to be best in the latter part of January after cabbage and cauliflower have been harvested but before the potato crop is planted, and again from mid- to late-September after the maize crop has been harvested but before the festival season commences. Household finances tend to be worst between late-February when maize plantation occurs and mid-June when the potato crop is harvested, and from the peak of the festival season in mid-October to late-November when the millet is harvested. The low point tends to occur in mid-June after the millet has been planted, but before the potato harvest. Households with salary and/or pension income have monthly income boosts which helps reduce the magnitude of seasonal variability in their finances. Households with wage and/or tomato

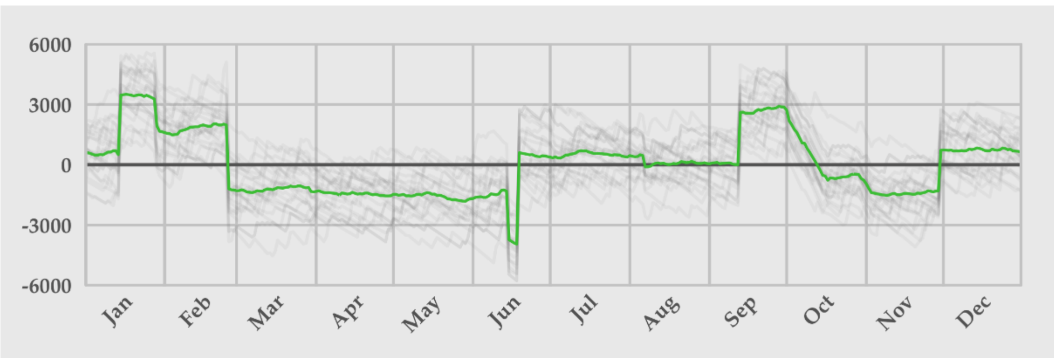

Figure 7.7. The average seasonality of household net finances for households with a single individual and no wage, salary, pension or tomato income. Households without such sources of income are the most exposed to seasonal fluctuations in income. A sample of 25 households of this type is used in the chart.

income also have their financial fluctuations smoothed somewhat, but in a slightly more sporadic manner. Households with more than one member will also find that their finance curves differ due to higher rates of expenditure.

Figure 7.8 shows the percentage of debt entrances that occur on each day of the year during the simulations. Unsurprisingly, many of the turn points in *Figure 7.7* are also significant in *Figure 7.8*. By far the worst day for entries into debt is 15 June when millet is planted. The maize and potato plantation days also see a spike in the number of debt entries as do the festival days. The October festival season furthermore sees a rise in entrances into debt as finances are eroded by a period of sustained festival expenditure. Outside of festival, plantation, and harvest days, entrances into debt still occur, but at a rather lower rate. Debt entries tend to be at their lowest between the potato harvest and the start of the October festival season.

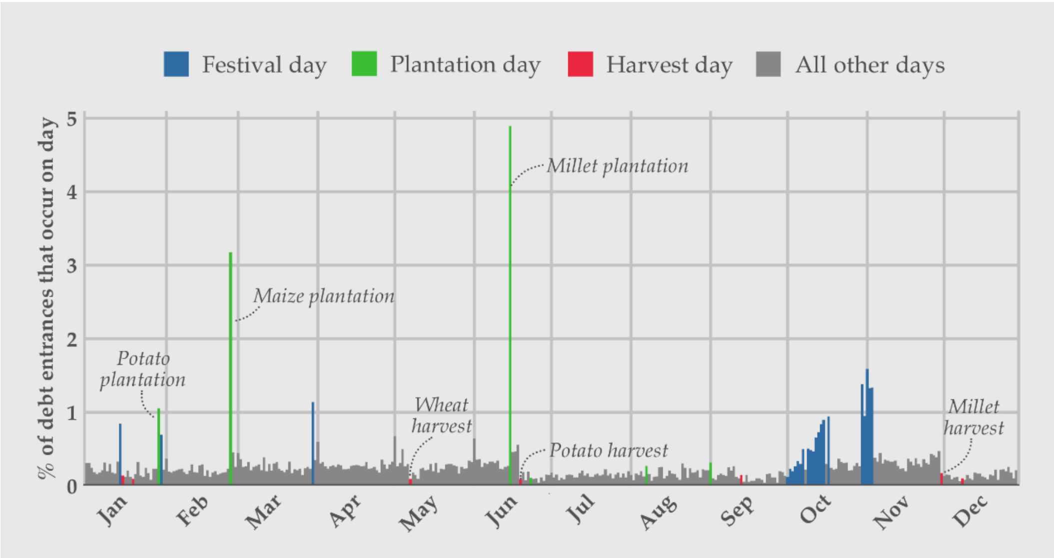

Figure 7.8. Percentage of debt entrances that occur on each day of the year during the simulations.

7.4 Role of household attributes in determining vulnerability to stressors

In this final section, I look at the association between various household attributes and household financial performance. Recognising that the role of attributes may change over time, the analysis considers three distinct time periods from the simulations: 2015-2019, 2020-2024, and 2025-2029. For each time period, Kendall's tau-b correlation was employed to assess the strength and direction of the relationship between changes in household net finances over the time period and nine household attributes. The attributes were chosen because they constitute the main determinants of household income and expenditure. The results are presented in *Table 7.2*. It is notable that all attributes have statistically significant associations with changes in household net finances over at least two of the periods at the < 0.01 level and most are statistically significant at the < 0.01 level across all of the time periods.

Table 7.2. Kendall's tau-b correlations showing the association between various household attributes and changes in household net finances over the course of three time periods.

		Change in household net finances		
		2015-2019	**2020-2024**	**2025-2029**
Fields	Correlation coefficient	0.022 *	-0.081 **	-0.045 **
	p-value	0.011	0	0
Polytunnels	Correlation coefficient	0.307 **	0.313 **	0.313 **
	p-value	0	0	0
Members	Correlation coefficient	0.023 *	-0.076 **	-0.152 **
	p-value	0.012	0	0
Youth dependents	Correlation coefficient	-0.001	-0.054 **	-0.149 **
	p-value	0.952	0	0
Non-earning adults	Correlation coefficient	-0.192 **	-0.289 **	-0.192 **
	p-value	0	0	0
Waged members	Correlation coefficient	0.238 **	0.113 **	0.14 **
	p-value	0	0	0
Salaried members	Correlation coefficient	0.269 **	0.327 **	0.392 **
	p-value	0	0	0
Members abroad	Correlation coefficient	0.238 **	0.113 **	0.14 **
	p-value	0	0	0
Pensioned members	Correlation coefficient	0.249 **	0.21 **	0.188 **
	p-value	0	0	0
	N	6527	4392	4378

*** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level.*

Polytunnels ($\tau b \geq 0.307$ and ≤ 0.313, $p < 0.01$) and salaried members ($\tau b \geq 0.269$ and ≤ 0.392, $p < 0.01$) have the strongest positive concordance with changes in household finances, although these correlations can only be considered moderate in strength. The polytunnels correlation coefficient is relatively stable across the time periods, but the salaried members coefficient grows in strength, likely because of salaried individuals receiving promotions. Waged members ($\tau b \geq 0.113$ and ≤ 0.238, $p < 0.01$), pensioned members ($\tau b \geq 0.188$ and ≤ 0.249, $p < 0.01$), and members abroad ($\tau b \geq 0.113$ and ≤ 0.238, $p < 0.01$) are also associated with positive changes in household finances, but the strength of the relationship is not quite as strong as it is in the case of polytunnels and salaried members, especially in the latter time periods. In contrast to the attributes thus far, non-earning adults ($\tau b \leq -0.192$ and ≥ -0.289, $p < 0.01$) have a negative concordance with changes in household finances across all of the time periods. This is also true for youth dependents, although the correlation is only statistically significant for the latter two time periods and it is notably small ($\tau b \geq -0.149$ and ≤ -0.054, $p < 0.01$). Land holdings appear to have very little effect on the financial performance of households when viewed from a village level perspective ($\tau b \geq -0.081$ and ≤ 0.022, $p < 0.011$).

To assess whether the correlations are affected by the scenarios, Kendall's tau-b correlation was run again for each attribute-finance combination but with the data disaggregated by scenario. The results, which are shown in *Table 7.3* to *Table 7.5*, show no major differences in correlations between the scenarios.

Table 7.3. Kendall's tau-b correlations showing the association between various household attributes and changes in household net finances for the 2015-2019 period for each scenario.

		Change in household net finances 2015-2019							
		NA-16-12	**NA-16-9**	**NA-21-12**	**NA-21-9**	**EQ-16-12**	**EQ-16-9**	**EQ-21-12**	**EQ-21-9**
Fields	Correlation coefficient	0.071†	0.069†	0.053*	0.044	-0.004	-0.017	-0.006	0.001
	p-value	0.001	0.002	0.02	0.056	0.89	0.473	0.842	0.963
Polytunnels	Correlation coefficient	0.321†	0.31†	0.329†	0.335†	0.308†	0.31†	0.318†	0.316†
	p-value	0	0	0	0	0	0	0	0
Members	Correlation coefficient	0.067†	0.057*	0.031	0.023	0.048	0.012	0.02	0.027
	p-value	0.003	0.014	0.186	0.327	0.097	0.634	0.51	0.38
Youth dependents	Correlation coefficient	0.041	0.039	0.015	0.017	0.005	-0.017	-0.035	-0.03
	p-value	0.091	0.117	0.542	0.509	0.877	0.512	0.269	0.351
Non-earning adults	Correlation coefficient	-0.165†	-0.185†	-0.209†	-0.223†	-0.164†	-0.214†	-0.164†	-0.144†
	p-value	0	0	0	0	0	0	0	0
Waged members	Correlation coefficient	0.288†	0.284†	0.234†	0.23†	0.239†	0.231†	0.228†	0.228†
	p-value	0	0	0	0	0	0	0	0
Salaried members	Correlation coefficient	0.274†	0.284†	0.261†	0.26†	0.284†	0.285†	0.269†	0.267†
	p-value	0	0	0	0	0	0	0	0
Members abroad	Correlation coefficient	0.288†	0.284†	0.234†	0.23†	0.239†	0.231†	0.228†	0.228†
	p-value	0	0	0	0	0	0	0	0
Pensioned members	Correlation coefficient	0.252†	0.256†	0.272†	0.269†	0.246†	0.238†	0.266†	0.258†
	p-value	0	0	0	0	0	0	0	0
	N	1004	985	932	927	637	887	597	558

† *Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level.*

Table 7.4. Kendall's tau-b correlations showing the association between various household attributes and changes in household net finances for the 2020-2024 period for each scenario.

