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Living with Volcan Tungurahua: The dynamics of vulnerability during prolonged volcanic activity

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ABSTRACT

For the people that live around many of the world's volcanos, the effects of eruptive activity on livelihoods and wellbeing are seldom experienced as a one-off event. Not only do volcanos commonly enter long-lived phases of activity, during which the physical hazards they create alter in characteristics, but the way exposure to such hazards generates impacts on society and shapes responses by people and institutions also modifies and evolves. Within this dynamic process, the behaviour of the volcano provides a framing, but social, economic and political changes interact to shape unfolding patterns of vulnerability. The research presented in this paper explored this complexity of impact and social change for the case of Volcan Tungurahua in Ecuador, which has been in eruptive phase since 1999. Focussing on the people who live in different areas around the volcano, the study used interview and survey evidence to examine changing knowledge about eruptions and how people have experienced the effects of the volcano over time on their economic livelihoods, mobility, residence patterns, and access to services and infrastructure. Crucially, this meant recognising that the existence of a threat from hazards had societal implications, regardless of whether or not the volcano is actually in a state of high activity. These implications played out differently for different sections of the neighbouring population, with the strongest contrast emerging between the rural and urban populations, though the complexity of the case defies a simple binary comparison. The research underlines the importance of building a longitudinal element into analysis.

1. Introduction

Research on the social dimensions of risk associated with volcanoes has focussed strongly on human safety and how people and authorities perceive and respond to the immediate threats to life from eruptive events (Gaillard and Dibben, 2008). Yet, as critical conceptions of disaster risk in general have widened their scope, so broader studies on human vulnerability to volcanic hazards have emerged. An increasing body of work is examining volcanic hazards through the lens of people's wellbeing and livelihoods, including recognition of the longer term implications (both positive and negative) of volcanic activity in shaping people's lives and in some cases shaping the structures of society, culture and economy within which people live and work (e.g. Bachri et al., 2015; Dove, 2008; Gaillard, 2008; Hicks and Few, 2015; Kelman and Mather, 2008; Paton et al., 2001; Thorvaldsdóttir and Sigbjörnsson, 2015). Inherent in that analysis should be recognition of two key points: volcanos commonly erupt in phases rather than one-off events; and a volcano's activity may provide the framing dynamic, but it is seldom the sole driver of change.

This paper reports findings from empirical research conducted in Ecuador through the Strengthening Resilience in Volcanic Areas (STREVA) project. The research took place at Volcán Tungurahua, a stratovolcano in the eastern cordillera of Ecuador, with the objective of analysing the long-term implications of a protracted phase of volcanic activity on the life trajectories, wellbeing and livelihoods of people living in its surrounding area. The paper is based on data gathered at the household level between November 2013 and March 2014 in urban and rural areas located in the two provinces influenced by the volcano, Tungurahua and Chimborazo.

Given that it has been in constant activity since 1999, Volcán Tungurahua provides an excellent case study for analysing the dynamics of risk and vulnerability in the long term, enabling us to draw directly on the perspectives of those who have experienced these changes. The study required us to explore actions and responses and their interaction with vulnerability not just during episodes of volcanic eruptions but also in the times between

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these events (Dove, 2008). The findings have relevance not just to a range of volcanic settings, but also to considerations of risk in settings where other forms of hazard such as drought, floods and landslides take on a long-duration or recurrent form in specific locations.

Following a brief literature review, the paper describes the case study context and methodology, sets out the detailed empirical findings on dynamics of impact and response at Tungurahua, and draws out a synthesis discussion that explores changes over the duration of the current active period and how and why they have played out differently for the communities surrounding the volcano.

2. Framing of the analysis

The framing of this paper draws on a critical approach to disaster risk dating from the 1970s and now well established within political ecology and associated fields that recognises not only that hazards affect people's lives through multiple pathways but that the chances of experiencing impacts are as socially determined as they are physically triggered (see e.g. Bankoff et al., 2004; Cutter, 1996; Hewitt, 1983; Wisner, 2004). Risk, in this sense, is defined as the interaction of hazard and vulnerability, with vulnerability commonly understood as a combination of exposure to hazard and susceptibility to its impacts. Critical research on disaster risk emphasizes that both exposure and susceptibility are to large extent socially-generated conditions, shaped differentially both by social structures and by aspects of human agency. Such a perspective also emphasises that different social groups experience and manage risk in different ways.