		Change in household net finances 2020-2024							
		NA-16-12	**NA-16-9**	**NA-21-12**	**NA-21-9**	**EQ-16-12**	**EQ-16-9**	**EQ-21-12**	**EQ-21-9**
Fields	Correlation coefficient	-0.019	-0.052*	-0.055*	-0.097†	-0.089†	-0.1†	-0.083*	-0.089*
	p-value	0.476	0.05	0.048	0	0.007	0.001	0.014	0.012
Polytunnels	Correlation coefficient	0.322†	0.324†	0.308†	0.305†	0.346†	0.322†	0.352†	0.363†
	p-value	0	0	0	0	0	0	0	0
Members	Correlation coefficient	-0.026	-0.038	-0.07*	-0.098†	-0.059	-0.058	-0.101†	-0.108†
	p-value	0.353	0.176	0.015	0.001	0.09	0.054	0.005	0.003
Youth dependents	Correlation coefficient	-0.001	-0.001	-0.052	-0.077*	-0.042	-0.018	-0.117†	-0.113†
	p-value	0.973	0.967	0.087	0.012	0.255	0.582	0.002	0.004
Non-earning adults	Correlation coefficient	-0.277†	-0.282†	-0.293†	-0.324†	-0.25†	-0.28†	-0.268†	-0.282†
	p-value	0	0	0	0	0	0	0	0
Waged members	Correlation coefficient	0.138†	0.139†	0.11†	0.105†	0.147†	0.113†	0.101	0.071
	p-value	0	0	0.001	0.001	0	0.001	0.012	0.092
Salaried members	Correlation coefficient	0.332†	0.333†	0.319†	0.328†	0.336†	0.325†	0.339†	0.331†
	p-value	0	0	0	0	0	0	0	0
Members abroad	Correlation coefficient	0.138†	0.139†	0.11†	0.105†	0.147†	0.113†	0.101*	0.071
	p-value	0	0	0.001	0.001	0	0.001	0.012	0.092
Pensioned members	Correlation coefficient	0.208†	0.212†	0.23†	0.245†	0.177†	0.195†	0.197†	0.226†
	p-value	0	0	0	0	0	0	0	0
	N	656	680	631	634	433	570	408	380

† *Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level.*

Table 7.5. Kendall's tau-b correlations showing the association between various household attributes and changes in household net finances for the 2025-2029 period for each scenario.

		Change in household net finances 2025-2029							
		NA-16-12	**NA-16-9**	**NA-21-12**	**NA-21-9**	**EQ-16-12**	**EQ-16-9**	**EQ-21-12**	**EQ-21-9**
Fields	Correlation coefficient	-0.034	-0.059*	-0.042	-0.049	-0.03	-0.047	-0.029	-0.043
	p-value	0.219	0.035	0.128	0.084	0.352	0.104	0.388	0.198
Polytunnels	Correlation coefficient	0.289†	0.269†	0.316†	0.303†	0.356†	0.305†	0.36†	0.362†
	p-value	0	0	0	0	0	0	0	0
Members	Correlation coefficient	-0.141†	-0.128†	-0.167†	-0.171†	-0.106†	-0.154†	-0.159†	-0.147†
	p-value	0	0	0	0	0.002	0	0	0
Youth dependents	Correlation coefficient	-0.124†	-0.135†	-0.162†	-0.159†	-0.125†	-0.176†	-0.154†	-0.141†
	p-value	0	0	0	0	0.001	0	0	0
Non-earning adults	Correlation coefficient	-0.218†	-0.192†	-0.222†	-0.221†	-0.143†	-0.173†	-0.161†	-0.149†
	p-value	0	0	0	0	0	0	0	0
Waged members	Correlation coefficient	0.161†	0.118†	0.168†	0.114†	0.173†	0.136†	0.149†	0.11†
	p-value	0	0	0	0.001	0	0	0	0.006
Salaried members	Correlation coefficient	0.392†	0.404†	0.372†	0.337†	0.452†	0.385†	0.41†	0.411†
	p-value	0	0	0	0	0	0	0	0
Members abroad	Correlation coefficient	0.161†	0.118†	0.168†	0.114†	0.173†	0.136†	0.149†	0.11†
	p-value	0	0	0	0.001	0	0	0	0.006
Pensioned members	Correlation coefficient	0.201†	0.217†	0.195†	0.218†	0.138†	0.203†	0.137†	0.119†
	p-value	0	0	0	0	0	0	0.001	0.003
	N	629	612	639	615	444	583	432	424

† *Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level.*

7.5 Concluding remarks

In this chapter, the results of the simulations have been set out, with both village- and household-level outcomes considered. It has been found that earthquakes have a significant long-term impact on both household finances and village demographics. Fertility rates and crop variability also have a discernible effect, although only on household finances in the latter case. Notably, however, there was no evidence of interaction effects between these stressors. Other important findings include the substantial seasonal variation identified in household finances and the timing of debt entry, and the discovery of just how financially significant deaths can be for households. Finally, in respect to household attributes, polytunnels and salaried members were revealed to have the strongest positive concordance with changes in finances while, interestingly, land holdings appear to have very little impact when viewed from a village level perspective. The potential implications of these findings are discussed in the next chapter.

Chapter 8: Discussion

Demographic & economic impact of scenarios on the village | Role of context in shaping stressor impact | Role of household attributes in determining vulnerability to stressors | Utility of the agent-based modelling approach

In this chapter, I discuss the model results and their implications for our understanding of how multiple stressors may affect rural mountain communities in the coming years. I also reflect on the utility of the agent-based modelling approach that was used to generate the results, highlighting the unique insights the approach provided, as well as the challenges I encountered. In doing this, I address objectives three and four of the research. These are recapped below.

Objective 3. To conduct simulation runs for a number of future stressor scenarios for the period 2015-2030, examining the impacts on village demographics and household finances. In particular, the following questions are addressed:

d. How do the various stressor scenarios affect the financial trajectory of households and the demographic trajectory of the village?
e. To what extent does the impact that a stressor has on household finances depend on the context in which it occurs?
f. What are the main attributes that determine the capacity of households to financially cope with stressors?

Objective 4. To critically reflect on the utility of the agent-based modelling approach that is outlined in this thesis as a tool for researchers in the development field.

8.1 Research question 3a: How do the various stressor scenarios affect the demographic trajectory of the village and the financial trajectory of households?

To answer this question, I begin by looking at each of the main stressors in turn, before then considering their combined impact.

8.1.1 Earthquakes

In the scenarios in which the earthquakes occurred, there was a fifty percent chance of individuals who lived alone leaving the village on a permanent basis and a fifty percent chance of households that were composed of two adults leaving the village on a permanent basis if one of those adults had a salaried job. It is therefore inevitable that the average number of households at the end of the runs is lower when the earthquakes are simulated compared to when they are not. The long-term impact on village demographics and economics of individuals from lone-member households migrating is notably different from that of individuals from two-adult households migrating. The individuals in lone-member households are typically from the older cohorts and their estates are destined to be dissolved upon their deaths. Therefore, their migration merely hastens that dissolution. In contrast, the salaried two-adult households are typically in the early stages of establishing a family, so their loss has much longer lasting demographic consequences when looked at from a village level perspective. In the model, this has very little consequence for the remaining households, but in the real world it would reduce the local labour pool and could have a very real social impact on the community. For example, a study in Italy which looked at the impact of the 2009 L’Aquila earthquake on quality of life and well-being found that many elderly residents in the affected areas struggled as a result of their friendship and support networks fragmenting as households relocated (Giuliani *et al.*, 2014). The possibility of this should be borne in mind by those working in post-disaster contexts.

Economically, it is clear that the earthquakes have a very profound impact. In the period immediately after the initial earthquake, households experience both income and expenditure shocks, followed by an extended period during which they are saddled with substantial reconstruction loan debt and repayment obligations. The implications of this varies notably between the households. Higher income households were able to absorb the initial shocks and make the loan repayments with relative ease, so their wealth accumulation slowed for a period but was not halted. Many middle- and low-income households, by contrast, found themselves needing to curtail spending on luxuries in order to meet repayment obligations and often found themselves flirting with debt. Furthermore, because many household cash stocks were depressed over an extended period by reconstruction loan repayments, households often ended up financially vulnerable to the effects of other shocks. Consequently, earthquake affected simulations saw higher numbers of households getting into debt at some stage during the simulation and there was a greater total number of household days spent in debt across the village. Such long-term financial struggles have been documented following other disaster events as well. For example, Dash *et al.* (2007) found that the financial impact of Hurricane Andrew in 1992 was still felt by many households a decade later, with some people needing to come out of retirement and others working multiple jobs to fund repairs. Also notable with many of the low- and medium-income households were longer reconstruction loan repayment periods than was the case for higher-income households due to the deferment of some (or sometimes many) repayments. This difficulty with repaying reconstruction loans chimes with reports in the media that suggest many real-world earthquake hit households in Nepal are struggling with making such repayments (Starr, 2018). Arguably, the reconstruction loans had the least impact on the households who were already trapped in debt at the time the loans were issued and who remained in debt during the remainder of the simulation as they will not have made any repayments. However, these households were still exposed to the earlier economic consequences of the earthquakes.

These findings highlight the need for greater thought as to how post-disaster reconstruction is financed. In particular, the impact that financing mechanisms can have on the future financial vulnerability of households needs more detailed consideration. Some potential alternatives to the approach used in Nepal are discussed by Freeman (2004) and by Linnerooth-Bayer, Hochreiner-Stigler and Mechler (2012). They include the use of the use of catastrophe bonds, international catastrophe insurance pools, and public-private insurance partnerships. While it is beyond the scope of the current work, the efficacy of these proposed mechanisms could potentially be evaluated in future research using the model developed in this thesis.

8.1.2 Fertility rates

The fertility rate scenarios only affected a subset of the households in the model – those that contained couples of child bearing age. Even then, the impact of the scenarios was only stochastically felt. Nevertheless, the fertility rate scenarios have a clearly discernible impact on overall village demographics and finances when the simulation results are averaged out. The average villager count under the higher fertility rate scenario was 3.5 persons more than that under the lower fertility rate scenario, while the average household size increased by 0.28 persons. Of course, the main impact of this is felt within the households to whom the children are born. Within the fifteen-year time period of the simulation, this impact primarily takes the form of higher food, education, and festival expenditure for those households who have more children. Interestingly, it appears that the households who are affected by this are in most cases able to absorb such costs relatively well as the fertility rate scenarios have little impact on the overall number of households who get into debt during the simulations. That said, households that have more children do find it slightly harder to get out of debt after going into the red as their margins are somewhat more squeezed. This means that at the village level, the total number of household days spent in debt tends to be slightly higher under the higher fertility scenario. The main reason for fertility rates having little effect on debt entry rates is that the parents of children born during the simulations tend to have relatively good income as a result of working abroad or in salaried jobs. They are members of a generation which is doing, by village standards, relatively well financially. Furthermore, the actual costs of supporting children are not all that high. As Libois and Somville (2018) note, many of the expenditures that are incurred in rural villages in Nepal are for goods and livelihood investments that are, in effect, public at the household level. The variable cost of additional members (e.g. food and education expenses) is often small relative to the other costs that households face (e.g. shelter and agricultural activities).