A substantial body of social science research has targeted human behaviour and institutional responses to the immediate threats to life posed by volcanic hazards (for recent additions see e.g. (for recent additions see e.g. De Bélizal et al., 2012; Meia et al., 2013). We contend that rather less attention has been paid to the impacts and implications of volcanic activity on the livelihoods and wellbeing of people who encounter volcanos and their hazards as part of their lived environment. Although work in this aspect is building (see e.g. Mercer and Kelman, 2010; Thorvaldsdóttir and Sigbjörnsson, 2015), including recognition of volcanic eruptions as potential catalysts of social change (Bachri et al., 2015; Dove, 2008; Hicks and Few, 2015), there are key aspects of vulnerability and response to volcanic activity that remain under-researched.

The hazards associated with volcanic activity are particularly varied in both their impacts and dispersal. Their characteristics are strongly related to the composition of magma erupted and the intensity with which it is erupted. Airborne hazards result from volcanic explosions where the acceleration and disintegration of magma produces a wide range of particles from large clasts that fly on a ballistic trajectory (ballistics) through to fine ash and volcanic aerosols. Larger eruptions disperse destructive volumes of volcanic ash in proximal locations (Wilson et al., 2012) and can cause wide ranging direct impacts across thousands of kilometres. Topographically-controlled hazards include lava flows, pyroclastic density currents (violent flows containing magmatic particles interspersed with volcanic gas) and lahars (violent floods charged with volcanic sediments). The remobilisation of loose deposits as lahars can cause persistent impacts for many years after the cessation of eruption (Pierson et al., 2014).

Volcanic hazards may be brief and episodic in their violent phases, but the long duration of high-risk periods that characterize many eruptions (eg. in recent years Soufrière Hills in Montserrat, Colima in Mexico, Mayon in Philippines, and Merapi in Indonesia) have complex and chronic patterns of social, economic and political impact. Like many hazards they also have long-term implications for recovery – and the ability to recover (or not) is another key facet of people's overall vulnerability to their impacts (Hicks and Few, 2015). In this sense, it is not just the experienced hazards that create impacts but also the threat of the impacts – in that existence of an active volcano can generate effects such as psychosocial stresses, investment constraints, economic disruption and outmigration.

This research therefore aims at going beyond a focus purely on volcanic hazard events to seeing volcanic risk as an on-going risk *process* with on-going social impacts for the vulnerable (including implications for recovery), punctuated (and reproduced) by actual volcanic hazard events. But as a process risk and its vulnerability component are therefore also inherently dynamic. Changes in vulnerability through the course of a prolonged period of volcanic activity are linked to, but not necessarily dependent on, variation in the physical characteristics of the hazard itself as the active period progresses. Hence there is a need to look at long-term patterns of change, covering impacts both of periods of exposure to volcanic hazards and periods of volcanic quiescence, and how this interacts with transformations in livelihoods, settlement patterns, social structures and risk behaviours.

3. Tungurahua case study

3.1. Case study context

Volcán Tungurahua is located on the border of Tungurahua and Chimborazo provinces in the Cordillera Central of the Andes Mountain Range of Ecuador. Around 200,000 people live in the influence zone of this volcano, and approximately 32,000 live within the higher risk areas, predominantly in rural settlements but including the town of Baños de Agua Santa (INEC, 2010; Mothes et al., 2015).

Since colonial times Volcán Tungurahua has had various periods of eruptive activity between: 1640–1641, 1773–1777, 1886–1888, 1916–1918 and from 1999 until the present (Biggs et al., 2010; Hall et al., 1999; Ramón, 2009). During the current period of volcanic activity, on which this research focuses, there have been eruptions ranging in magnitude of volcano explosivity index (VEI) levels of <1 to 3 and with associated hazards including ash fall, tephra falls, pyroclastic flows, gas emissions and lahars (Mothes et al., 2015). The reactivation of Volcán Tungurahua in September 1999 led to an evacuation order for the population around the volcano because of concern that a large eruption might follow. Minor explosions and sustained ash emissions ensued, but after a few months without intensification of the activity residents of Baños and the villages on the flanks urged the authorities to let them return (Tobin and Whiteford, 2002b; Vieira, 2003). The strength of opposition to the continued evacuation grew, and in January 2000 restrictions were lifted and people were allowed to go back to their homes (Vieira, 2003).

However, the eruptive phase of the volcano had not ceased, and several years later major eruptions of Volcán Tungurahua occurred in July and August 2006, which produced, ash fall, tephra falls and large pyroclastic density currents causing loss of life and significant infrastructure and economic losses across Tungurahua and Chimborazo provinces (Biggs et al., 2010; Mothes et al., 2015; Ramón, 2009; Sword-Daniels et al., 2011). Pyroclastic density currents impacted settled areas and caused 5 deaths and 61 injuries. In addition, 15 houses in the town of Palictahua and more than 40 in Juive Grande were completely destroyed, while almost 4000 houses were damaged across different locations in the influence zone of the volcano (Cevallos, 2006; Mothes et al., 2015; Ramón, 2009; Valencia, 2010). After these events the state and some non-profit organisations began a series of resettlement projects for families living on the slopes of the volcano.

The ensuing period from 2007 through to the present day has seen a series of eruptions of different magnitudes, the most significant during 2008, 2010, 2013, 2014 and 2016, with major ashfalls and some pyroclastic density currents and continuing effects on people's livelihoods, particularly agricultural activities (Hall et al., 2015). Since 2006 new governance structures for disaster risk management have been established at the national level, as well as strengthening of the early warning functions of the Tungurahua Observatory run by the Instituto Geofísico of the Escuela Politécnica Nacional (IGEPN) and establishment of a community-based volcanomonitoring system comprising volunteer observers (*vigias*) (Mothes et al., 2015; Ramón, 2009; Stone et al., 2014).

3.2. Research methods

Research took place across a continuous area around the northern, western and south-western flanks of the volcano (areas to the east and south-east of the volcano have very little human settlement) and in each of the official resettlement sites for displaced communities (see Figs. 1 and 2). The study population comprised four main groups: 17 rural communities on the northern to south-eastern slopes of the volcano with high exposure to volcanic hazards; residents of 5 resettlement sites for these communities in Tungurahua and Chimborazo provinces; 6 rural communities located in areas immediately adjacent to the volcano to the west and south-west, with high exposure to ash and tephra falls; and the urban population of Baños de Agua Santa, located at the northern perimeter of the volcano, approximately 8 km from the summit.

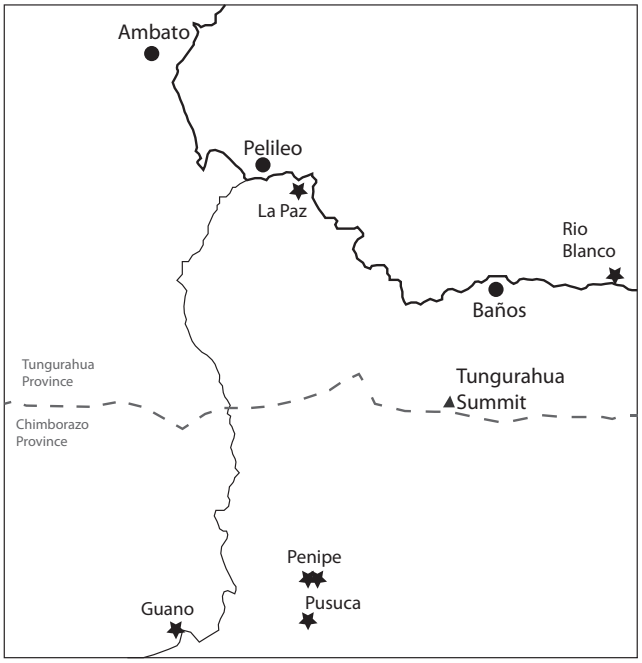

Fig. 2. Regional location, indicating resettlement sites (★).

While the town of Baños de Agua Santa has an economy centred on tourism, the rural communities are mostly engaged in agricultural production for local markets. People living in the