The simulations were run till 2030, in line with the time horizon considered by the INGO that partnered the project. Should the simulations have been longer, the impact of the fertility scenarios would have become more multidimensional and consequential. The children born in the period up to 2030 would have begun to impose ever greater costs on their parents' households as their food needs increased, as they undertook their +2, and as they got married. As some of them began to work, they would then have transitioned from being net spenders to net earners, meaning that they would have morphed from being burdens on their households to potential assets. On top of this, as they married, the girls would have left the village, while the boys would have been joined by wives, further reshaping village demographics and bringing about additional instances of household fission. Consequently, the effect of fertility rates on village demographics and economics needs to be recognised as ever evolving. Indeed, this assertion is consistent with findings within the demography literature that suggest changing age structures are what matter most from an economics standpoint, rather than the population growth rate *per se* (Kelley and Schmidt, 2007; Eastwood and Lipton, 2012). Bloom and Williamson (1998), for example, estimated that between 1.37% and 1.87% of annual economic growth in East Asia during the 1965-90 period was caused by age structure change alone. While the results of the model provide insights into only a limited window in time, this is still a much greater window in time than standard research approaches provide.

8.1.3 Crop variability

As all of the households in the model engage in agriculture, they were all affected by the crop variability scenarios. That said, the nature and degree of their exposure to the effects of the scenarios varied due to differences in the size of land holdings and crop strategies. Furthermore, households differed in their reliance on agriculture as an income source. This meant that the consequences of changing the degree of crop variability was somewhat heterogenous across the simulated village. Households with large land holdings were most affected in absolute terms, especially in respect to changes in cash crop variability as these households tend to grow far more cash crops than households with smaller land holdings. Meanwhile, households with no off-farm income sources were usually the most financially vulnerable to the effect of higher crop variability because they were particularly reliant on agricultural income. These findings are very much consistent with those of other studies that have examined factors shaping vulnerability of smallholder households to variable and changing climates (e.g. Rurinda *et al*., 2014; Williams *et al*., 2016; Lopez-Ridaura *et al*., 2018).

In terms of the two scenarios, the higher rate of crop variability was found to have a slight negative effect on household net earnings when the runs are averaged out and it increased the total number of household days in debt across the village. However, it had little impact on the total number of households to ever get into debt. This suggests that most households are able to absorb the financial consequences of the modelled increase in crop variability reasonably well. There are a couple of factors that might explain this. Firstly, as households base their spending on conservative forecasts of their future finances, those households that are somewhat vulnerable to getting into debt will typically have given themselves some leeway for such eventualities. Secondly, poor harvests do not have an immediate negative impact on household finances unlike expenditure shocks – they constitute financial disappointments rather than losses *per se*. Consequently, households have a period of time after the harvests during which they can attempt to mitigate the impact. All that said, there were phases in some of the simulations when poor harvests did have very significant negative effects on the village. In particular, sequences of poor harvests seemed to hit households hard. While the higher rate of crop variability will have made such sequences more likely, these sequences were also possible in the lower crop variability scenario. Perhaps unsurprisingly, differences in crop variability were found to have no discernible impact on village demographics – there are no mechanisms in the model by which crop yields could have such an effect. However, as the impacts of climate change on agriculture in the Mid-Hills intensify, it has been suggested that increasing numbers of individuals and households may turn their backs on agriculture and migrate to urban settlements (Bardsley and Hugo, 2010). From my discussions with the villagers, this did not seem likely for them in the near term, but it might be necessary to integrate mechanisms to capture the potential for push migration if the model is reconfigured for sites other than Namsa.

8.2 Research question 3b: To what extent does the impact that a stressor has on household finances depend on the context in which it occurs?

8.2.1 Interaction of earthquakes, fertility rates, & crop yields

The three-way between-groups ANOVA tests that were performed on the village count metrics, on the total village income and expenditure metrics, and on the total household days in debt metrics, found no statistically significant interaction effects between the earthquake, fertility rate, and crop yield scenarios. Consequently, it appears that these stressors simply have an additive effect on village demographics and household finances. Given the interconnectedness of many of the processes in the model, the lack of significant interaction effects may be considered surprising. However, such a finding perhaps could have been foreseen given the design of the model. The stressors themselves do not directly interact and there are relatively few feedback loops and adaptive behaviours at play – compound interest payments on debt and flexibility in spending on luxuries being the obvious exceptions. As a result, there is limited scope for non-linear interactions occurring. One possibility is that the model does do a good job in reflecting all of the main processes at play in the village and that there are indeed few significant interaction effects at play. But it is also conceivable that important avenues for interaction between the stressors may have been missed. As it is not currently possible to prove that the latter is not the case, the ‘no interaction effects’ finding should be treated with caution. Ideally, further fieldwork would look more deeply at this question or the impact of altering the mechanisms in the model would be investigated.

8.2.2 Other shocks and stressors

The stressors that have so far been discussed are not the only challenges households faced during the simulations. Events such as deaths, weddings, and changes in employment also had the potential to negatively impact household finances and to reshape village demographics. As highlighted in the results chapter, deaths appear to be particularly significant events economically as they are associated with substantial funeral expenses and, potentially, they rob households of income earners. They can also lead to households adjusting their livestock and agricultural strategies and they have implications for domestic expenditure, although these latter changes are not quite so consequential. Weddings can have similar effects, but the cost of weddings is not as great for individual households as the cost of funerals, and individuals who get married will have often been financially independent from their parents' household at the time of the marriage, so loss of earnings is typically not an issue for the parent household. It makes sense, therefore, that deaths are much more commonly associated with households getting into financial trouble, as *Table 7.1* in the previous chapter shows. Indeed, around two in five households who experience the death of a member get into debt within a year of the event happening. The figure is around two in seven for households who host a wedding. Cultural variations in funeral and wedding practices mean that the financial impact of the rituals themselves can vary substantially from place to place (Monger, 2004; Parkes *et al.*, 2015). Consequently, the relative significance of these events may be somewhat case specific. The long-term impact on households of losing income earners is also likely to vary between communities because of different degrees of dependence on individual earners and different coping strategies (Alam and Mahal, 2014). For example, Yamauchi *et al.* (2008) found that in South Africa there was a particular tendency for women and adolescents to enter the labour market following the death of an income earner – a tendency that was not so apparent in Namsa. Despite these potential differences, the suggestion that the death of household members can lead to a substantial fall in household income does seem to be supported by evidence from elsewhere. Studies in Vietnam (Wagstaff, 2007) and Kenya (Yamano and Jayne, 2004), for instance, suggest that rural households in those countries typically experience a decline in income in the region of 26-40%

following the death of an adult member. Given this, development practitioners should perhaps consider prioritising bereaved families for support.

After deaths and weddings, the next most potent shock for households appears to be the need to replace an ox or cow. One in eighteen households who experience this end up in debt within a year. The proportion of households who get into debt in the year following a poor harvest (defined here as a crop yield being at least 50% below its median yield), is even lower. Approximately one in twenty-two households get into debt within a year of experiencing a poor cabbage or cauliflower harvest, with the figure being as low as one in twenty-four for some of the other crops. Interestingly, a fall in milk production is rarely associated with entry into debt. This may be because households are able to build up savings during the period when their animals are lactating. Perhaps the main conclusion to draw from this is that regular happenstance can be just as important, if not more so, than contemporary stressors in influencing the course of village life. By narrowly focusing on topics that are in academic vogue like climate change, demographic change, and economic change, it is possible that we are missing some of the biggest and more mundane reasons why households get into trouble. This is a concern that others have also raised. For example, Nielsen and Reenberg (2010) found that in Tuvalu non-climatic stressors were often considered more immediately pertinent to people's lives than climate change, even though much of the academic attention that Tuvalu commands is focused on the latter topic. Similarly, Martin *et al*. (2016) found that despite drought frequently being cited as the most important threat to pastoral livelihoods, other stressors were actually more significant drivers of change – they cited oscillations in herd size caused by resource-consumer interactions and natural rainfall variability,[78] in particular. Another important insight is that judgments on the significance of a stressor or shock can be strongly influenced by the scale at which such events are viewed. A poor potato harvest may have a larger overall impact on village finance statistics, but a single death or marriage in most cases will be more consequential for the affected households. Titeux *et al*. (2016) raised a similar point in a study they conducted looking at the threats to biodiversity. Specifically, they considered the

[78] Meaning natural rainfall variability that is not associated with drought events.

factors that are driving land-use change, noting that although large-scale forces linked to economic globalisation are the prime drivers internationally, actual changes in land-use are largely determined by local factors. Likewise, Antwi-Agyei *et al*. (2017) found that stakeholders in Ghana perceived stressors differently depending on whether they viewed them from a local level perspective or a district level perspective. All of this suggests that for researchers and decision-makers to develop a truly rounded understanding of stressor contexts, they need to consider those contexts at a variety of different levels and keep an open mind as to what may be significant.

It should be noted that while the analysis in this section has focused on the *individual* association of stressors/shocks with households getting into financial difficulties, households occasionally experienced successions of stressors and/or shocks. *Figure 8.1* illustrates two examples of this. In the case of household two, an animal that had been providing milk which the lone household member could sell, ceased to do so in early 2017, around two years after the village had been struck by the earthquakes and just a few months after the household had been issued with a reconstruction loan. This meant that the household lost a regular source of income shortly after being burdened with significant repayment obligations. The sum result was that the household ended up running down its savings and had to reduce expenditure on meat to stay in the black. Only after another animal began to provide milk did they household's financial situation begin to improve. Had the household just experienced the earthquakes or just experienced the fall in milk production, its finances would not have been stretched to the limit. Household thirteen, meanwhile, was also affected by the earthquake and the burden of repayments, but then had the additional shock of two household members dying in relatively quick succession – something that pushed them into the red after having initially had relatively healthy finances. It took the third event to push them into debt. This phenomenon of households expending limited resources to respond to a stressor or set of stressors, only to increase their vulnerability to future risks because they have eroded their asset base, has been one of the key themes of the multiple stressors literature (McDowell and Hess, 2012). The is no magic bullet when it comes to dealing with this. However, chipping away at the threat posed by individual stressors should enhance the capacity of households to confront them as collectives (Antwi-Agyei *et al.*, 2017).

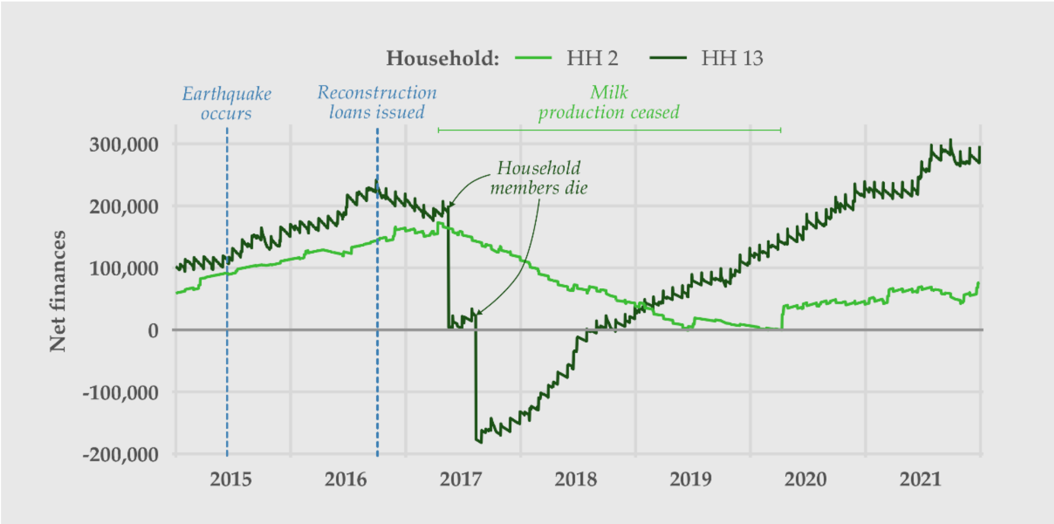

Figure 8.1. An example of two households that experienced multiple stressors (taken from seed 3 of the EQ-16-9 scenario).

8.2.3 Seasonality in household finances and debt entry

As *Figure 7.7* showed in the results chapter, households are subject to substantial temporal variations in agricultural income and expenditure across the course of any given year. For households that are relatively dependent on agriculture as a source of income and for whom the general trajectory of household finances is horizontal or downwards, this temporal variation in income and expenditure will translate into temporal variation in financial vulnerability. Indeed, the debt entry timings shown in *Figure 7.8* of the results chapter bear out this reality. This is significant because it shows not only that certain crop plantation days have the potential to push at risk households into the red, but it also shows that the timing of stressors and shocks relative to the agricultural calendar can be significant. For example, *Figure 7.7* would suggest that the occurrence of the earthquake in late April was particularly unfortunate as the finances of many of the households will have been stretched at that time having made large outlays to plant potato and maize in the months beforehand. A number of other studies have also highlighted seasonal fluctuations in household finances as a significant challenge for many communities. For example, Dercon and Krishnan (2000) examined seasonality in consumption in rural Ethiopia. They found that fluctuations in income and seasonal differences in needs and relative prices meant that communities often oscillated between being in and out of poverty and that their vulnerability to shocks similarly varied over time. Likewise, Khandker (2012) found that seasonality of agricultural income led to seasonal differences in poverty and vulnerability in Rangpur, Bangladesh. In particular, Khandker identified the period before the rice harvest has being challenging for many households. Several additional examples are discussed in a book by Devereux, Sabates-Wheeler, and Longhurst (2013) on seasonality and rural livelihoods. A potential means of mitigating the impact of the seasonal fluctuations in income and expenditure that currently exist is to promote livelihood activities that are suitable for the agricultural off-season. Some of the cottage industries do this already, but their earnings potential is currently small.

8.3 Research question 3c: What are the main attributes that determine the capacity of households to financially cope with stressors?

The correlation coefficients in *Table 7.2* of the results chapter show that polytunnels and salaried household members are the assets most strongly associated with households performing well economically. Pensioned members, waged members, and members abroad were also positively correlated with long-term changes in household net finances, albeit somewhat less strongly. That members with an external source of income are economically beneficial for households is perhaps not surprising. However, the significance of polytunnels as an income source was not so anticipated. They are a relatively new addition to the livelihood mix in Namsa having been brought to the village as part of an initiative by JICA in 2012 and only three households possessed them at the time of the main phase of fieldwork. While those households had been very positive about them as an income source, it had been difficult to judge the relative value of the polytunnels against other livelihood activities because the tomatoes tended to be sold in an *ad hoc* fashion over the course of a few months each year. According to Brown and Shrestha (2000), tomato production in the central Mid-Hills region of Nepal began to take-off in the 1990s. Brown and Kennedy (2005) found that, at the time of their study, the median gross margin of irrigated tomato crops in the Bela watershed near Kathmandu was more than double that of potato crops and around fourteen times that of maize and rice. However, they noted that tomato crops are difficult to upscale because they are demanding of soil, water, and human resources, and they highlighted issues around erratic yields and retail price fluctuations. The erratic yields seem to be less of an issue in Namsa thanks to the equipment and training provided by JICA, but many of the other challenges to scaling remain. Indeed, labour demands and the cost of purchasing materials to construct new polytunnels and to set up drip-irrigation pose significant barriers to entry for many of the households who had not been part of the original JICA scheme. If other households are to benefit from the opportunity that such crops offer, they will likely need financial or material support. Given the apparent effectiveness of the scheme in terms of boosting household earnings and reducing vulnerability to stressors, there is a strong case for such support being provided.

That non-earning adults and youth dependants are negatively correlated with changes in household net finances is to be expected as such individuals do not bring in income but do incur costs. More interesting was that land holdings have very little correlation with the financial performance of households. Historically, land has been considered among the most important assets that households could have (Crone, 2013), but the simulation results suggest that traditional agriculture is now very much economically subordinate to off-farm livelihoods and high-value crop cultivation. For some households, agriculture and livestock are the only source of income so for them having sufficient land holdings will remain important, but it appears that scaling agriculture brings little additional return. Over the years there has been a great deal of discussion around the role that agriculture can play in the development of low-income countries (Haggblade *et al.*, 1991; Birdsall *et al.*, 1995; Hart, 1998; Rosegrant and Hazell, 2000; Adelman, 2001; Diao *et al.*, 2010). This finding that traditional agriculture offers households in Namsa a means for economic subsistence but little more than that appears to lend weight to the sceptics in the debate – those like Hart (1998) who think that growth will need to be driven by other sectors.[79] It appears that livelihood diversification

[79] This might be considered surprising given the substantial improvements in yield that have been reported for recent decades but paralleling those improvements has been a rise in domestic and

and off-farm employment is not only the best means of hedging against the risk of stressors and shocks, it is also the best route to economic furtherance.

Of the household types that are generated at initialisation (see *Chapter 6*), the lone individual and lone couple structures will typically be endowed with the fewest attributes and assets associated with strong financial performance over time. This is because these households tend to be composed solely of members who are either retired or engaged in short-term labouring and who are nearing retirement. Only occasionally will they have pensions. As a result, these households will often be reliant on on-farm livelihood activities so will be particularly vulnerable to crop yield and livestock shocks. On the other hand, because of their demographic circumstances they will never be subject to the costs associated with weddings and births, and the lone individuals will never have to deal with the financial aftermath of funerals. The other household types, in contrast, may have to deal with such events, but they will typically have more working age adults among their members which increases the likelihood that they will have sources of off-farm income. That said, fate can dictate that some of these households lose their off-farm income earners, leaving them in a similar boat to lone individual and lone couple households in terms of dependence on on-farm livelihoods, unless they are entitled to inherit a pension. Overall, it can be said that lone individual and lone couple households will often be more vulnerable to the impact of shocks, but the other household types face a greater diversity of potential financial shocks. These differences should be taken into account when interventions are planned – household needs differ, even within villages.

Interestingly, the data in *Table 7.2* of the results chapter indicates that the number of children a household has had little correlation with their economic performance over the first ten years of the model. However, during the final five years, the correlation between youth dependents and change in household net finances turned more negative ($\tau_b \geq -0.149$, $p < 0.01$). This appears to be due to an increase in the average age of youngsters over time (see the population pyramids in *Figure 7.3*). The older the children get, the greater the costs associated with supporting

international competition which has squeezed margins and kept potential earnings low (Diao *et al.*, 2010).

them so the greater their financial consequence for the households. Indeed, many aspects of household circumstances are dynamic. Consequently, household fortunes are liable to change over time. With this in mind, development practitioners should consider how circumstances might evolve before deciding who is most in need of support and how that support is best delivered because if they do not, interventions may only be effective in the short-term. A final point of importance is that the correlation coefficients are only small or medium in strength, so while the attributes that have been discussed here do appear to play a role in shaping household outcomes, they do not do so in a deterministic manner.

Summary of recommendations for decision-makers

- Multiple stressors should be taken into account when assessing household and village vulnerability, resilience, and adaptation options.
- Governments should proactively consider instituting post-disaster reconstruction financing mechanisms that avoid burdening low-income households with long-term debt.
- Support should be targeted at newly bereaved families to mitigate the impact of funeral expenses and any income shocks they may experience.
- Off-season livelihood activities – both on-farm and local – should be promoted to help smooth household income.
- Financial and/or material support should be provided to vulnerable, low-income households to enable them to engage in high-value crop agriculture.
- When selecting project beneficiaries, greater heed should be paid to individual household circumstances – both current and future – in order to maximise impact.

8.4 Objective 4: To critically reflect on the utility of the agent-based modelling approach that is outlined in this thesis as a tool for researchers in the development field.

8.4.1 Advantages of using the Nepal SIM model

The agent-based modelling method used in this study offered a combination of advantages that the more conventional approaches that are typically used to study multiple stressors lack. Firstly, the model output helped to provide some clarity around the plausible range of outcomes that each stressor scenario could bring about and it enabled the effect of different processes – and combinations of processes – to be quantified. This quantitative clarity helps discussions about stressor impacts to be more disciplined than they might otherwise be by reducing both the need and the scope for speculation (Epstein, 2008). This could be particularly useful when it comes to determining what actions to prioritise and it could provide decision makers with a ready way of justifying the course they choose to pursue. Of course, plausibility claims depend on the assumptions in the model being considered reasonable and there are a range of other limitations associated with this study which should be taken into account. However, all studies are subject to certain assumptions and limitations. The important thing is that these are clearly flagged, and that their implications are considered. This is something that has been done in a systematic fashion in the ODD protocol and in the sensitivity analysis, and which is continued in the discussions which follow.

A second advantage of the method that was of particular note during the study was that it allowed the impact of stressors and shocks to be investigated at multiple scales and from many different angles. Village level, household level, and individual level outcomes could be scrutinised using a wide variety of metrics, with each offering subtly different insight. This enabled a much rounder picture of stressor impact to be formed than might otherwise have been the case. This is valuable because data often needs to be examined in several different ways before you can really understand what is going on (Silver, 2012). For studies of multiple stressors in complex systems this is particularly useful because chains of causation can often be obscure (Burnham *et al.*, 2018). While the model is an advance on many existing methods when it comes to examining processes at different spatial and temporal scales, there is scope for future studies to go even further by, for example, integrating higher-level dynamics. For instance, neighbouring villages and local labour markets could be incorporated, allowing the cascading impact of stressors and shocks on the local area to be captured.

A third advantage of the modelling method was that it forced me to think in depth about how systems function in a processes-oriented fashion. For example, in the course of developing the model in this thesis, I had to examine topics that had previously received very little attention in the multiple stressors field such as the life course of poultry and livestock. As a result of doing so, I found that cow and buffalo lactation patterns and chicken egg laying cycles can play a very significant role in determining the short-term financial fortune of households. This in turn can affect their capacity to ride out the effect of shocks and stressors. Such insights would have been easy to miss if I had not needed to think about how to recreate poultry and livestock in code. Another related benefit of being forced to think in depth about how systems work is that it helps illuminate core uncertainties, the implications of which can then be examined through the use of techniques like sensitivity analysis (Epstein, 2008). In the case of this study, the likelihood of career advancement was a prime example of this. The young person's focus group could provide educated guesses about what might happen, but some uncertainty inevitably remained – the potential consequence of which could then be quantified. By establishing the significance of uncertainties such as this, researchers can better determine future research needs.