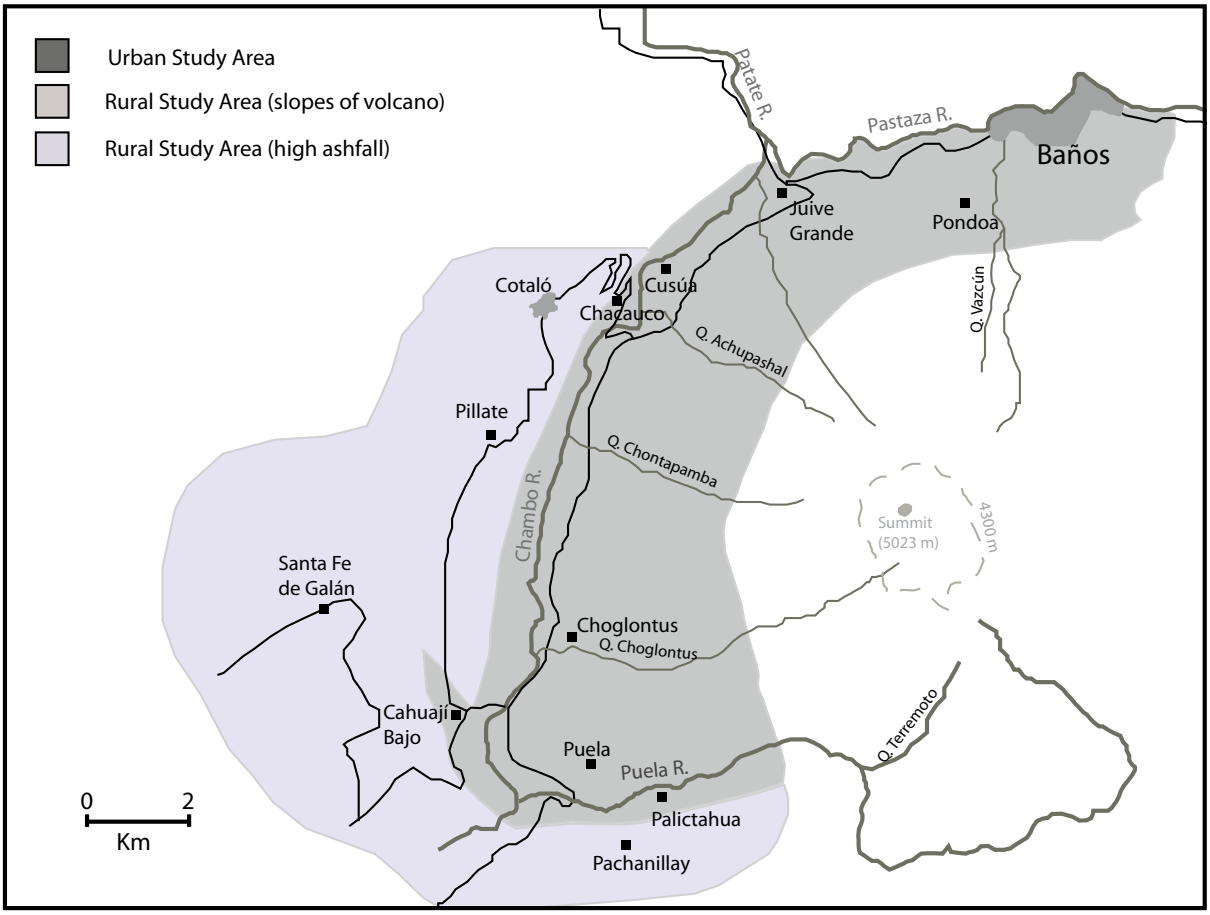

Fig. 1. Volcan Tungurahua and the study areas.

resettlement sites conduct different activities that range from agriculture, mostly in their fields situated on the slopes of the volcano, to private and public sector jobs in towns and cities in the region.

Although all four groups were included in the research, special attention was given to communities in the rural and resettlement areas given that most research in connection to Volcán Tungurahua has been conducted in urban centres, particularly in Baños, and also in Penipe to the south (Jones et al., 2013; Lane et al., 2003; Tobin and Whiteford, 2002a).

Data collection for this report was conducted using a range of qualitative methods that included semi-structured interviews, a questionnaire survey, conversations with local residents and participant observation.

Semi-structured interviews with a total of 67 people from rural communities, urban areas and resettlement sites were completed using a mix of snowball and purposive sampling methods. Most of the interviews were conducted on the second or third visit to each particular household or individual, which helped build trust and strengthened the quality and depth of the gathered information. The sample comprised women and men of different ages and social status, in order to gather in-depth information from multiple perspectives. Interviews were carried out in Spanish at people's homes or fields. Unless otherwise noted, all of the interviewee's names mentioned in this report have been anonymised by using pseudonyms.

To complement the main qualitative data, a survey questionnaire was also administered in 411 households randomly-selected across the four study groups (in Baños the sampling area was limited to the most high risk neighbourhood of the town at the mouth of the Vazcún valley). The survey questionnaire included information about employment, residence patterns, impact of volcanic hazards, recovery and other shocks to state assistance and evacuation.