Finally, the model enabled the heterogeneous impact of stressors on households to be examined and showed the importance of happenstance in determining outcomes. While many studies have considered the correlation between certain household attributes and outcomes (e.g. Piya *et al.*, 2016; Cooper and Wheeler, 2017; Okpara *et al.*, 2017), few have been able to consider the nuances and quirks of individual household experiences in the detail that the model here has allowed. In saying this I am thinking in particular about the opportunity the model provided to review the demographic and financial histories of many thousands of households. To provide an analogy, it is like being able to review the black box recordings of a flight simulator – every little input and response can be probed in order to piece together the precise circumstances that led to a particular outcome (Waldrop, 1993). Outside of a simulated environment, data of such granularity would ordinarily be extremely difficult, time consuming, and costly to collect. In this study, the potential insights that this detailed data can provide have only been partially exploited – this is something that future research should address. Of course, agent-based modelling methods offer a number of other potential advantages as mentioned earlier in the thesis, but the ones discussed above proved to be among the most pertinent in this study.

8.4.2 Model limitations and challenges

While many positives came out of using the modelling approach, I also encountered some challenges and limitations which merit highlighting. These primarily related to the depiction of certain process, the subjectivity around simplification decisions, difficulties in validation, and the time, data, and resource intensiveness of the work.

Like all models, the one developed for this thesis is a simplified representation of reality (Castle and Crooks, 2006). Making simplifications is a necessary part of the modelling process, but it is not always clear what to simplify or how – judgement calls are required. Some of these judgement calls will be relatively uncontroversial, but others may be more open to questioning. Determining what kind of simplifications are justified and which are not is going to be critical if agent-based models are going to gain acceptance as credible tools among development practitioners. Sensitivity analyses, such as the one performed in *Chapter 6*, provide a sense of which parameters are particularly influential in shaping model outcomes and, thus, which processes may be worth paying particular heed to. However, it would be better yet if the sensitivity of the model to alternative model mechanisms is tested as well. For example, in the Nepal SIM model I could examine the effect of introducing more adaptive behaviours when it comes to the management of household finances or I could test whether including cottage industries really does make a meaningful difference to the results. Doing so would improve understanding of the individual subsystems and decrease the subjectivity of the judgement calls, ultimately improving the perceived credibility of models, even before any validation takes place. Schlüter *et al*. (2017) have already argued for the systematic testing of alternative theories when it comes to modelling human behaviour. My proposal is for the practice to also be applied to modelling processes at different levels of complexity. In this study, the computationally demanding nature of the model meant that this was not possible within the time and resource constraints that I had, but it should be a priority going forward.

The second substantive issue that was encountered during the course of the modelling work was the challenge of model validation. The original research plan had been to build a prototype model after the main fieldwork spell in 2015. I was then going to test how well it captured village dynamics by comparing the first year of its simulation outputs against a fresh tranche of data that would have been gathered in Namsa a year after the initial fieldwork. However, the earthquake forced me to delay my return. When I did eventually get back in early 2017, I was able to discuss the appropriateness of the various design decisions that had been made in the prototype model. However, it was immediately clear that any efforts at quantitative validation of the model against 2017 data would have been futile given the dramatic change in circumstances in Namsa following the earthquakes. I therefore opted to instead evaluate the first year of the model simulations against the annual income and expenditure metrics that had been determined for the year preceding the 2015 fieldwork – the results of this were outlined in *Chapter 6*. I uncovered a number of limitations to the approach in the process. Importantly, these limitations would have occurred whether I had attempted the validation using forward looking data or backwards looking data. Firstly, the actual data and the simulated data were not wholly equivalent which made comparisons difficult. For example, certain things were monetised in the model that were not monetised in the real village. This skewed some of the finance metrics. The second issue – one that is perhaps less easy to overcome – is the relatively small size of the population at the fieldsite. Small populations mean that the law of large numbers does not apply and thus I am not able to confidently assume that the new tranche of data was, as a whole, reflective of typical village dynamics. This would have been so if I had been able to gather new data in 2017 as well. The issue is further complicated by the obfuscation techniques that were used in the population synthesis and the number of stochastic processes that are at play. The implication is that qualitative approaches to model validation – such as those promoted by Bousquet *et al*. (1999) and Castella *et al*. (2005) – may be the only realistic means of undertaking validation in cases like this. It is difficult to see how any kind of convincing quantitative validation can be performed, at least on village level metrics.

The final issue that researchers should think about when considering the use of methods similar to the one in this thesis is its time, data, and resource intensive nature. The process of familiarising oneself with a fieldsite, gathering the wide range of data that is necessary, developing and debugging a complex model, and then processing vast amounts of output is highly involved. For many research questions there will be more resource efficient methods available which will still be able to deliver many of the same insights. However, as previously argued, there are a number of questions for which there is no practical, effective alternative to the kind of agent-based modelling approach that has been outlined in this thesis. Consequently, agent-based modelling clearly merits its place within the disciplinary toolkit.

8.5 Concluding remarks

In this chapter, the results of the model simulations have been discussed, along with the efficacy of the agent-based modelling approach that has been employed. In respect to the former, a number of interesting findings were highlighted, and several recommendations were made for policy makers and development practitioners. In regards the latter, the strengths, challenges, and limitations of the particular approach that was used have been flagged. In *Chapter 9*, I discuss the conclusions of the research, highlighting – once again – the key findings and making suggestions for future research.

Chapter 9: Conclusions

Summary of findings | Utility of the agent-based modelling approach | Priorities for future research

Rural mountain communities in developing and transitioning countries are currently experiencing a period of rapid social, economic, and environmental change. Alongside contemporary stressors, shocks, and transformations, they must also deal with a range of age-old pressures. Collectively, these factors pose a huge challenge for mountain communities going forward, but there remains substantial uncertainty around precisely how the future will play out and what the cumulative impact of the processes will be. If communities are to effectively plan for the future and be supported in adapting to it, it is important that there be more knowledge as to what it may entail. In this thesis, I have developed an innovative modelling approach that allows the impact of plausible future stressor scenarios to be simulated over a fifteen-year period, enabling the consequences of the stressors to be studied in detail. This has provided a number of valuable insights into the nature of particular stressors, the role of context in affecting stressor impact, and the vulnerability of different household types to stressors. In this chapter, I summarise the main findings of the research, I flag up the main strengths and weaknesses of the modelling approach that was developed, and I recommend a number of potential avenues for future research.

9.1 Summary of Findings

9.1.1 Impact of stressors on financial and demographic trajectories

The simulation results from the model showed that the 2015 earthquake is likely to have a particularly profound impact on village finances and, to a lesser extent, on long-term demographics. The earthquake resulted in near-immediate income and expenditure shocks, and then a long period of repayment obligations. The implications varied between households, but it was evident from the results that high-income households found it much easier to absorb the fall-out than medium- to low-income households who often ended up flirting with debt and frequently needed to curtail their spending. These findings highlight the need for greater proactive consideration by governments of how post-disaster reconstruction can be financed.

The fertility scenarios, meanwhile, suggest that fertility rate changes will be somewhat less impactful in the near-term than the earthquake was found to be. On average, the higher fertility rate resulted in there being an average of 3.5 more villagers in 2030 than there would be under the lower fertility rate. For the households affected, this will mean higher expenses under the former scenario, but the model suggests that these higher expenses should be, for the most part, readily absorbed. While the burden of additional children makes it slightly harder for households who get into debt to exit debt, the fertility scenarios appear to have only a small impact on the frequency that households get into debt in the first place.

In respect to crop yield variability, it was found that the nature and degree of exposure varied substantially between households due to differences in land holdings and crop strategies. Differences in the extent to which households were reliant on agricultural income also contributed to differentials in vulnerability. Households with large holdings were clearly the most impacted by increased crop yield variability in absolute terms, but those households that had no source of off-farm income were the most vulnerable when crop yields were poor. Overall, it was found that poor harvests were not a particularly big contributor of households getting into financial difficulties, but greater crop yield variability did negatively affect household finances.

9.1.2 Role of context in shaping stressor impacts

Of course, the main focus of the research has been on how concurrent and successive stressors can affect households and villagers. The literature suggests that stressors can interact in nonlinear ways, fundamentally changing the nature of the stressors from what they would be when operating alone (O'Brien and Leichenko, 2000; Crain *et al.*, 2008; O'Brien *et al.*, 2009; Olsson *et al.*, 2014). However, the model findings revealed no statistically significant interaction effects between the earthquake, fertility rate, and crop yield variability scenarios. A lack of interaction effects would make understanding multiple stressors more straightforward, but the fact that no interaction effects were found in this case does not mean that they are not present in other stressor combinations. Furthermore, it is possible that the model may have missed out important linkages between the stressors that were considered – linkages that were not obvious from the fieldwork. Whether such interactions are present or not, it was clear from the results that experience of concurrent or successive stressors is a significant reason why many households get into financial difficulties. The impact of one stressor reduces the capacity of households to cope with others. The logical implication, then, is that mitigating the impact of one stressor will help households in dealing with others.

Also important in respect to context was the finding that happenstance plays a very significant role in shaping household experiences. Deaths, marriages, and changes in employment all have a big impact on household finances and demographics. Deaths were found to be particularly important as they potentially rob households of income earners and they are associated with substantial funeral expenses. Consequently, they are frequently associated with households getting into financial difficulties. Given this, it has been recommended that bereaved families be targeted for support. Weddings are also associated with increased rates of debt entry, but to a lesser degree. The significance of happenstance demonstrates the need to look beyond the likes of climate change and other high-profile contemporary stressors when thinking about household vulnerability and resilience – many age-old challenges remain important.

Finally, in respect to context, it was found that some households experience significant seasonality in their finances due to temporal variations in agricultural income and expenditures. This leads to temporal variation in vulnerability, particularly for those households that have no off-farm sources of income. The findings suggest that the timing of the earthquake was particularly unfortunate as it occurred during a period when household finances are typically squeezed. The promotion of off-season livelihoods has been recommended as a way of mitigating the impact of seasonal variations in finances.

9.1.3 Attributes determining the capacity of households to cope with stressors

When it came to assessing the role of household attributes in shaping economic outcomes, it was found that the presence of salaried members and engagement in commercial tomato cultivation were the factors most strongly associated with households doing well economically. Receipt of pensions and wages from short-term labouring were also positively correlated with household financial performance, but to a slightly lesser degree. The presence of non-earning adults and youth dependents had a slight negative impact, while the size of land holdings was found to be of little consequence. Of these findings, the significance of tomato cultivation was the most surprising. It suggests that promoting the farming of high value crops could be an effective means of helping households boost revenues. They also offer a valuable means of diversifying on-farm livelihoods which helps further reduce vulnerability.

9.2 Utility of Agent Based Modelling approach

The most novel aspect of the research has been the methodology that was employed. While ethnographically informed agent-based models of socio-ecological systems have been created before (e.g. Castella *et al.*, 2005; Zvoleff and An, 2014), few have incorporated the level of detail that is depicted in the Nepal SIM model or conducted simulations at such a high temporal resolution. Furthermore, while agent-based modelling has previously been used to study multiple stressors (e.g. Acosta-Michlik and Espaldon, 2008; Dressler *et al*., 2019), to the best of my knowledge, no models have considered the range of stressors and shocks considered in this thesis. Many of the components in the Nepal SIM model are also innovative in design – something that is in large part the result of being primarily guided by the fieldwork findings rather than by past modelling practice.

As discussed in *Chapter 2* and *Chapter 8*, agent-based modelling approaches have a number of strengths. These include allowing "what if?" questions to be explored in a scientifically rigorous fashion (Epstein, 2008) and letting system dynamics be intensively probed. Critically for this study, they also enable a wide range of processes to be simulated concurrently, including processes that occur at various different scales, and they excel in capturing the differential impact that processes can have on agents. This makes them ideal for multiple stressor studies and for exploring how villager and household attributes can affected experiences. All of these strengths proved to be of value in the thesis, but challenges were also encountered. In particular, model validation proved difficult, although this was in large part down to an act of God. Other challenges included the need to make numerous fuzzy judgement calls when designing the model, and characterising model behaviour in a comprehensive fashion. The latter was hindered by the computationally demanding nature of the simulations. Unfortunately, these challenges are difficult to avoid when building detailed, empirically informed models. However, the benefits do, arguably, outweigh them.

9.3 Priorities for future research

The fieldsite that was examined in this thesis – Namsa – was something of an exemplar of a community experiencing multiple stressors and undergoing rapid change. However, the stressors that are being experienced in the village are by no means exhaustive of the challenges mountain population's face and it should be recognised that the particularities of how stressors and transitions play out will differ by context. Consequently, there will be value in applying the approach that has been developed in this thesis to other case studies so that potential commonalities and differences in projected experiences can be identified. While the approach is relatively time and data intensive, the groundwork that has been laid in this thesis in regards the modelling should help accelerate the process.

Additional research should also be conducted into how stressors may interact with one another. As discussed in *Chapter 7*, the results showed no statistically significant interaction effects between the earthquake, fertility rate, and crop yield variability scenarios. But, as noted in *Chapter 8*, this may have been down to how the model was designed. Further in-depth fieldwork and experimentation with alternative model mechanisms may help elucidate whether the findings are a reflection of the reality or whether they are a product of the model design.

Further priorities for future research include imbuing the virtual villagers and households with greater agency, particularly when it comes to managing their finances – something that was also touched on in *Chapter 8*. In particular, greater attention should be paid to how villagers go about escaping debt spirals, and to how they use surplus income. More sophisticated modelling of how food is bought, sold, and consumed would also be valuable as it would allow food security to be considered alongside financial security. At present, it is assumed that all agricultural produce is sold, with food then being bought as required. Future models should account for how produce is instead split between domestic consumption and sale. A final priority should be to conduct additional validation of the Nepal SIM model. Although the 2015 earthquake undermined the original model validation strategy, follow-up fieldwork during the coming years would allow the performance of the model to be assessed against the reality of how village dynamics have played out. As discussed in the preceding chapters, there are a number of other avenues for improving on the model, but the ones discussed above are arguably the most significant.

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Appendix 1: Fieldsite climate

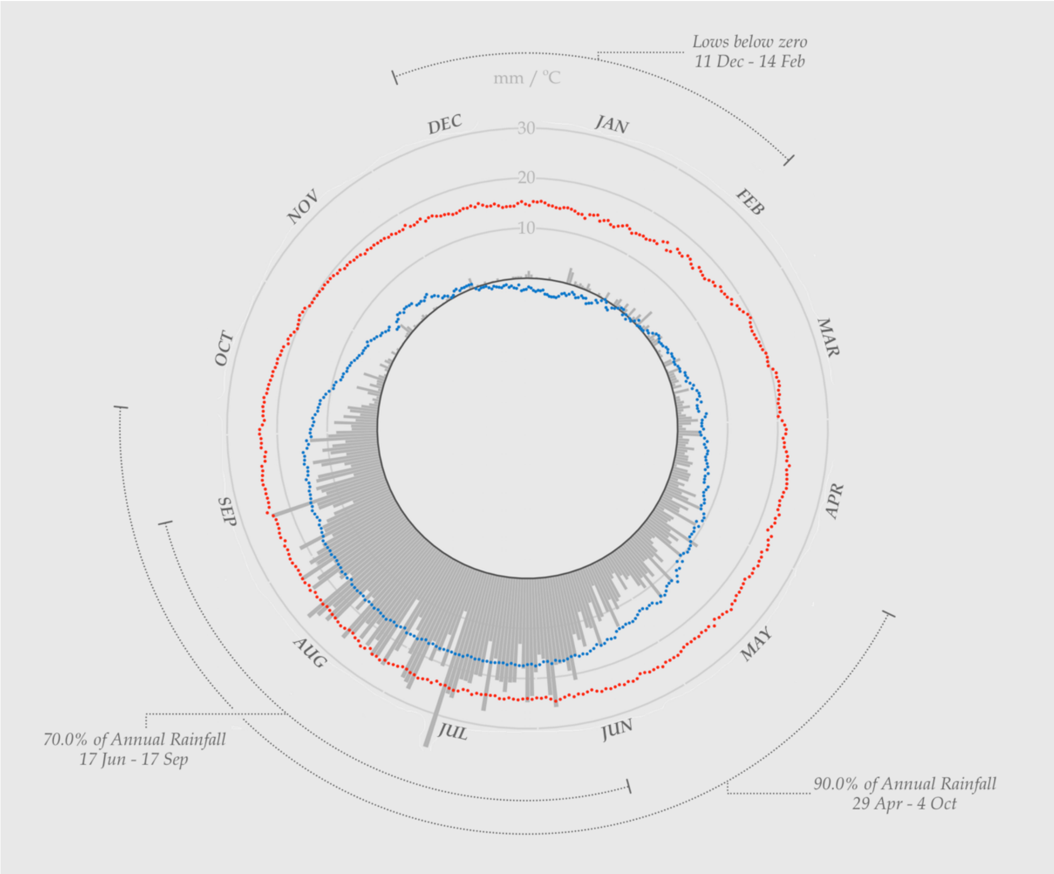

Figure A1. Average daily rainfall, plus maximum (red) and minimum (blue) temperatures for Jiri – where the nearest weather station to Namsa is located – between January 1994 and December 2013 (Data source: DMH, 2015).

Appendix 2: Using the Nepal SIM model

The Nepal SIM Model code, its associated files, example output, and R scripts for analysing the output are available upon request from the author.

Before using the Nepal SIM model, it is important to note that it differs substantially from standard NetLogo models in its functioning. Firstly, it relies heavily on the R extension to perform some of the more complex operations, such as data synthesis at initialisation. R is therefore required. Secondly, it records an extremely large volume of data to aid subsequent analysis. This recording is done using a bespoke method that calls on the csv extension, rather than using the standard methods for outputting data. Thirdly, rather than using BehaviorSpace for managing batch experiments, a bespoke function has been written for this purpose. It can be called using the `Conduct a Scenario Sweep` button. The function itself is named `scenario-sweep`. It simulates the eight scenario combinations a designated number of times, each time with a different seed (see below).

Prior to running the model, the following needs to be done:

1. The paths to the R scripts must be updated. The paths are set in the `to load-r-scripts` function.
2. The path name for the output data needs to be updated. The path is set in the `to prepare-data-log` function. Data logging can be turned on or off using the `logData?` switch on the interface.
3. The paths at the top of the `simulateMarriage.R`, `simulateFertility.R`, and `simulateDeath.R` scripts need to be updated so that they point towards the data in the data folder. These scripts can be found in the `r_scripts` folder.
4. If conducting one run at a time, the scenario chooser menus on the NetLogo interface can be used to set the cash crop and subsistence crop half yield frequency parameters, to set the average fertility parameter, and to determine whether or not to simulate an earthquake. If conducting a scenario sweep, this is not necessary.
5. To change the other parameters from their defaults, update the values that are set in the `to initiate-parameters` function and search for other instances of the variables which may require updating. Note that changes made to these parameters on the interface will be reset when the `to initiate-parameters` function is called on setup, so the changes need to be made directly in the code. Also note that crop yields cannot be set by the user. They are determined by the `initiate-future-yields` function at initialisation.
6. If conducting a scenario sweep, the number of replications that should be run for each scenario combination can be set using the `numberOfRuns` slider on the interface. Each replication uses a different seed.

To run a single simulation: Set the parameter values using the methods explained above, click `Setup`, and then either repeatedly click `Step` to advance one day at a time or click `Run Simulation` to run the model for the period of time determined by the `simulationLength` slider.

To run a batch of simulations: Determine the number of runs to conduct for each scenario combination using the method described above and then click `Conduct a Scenario Sweep`. If a non-standard batch of simulations is desired, adjust the `scenario-sweep` function and any other parameters as required following the previously stated advice.

Other things to note:

- A csv file is created for each simulation run. The file name shows the earthquake, fertility, and crop variability scenarios that were simulated, as well as the seed. For example, `EQ-21-12-01.csv` stands for the earthquake scenario, the 2.1 fertility rate, the 12/10 crop variability scenario, and seed #1.
- It is advisable to turn off the `view updates` tick box to speed up the simulations.
- To parallelise the simulations, open multiple instances of NetLogo and adjust the `scenario-sweep` function so that different parameter combinations and/or seeds are run in each instance.

- The model is computationally expensive relative to most NetLogo ABMs. It is therefore advisable to run it on relatively powerful devices only.
- Each output file is around 30 MB. It is therefore advisable to ensure sufficient storage is available before running large batches of simulations.
- The land holdings of each household can be highlighted by clicking the `Highlight a HH` button after setup and then clicking on the centre of a household in the world window. Click the `Highlight a HH` button again to return to the normal view.

Analysing output from Nepal SIM

Example output from the simulations is provided in the `example_output` folder, in the `data_analysis` folder.

If you have RStudio, the files can be explored using the `output_viewer.R` application. To do this:

1. Open RStudio and install the `Shiny` package if it has not already been installed.
2. Open the `output_viewer.R` script in RStudio and click `Run App`.
3. When the app opens, click the `Browse…` button and select a data output file of interest e.g. a file from the `example_output` folder.
4. Once the upload is complete, select one of the tabs to see an overview of the data, bearing in mind that it can take a while to process, even on a relatively high-performance machine. If the seasonal decomposition charts throw an error, try deselecting some households.

The data can alternatively be explored using custom R scripts. Examples are provided in the `data_analysis` folder. By default, the script is set up to analyse the 10 example outputs that are provided on the USB drive. To use the script:

1. Open the script in RStudio and ensure that the required packages are installed.
2. Update the path names so that they point to the data that is to be analysed.
3. Run the code.

The `village_statistics.R` script calculates key demographic and financial variables for each of the simulations. The `financial_trajectory.R` script plots household finances over time for each scenario combination.

Appendix 3: Household questionnaire

HOUSEHOLD SURVEY

[Read the consent statement to the potential respondent prior to commencing the survey]

A. Consent & Respondent Details

Questionnaire ID	M	M	D	D	h	h	m	m				
Respondent Name												
GPS Coordinates												
Age 18+					**Consent Provided?**							
Religion					**Caste/Ethnicity**							

B. Household Characteristics & Assets

B 01	How many rooms in this house are used for sleeping?	
B 02	Is this house (1) owned, (2) rented, (3) rent-free, or (4) mortgaged? If other, specify.	
B 03	How long have you/members of your household been living on this plot?	
B 04	How much agricultural land do the household members own in total?	
B 05	Does your household have a kitchen garden and if so, how large is it?	
B 06	What is the main material of the floor?	
B 07	What is the main material of the walls?	
B 08	What is the main material of the roof?	
B 09	What type of fuel does your household mainly use for cooking?	

B 10	Does your household have the following?	a. Electricity		b. Radio	
		c. Television		d. Refrigerator	
		e. Basic mobile phone		f. Smart phone	
		g. Air conditioner		h. Washing machine	
		i. Water pump		j. Bed	
		k. Chairs		l. Cabinet	
		m. Clock		n. Sofa	
		o. Sewing machine		p. Camera	
		q. Personal computer		r. Watch	
		s. Bicycle		t. Room cooler	
		u. Animal drawn cart		v. Car/truck	

B 11	How many of the following animals does this household own?	a. Buffalo	M	F	b. Donkey/Mules	M	F
		c. Chickens	M	F	d. Cows/Bulls	M	F
		e. Goats	M	F	f. Pig	M	F
		g. Sheep	M	F	h. Other ______________	M	F
		i. None	M	F	j. Don't know	M	F

C. Household Migration

Permanent Migration		1	2	3	4
C 01	Please give the names of any former hh members who are living outside this household on a permanent basis (**Note initials only**)				
C 02	Is [name] male or female?				
C 03	In what month & year did [name] move away?	MM/YY	MM/YY	MM/YY	MM/YY
C 04	How old was [name] when s/he moved away?				
C 05	Where does [name] now live? (**See codes below**)				
C 06	What was the main reason that [name] moved away? (**See codes below**)				
C 07	Does [name] send remittance?				

Potential Migration		1	2	3	4
C 08	Please give the names of any other hh members who are considering leaving permanently in the near future (**Note initials only**)				
C 09	Where is [name] considering moving to? (**See codes below**)				
C 10	For what reason is [name] considering moving? (**See codes below**)				

Seasonal Migration		1	2	3	4
C 11	Please give the names of any hh members who migrate seasonally or temporarily for work (**Note initials only**)				
C 12	Where does [name] migrate to? (**See codes below**)				
C 13	During which months is [name] typically away?	MM-MM	MM-MM	MM-MM	MM-MM

Code					
	Reasons for moving:	a. Work	b. Study	c. Marriage	d. Family
		e. Security	f. Other (specify)	g. Don't know	
	Destinations:	a. Same village	b. Same district	c. Other district	d. India
		e. Middle East	f. Other country	g. Don't know	

D. Household Members

Household Roster		1	2	3	4	5	6	7	8
D 01	Please let me know the names of the persons who usually live and eat in your household, starting with the head of the household (**Note initials only**)								
D 02	What is the relationship of [name] with the head of the household? (**See codes below**)								
D 03	Is [name] male or female?								
D 04	How old is [name]?								
D 05	Is [name] married to another member of the hh? (**Specify initials of other individual**)								
D 06	What is the highest level of education participated in by [name]? (**See codes below**)								
D 07	What are the main occupations of [name]? (**See codes below | Can state multiple**)								
D 08	For none-village jobs, does [name] do this work for (1) a member of your household, (2) for someone else, or are they (3) self-employed?								
D 09	For village jobs, does [name] usually work (1) throughout the year, or does s/he (2) work seasonally, or only (3) once in a while?								
D 10	Is [name] paid in (1) cash or (2) kind for any of these jobs, or (3) not at all?								

Code						
	Relationship with head of household:	a. Spouse	b. Child	c. Grandchild	d. Nephew/Niece	e. Cousin
		f. Uncle/Aunt	g. Sibling	g. Parent	h. Parent-in-law	i. Sibling-in-law
		j. Other (**Specify**)	k. Don't know			
	Highest level of formal education:	a. None	b. Primary	c. Secondary	d. Higher	e. Don't know
	Main occupation:	a. Agriculture	b. Cottage Industry	c. Skilled manual	d. Unskilled manual	e. Housework
		f. Housekeeping	g. Caring for kids	h. Study/Student	i. Unemployed	j. Other (**Specify**)

[Provide further notes on the roles different members of the household play and their occupations, including likely changes to the above in the near future:]

Community Groups		Group Name/Type	Initials of Household Member(s)
D 11	Are any of the members of the household directly involved in a community group?		

E. Household Income

E 01	What is the approximate annual income of this hh including money from any & all source? (**Npr.**)						
What is the percentage contribution of the following sources to the total yearly household income & during which months is the revenue primarily received?							
E 02	Crop, vegetable, fruit & herb sales	MM-MM		E 03	Livestock & livestock product sales	MM-MM	
E 04	Forest product sales	MM-MM		E 05	Medicinal & aromatic plant sales	MM-MM	
E 06	Daily wages (in community/area)	MM-MM		E 07	Salaried employment (in community/area)	MM-MM	
E 08	Other business/trade income	MM-MM		E 09	Rent, interest on loans, or returns on shares	MM-MM	
E 10	Pensions	MM-MM		E 11	Remittances	MM-MM	
E 12	Development aid projects	MM-MM		E 13	Gifts	MM-MM	
E 14	Governmental social benefit schemes	MM-MM		E15	Total %		
E 16	Does any member of this household have a bank account?						
E 17	Does the household have savings? (**Ask for amount if they are willing & able to disclose**)						
E 18	Does the household have loans? (**Ask for amount if they are willing & able to disclose**)						
E 19	If your household wanted to borrow money, whom would you approach first? (**See codes**)						
E 20	How easy would it be to borrow money? (a) Very difficult (b) Fairly difficult (c) Somewhat difficult (d) Fairly easy (e) Easy						

Code	Loan Access:	a. Relative	b. Friends	c. Village fund	d. VDC
		e. Rural credit coop	f. Microfinance institution	g. Private bank	h. Private lender
		i. Other (**specify**)			

F. Household Expenditure

F 01	What is the approximate total annual expenditure of this household? (**Rs.**)			
	What are your household's main annual expenditures and in what months are these expenditures endured? (**See codes & rank in order of importance**)	Expenditure	Amount (**Annual Rs.**)	Months
F 02				–
F 03				–
F 04				–
F 05				–
F 06				–
F 07				–
F 08				–
F 09				–
F 10	Day-to-day, who usually decides how the money earned by the household will be used? (**Give initials**)			
F 11	Who usually makes decisions about major household purchases or investments? (**Give initials**)			
F 12	In the last decade, how has the economic situation of your household changed? (**See codes**)			

Code					
	Expenditure:	a. Food	b. Water	c. Accom.	d. Livelihood related spend
		e. Health	f. Transport	g. Education	h. Infrastructure maintenance
		i. Utensils	j. Luxury good	k. Savings	l. Infrastructure improvements
		m. Celebrations	n. Gifts	o. Tax	p. Other (**Specify**)
	Economic situation:	a. Worsened a lot	b. Worsened moderately	c. Worsened slightly	
		d. No significant change	e. Improved slightly	f. Improved moderately	
		g. Improved a lot			

[Provide further notes on household income and expenditure e.g. who are the main earners, & how do income & expenditure vary year-to-year?]

G. Water Access & Usage

Post-MUS Installation		1	2	3	4
G 01	Please tell us about the different water points your household uses for **any** purpose, starting with the most frequently used source. (**Enter map code**)				
G 02	For how many years have you been using this source?				
G 03	How frequently do you use this water point? (**See codes**)				
G 04	Do you use water from this water point for drinking?				
G 05	Do you use water from this point for other domestic use? (e.g. cooking, dish washing, hand washing, bathing)				
G 06	Do you use water from this point for irrigating a kitchen garden?				
G 07	Do you use water from this point for irrigating agricultural land/livestock?				
G 08	Who usually goes to this water point to fetch the water for your household? (**State initials**)				
G 09	On average, how long does it take to travel one-way to this water point? (**Min**)				
G 10	On average, how many trips are made **to** this water point each day?				
G 11	How many days in a month is water usually available from this water point?				
G 12	How many months in a year is water usually available from this water point?				
G13	During which months, if any, is water usually not available from this source?	MM-MM	MM-MM	MM-MM	MM-MM
G 14	To what extent can you usually predict that water will be available from this water point? (**See codes**)				
G 15	**If not MUS**, what type of container do you usually use to carry from this water point that would be best for estimating daily use? (**Specify litres**)				
G 16	How many units of the container does your household usually collect per day from this source for domestic use?				
G 17	Do you pay anything for water from this water point, and if so, how much? (**Rs.**)				

Pre-MUS Installation		1	2	3	4
G 18	Please tell us about the different water points your household used for any purpose, prior to the MUS system being installed. (**Enter map code**)				
G 19	For how many years had you been using this source prior to MUS?				
G 20	How frequently did you use this water point? (**See codes**)				

G 21	Did you use water from this water point for drinking?				
G 22	Did you use water from this point for other domestic use? (e.g. cooking, dish washing, hand washing, bathing)				
G 23	Did you use water from this point for irrigating a kitchen garden?				
G 24	Did you use water from this point for irrigating agricultural land/livestock?				
G 25	Who usually went to this water point to fetch the water for your household? (**State initials**)				
G 26	On average, how many trips were made **to** this water point each day?				
G 27	What type of container did you usually use to carry or store water from this water point that would be best for estimating daily use? (**Specify litres**)				
G 28	How many units of the container did your household usually collect per day from this source for domestic use?				
Only complete the below if the source was not mentioned in G 01					
G 29	On average, how long did it take to travel one-way to this water point? (**Min**)				
G 30	How many days in a month was water usually available from this water point?				
G 31	How many months in a year was water usually available from this water point?				
G32	During which months, if any, was water usually not available from this source?	MM-MM	MM-MM	MM-MM	MM-MM
G 33	To what extent could you usually predict that water would be available from this water point? (**See codes**)				
G 34	Did you pay anything for water from this water point, and if so, how much? (**Rs.**)				

Code	Frequency of use:	a. Daily (**Specify #**)	b. Weekly	c. Monthly	d. Seasonal (Wet)
		e. Seasonal (Dry)	f. Infrequently	g. Don't know	
	Predictability:	a. Very easy	b. Easy	c. Difficult	d. Very difficult

G 35	Post MUS, how much water do you typically have stored in your household compound at the end of a day? (**Estimate in litres**)			
G 36	Prior to MUS, how much water did you typically have stored in your household compound at the end of a day? (**Estimate in litres**)			
G 37	What do you normally do when water availability is reduced for an extended period? (**Rank**)			
	Use stored reserves		Reduce amount used for cooking	
	Buy water from water trader		Reduce amount used for drinking	
	Recycle water more		Reduce amount used for irrigation	
	Reduce amount used for clothes wash		Reduce amount used for livestock	
	Reduce amount used for body washing			

G 38	Since MUS was installed, how has the water consumption of your household typically changed for the following activities? (**Specify direction of change & change in litres/day**)	Cleaning house & utensils	↑ ↓	
G 39		Washing clothes	↑ ↓	
G 40		Personal cleanliness	↑ ↓	
G 41		Cooking	↑ ↓	
G 42		Drinking	↑ ↓	

	Since MUS was installed, how much extra agricultural land has your household been irrigating? (**Break down by plot, & specify months irrigated & crops grown**)	Plot Size	Months Irrigated	Crops Grown
G 43			MM-MM	
G 44			MM-MM	
G 45			MM-MM	
G 46			MM-MM	

G 47	If MUS has reduced the time your household takes to collect water each day, what is this time now used for? (**Specify**)	
G 48	Has MUS helped your household increase its income, and if so, by how much? (**Specify in NPR.**)	
G 49	If you stated yes to the above question, what has the main reason been for this increase in income? (**See codes**)	
G 50	Have you encountered any problems with the MUS system since it has been installed? (**Specify**)	
G 51	How often is there conflict over the use of water in your community? (**See codes**)	
G 52	How often is there conflict over the use of water between your community and other communities? (**See codes**)	
G 53	To what extent do you feel the MUS system has impacted on life in the village? (**See codes**)	

Code			
	Reason for income rise:	a. Improved yields due directly to better water availability c. More time to spend farming rather than water collection e. Other (Specify)	b. Opportunity to grow higher revenue crops d. More time to spend on other income earning activities instead of water collection f. Don't know
	Frequency of conflict:	a. Never; b. Rarely	c. Sometimes; d. Often
	MUS Impact:	a. Made it much worse; b. Made it a little worse; c. No impact d. Made it a little better; e. Made it much better	

[Provide further notes water access, seasonal availability & conflicts:]

H. Sanitation

H 01	Does your household have a toilet within the household compound?	YES-NO
H 02	Are water and a cleansing agent (soap, detergent, etc.) available at this place?	YES-NO

Perception of Households Sanitation Facilities		Very Bad	Bad	Okay	Good	Very Good
H 03	Quality of construction					
H 04	Ease of access					
H 05	Privacy					
H 06	Cleanliness					

[Provide further notes on location and nature of the sanitation facilities e.g. when not at home:]

I. Food Security

Please tell us about the main food and drinks that your household consumes during the year				
	Food/Drink (**Specify**)	Main months consumed in	Homegrown, purchased or both?	Quantity (**kg or litres/week**)
I 1		MM-MM	H/P/B	
I 2		MM-MM	H/P/B	
I 3		MM-MM	H/P/B	
I 4		MM-MM	H/P/B	
I 5		MM-MM	H/P/B	
I 6		MM-MM	H/P/B	
I 7		MM-MM	H/P/B	
I 8		MM-MM	H/P/B	
I 9		MM-MM	H/P/B	
I 10		MM-MM	H/P/B	

Have you noticed a change in availability or price of any of the aforementioned goods over the last 10 years? (**Please list**)		Change in availability in last 10 years?	Change in price in last 10 years?
I 11		↑ ↓	↑ ↓ %
I 12		↑ ↓	↑ ↓ %
I 13		↑ ↓	↑ ↓ %
I 14		↑ ↓	↑ ↓ %
I 15		↑ ↓	↑ ↓ %

I 16	In the past five years, how often did you or any household member have to eat smaller or fewer meals than you felt you needed because there was not enough food? (**See codes**)				
I 17	What were the causes of the food deficiency in your household in the last five years? Rank by importance. (**See codes**)	1	2	3	4
I 18	During which months does food availability tend to be worst?	MM–MM			

I 19	Did your household have to adopt any of the following to meet the household food needs in the last five years? (**Rank by importance**)	a. Take a loan		f. Collect wild food	
		b. Sell household assets		g. Consume seed stock for next season	
		c. Sell livestock		h. Migrate seasonally	
		d. Sell land		i. Migrate permanently	
		e. Sell labour		j. Other (**Specify**)	

Code	Frequency of deficiency:	a. Never	b. Rarely	c. Sometimes	d. Often
		e. Don't know			
	Causes of deficiency:	a. Income fall	b. Market price rise	c. Local drought	d. Local flood
		e. Local storm	f. Local landslide	g. Market availability	

[Provide further notes food security:]

J. Livelihoods

During the last 12 months, what kind of crops did your household grow (**List by importance**)

	Crop (**Specify**)	Total land crop grown on	Annual yield (**kg**)	Revenue earned from crop sale	Land irrigated?	Month(s) planted	Month(s) harvested	Chemical fertiliser used?	Pesticide used?	Crop sold, consumed by hh or both
J 01					Y-N	MM-MM	MM-MM	Y-N	Y-N	S/C/B
J 02					Y-N	MM-MM	MM-MM	Y-N	Y-N	S/C/B
J 03					Y-N	MM-MM	MM-MM	Y-N	Y-N	S/C/B
J 04					Y-N	MM-MM	MM-MM	Y-N	Y-N	S/C/B
J 05					Y-N	MM-MM	MM-MM	Y-N	Y-N	S/C/B
J 06					Y-N	MM-MM	MM-MM	Y-N	Y-N	S/C/B
J 07					Y-N	MM-MM	MM-MM	Y-N	Y-N	S/C/B

J 08	How much agricultural land does your household have that has not been used in the last 12 months?	

Of the aforementioned crops, which did you grow less of or not at all ten years ago? (**State how much less as %**)

J 09		
J 10		
J 11		
J 12		
J 13		

Which crops did you grow more of ten years ago? (**State how much less as % if listed above**)

J 14		
J 15		
J16		
J 17		
J 18		
J 19		

[What are the main reasons for the change in crops grown over the last ten years?]

J 20	Approximately, how much time does it take in minutes to get from your house to your households furthest plot?								
J 21	Does your household mainly (a) buy seeds, (b) save seeds, or (c) receive seeds for free for the crops you grow?								
J 22	How often does your household have enough household members to work/manage your farm? (**See codes**)								
J 23	If your farm does have labour shortages, how do you overcome these? (**See codes & rank by importance**)	1	2	3	4				
J 24	How many days a week does your household collect fodder/fuel wood and other forest products from the jungle?								
J 25	Over the last 12 months, how many of the following animals have you bought, sold, or slaughtered for hh consumption?	a. Buffalo	B	S	SI	b. Cows/Bulls	B	S	SI
		c. Chickens	B	S	SI	d. Pig	B	S	SI
		e. Goats	B	S	SI	f. Sheep	B	S	SI
		g. Other ________________________					B	S	SI

[Has the number and type of animal your household owns changed over the last ten years, and if so, for what reason?]

Code	Availability of hh members:	a. Never b. Rarely c. Sometimes d. Often e. Always	
	Overcome shortages:	a. HH members work extra hours	b. Hired labour
		c. Gave up labour intensive crop species	d. Introduced less labour intensive crop species
		e. Let land fallow	f. Reduced the number of livestock
		g. Changed the type of livestock	h. Exchanged labour with other hh
		i. Other (**Specify**)	

Plot purchase & sale		1	2	3	4
J 26	In recent years, have you bought or sold any land used for agriculture or livestock? (**List transactions 1–4**)	B/S	B/S	B/S	B/S
J 27	When did you buy/sell this land?	YY-MM	YY-MM	YY-MM	YY-MM
J 28	How much money did you pay/receive?				
J 29	How far is this plot from your household in minutes?				
J 30	Is this plot (1) MUS-irrigated, (2) irrigated by another source, (3) not irrigated?				

[For what reasons did you buy or sell the land:]

[Is any of the land you own or farm operated under an adiya agreement? (**If so, give details**)]

J 31	When your household has experienced crop failures, falls in yield, or other negative events in the past, what strategies did you employ to cope? (**See codes and rank by importance**)	1	2	3	4	5

Code	Coping strategies:	a. Relied on less expensive food	b. Bought food on credit
		c. Borrowed money from financial service	d. Borrowed money from relatives
		e. Borrowed money from friends	f. Borrowed money from coop/local fund
		g. Begged for money or food	h. Spent savings on food
		i. Collected wild food	j. Collected & sold forest products
		k. Reduced size/number of meals	l. Consumed seed stocks for next season
		m. Took children out of school to work	n. Reduced spending on education
		o. Non-working hh member started work	p. Sought work in same village
		q. Sought work elsewhere (migration)	r. Reduced spending on health
		s. Reduced spending on clothes	t. Leased out farmland
		u. Sold farmland	v. Sold animals
		x. Sold hh assets	y. Sold agricultural assets

Please give details of any non-agricultural business that members of your household have managed/run at any point during the last 12 months				
	Type of business (**Specify**)	HH members involved (Initials)	Months in which it operated	Income earned from business (**Npr.**)
J 32			MM-MM	
J 33			MM-MM	
J 34			MM-MM	
J 35			MM-MM	

Please let me know which members of your household have primary responsibility for the following tasks (**State initials**)				
J 36	Cooking		Cleaning the house	
	Washing clothes		Caring for young children	
	Feeding/caring for chickens		Feeding/caring for pigs	
	Feeding/caring for goats		Taking goats to jungle	
	Feeding/caring for buffalo/bull		Collecting forest products	
	Construction/repair of household infrastructure		Care of kitchen garden	
	Planting of seeds		Weeding agricultural land	
	Irrigation of agricultural land		Harvesting agricultural land	
	Selling agricultural produce		Buying food, clothing & other low value goods	
	Deciding what to plant & when		Deciding when to buy, sell or slaughter animals	

K. Health

K 01	In the last 12 months, how often has someone in your household been seriously ill (meaning they are so ill that they cannot work? (**See codes**)		
K 02	Can your household afford professional treatment for serious illness or injury? (**See codes**)		
K 03	What age were the last two household members at the time they passed away?		

Code					
	Frequency of illness:	a. Never	b. Once or twice	c. Once a month	d. A few times a month
		e. About once a week	f. A few times a week	g. Every day	h. Don't know
	Affordability of healthcare:	a. Yes, household can afford it	b. Yes, if money is borrowed	c. Yes, with much difficulty	d. Yes, with some difficulty
		e. No	f. Not sure		

THAT'S IT. THANK YOU FOR YOUR ASSISTANCE!