During the main 4-month fieldwork period, a considerable amount of time was spent informally with local residents while they conducted their daily routines and activities. This included long conversations with different people while they were working on their fields. Coincidentally, during the fieldwork, there was a strong volcanic eruption, which allowed the researchers to experience first hand how different people and authorities respond during such crises.

4. Dynamics of impact and response

In this detailed empirical (results) section of the paper we trace out a series of changes that have occurred since 1999. These cover the volcanic hazards presented by Volcán Tungurahua and scientific/public understanding of them, impacts on economic livelihoods and people's response to those, changing settlement and residence patterns, and dynamics in provision of services and infrastructure.

4.1. Evolution of the physical hazards and scientific/public understanding

For the duration of the present eruptive phase of Tungurahua, typical patterns of volcanic activity have changed, and scientific understanding of typical precursory or 'warning' behaviour has also evolved.

This current unrest has been divided into distinct phases of eruptive style, associated with different forms of hazards (Bernard, 2013; Hall et al., 2015):

(i) Between 1999 and 2006 activity alternated between predominantly minor explosive (Strombolian) activity interspersed with relatively quiet intervals (Arellano et al., 2008);
(ii) 2006 marked the first episode of activity that generated pyroclastic density currents (July and August 2006) and more intense (sub-Plinan to Plinian) explosions, preceded by three months of comparatively intense unrest (Arellano et al., 2008);
(iii) From 2007present, eruptive activity initially involved longer episodes of mainly Strombolian activity, but between 2010 and the date of writing the eruptive episodes became shorter in duration but marked by more intense explosive activity (Hall et al., 2015; Mothes et al., 2015).

The provision of warnings was dependent on the longer term interpretation of the geophysical and geochemical signals associated with these events. The relatively uncertain outlook early in the eruptive phase meant that a much larger eruption (requiring evacuation) consistent with the historical record could not be ruled out. Before the current phaseTungurahua had experienced an 84 year pause in activity. Thus, there was no geophysical or geochemical record of activity in the modern era of volcano monitoring, and no indicators of surface activity existed against which new records could be interpreted. There is now a rich record of past data which are used to interpret new unrest and activity.

The more intense activity during and after 2006 was inferred to have arisen from the intrusion of a gas-rich basaltic andesite into the storage region within the volcano during seismic unrest (Myers et al., 2014; Samaniego et al., 2011). This activity has an association with both seismic and infrasonic precursor signals, as well as changing ground deformation patterns at the surface (Hall et al., 2013; Ruiz et al., 2006). Similar gas-rich pulses have continued from 2010 to the present. The more violent explosive activity is attributed to the interplay between this material and stiff viscous plugs developing at depth within the conduit which brings the material to the surface. The disruption and failure of these plugs happen with comparatively less warning (Hall et al., 2015).

Just as scientific understanding of the volcano has developed over the eruptive period, so local people's cognitive relation to the volcano has evolved since 1999. Since the reactivation, as people have experienced different magnitude explosions and types of hazards, knowledge about risk has been acquired through personal exposure. This experiential understanding has evolved in combination with training and information received from authorities and scientists during the eruptive period (Mothes et al., 2015). The importance of this knowledge is fundamental for those living in the slopes of the volcano. It has a practical but also symbolic value for the local residents, in that they view it as their own knowledge as much as that of the authorities and the scientists. The community-based *vigías* appear to have taken on a key role here, providing support and information to community members during emergencies as well as during periods of prolonged volcanic activity (Stone et al., 2014). The *vigías* are widely perceived by interviewees to play a significant part in helping people to maintain their livelihoods, particularly on the slopes of the volcano.

What is important to highlight here is that knowing more about the volcano's behaviour means being able to take independent decisions. As one interviewee noted:

> "When the volcano is about to erupt it behaves differently. The movement on the roof of my house is different. It is not like when it is only rumbling and it does not make any movements. But

when it is about to explode it shakes in a different way. This is why we are so confident, because we know what it is going to do." [Esperanza from Cusua]

Put in a different way, experience and knowledge is an important element of people's ability to cope with long term exposure to volcanic activity of the same magnitude as they have previously experienced. In this light, here we are not suggesting that local residents are 'safe' because they know more about the volcano. On the contrary, some of those interviewed have a clear awareness that it is a volcano with explosive behaviour that is capable of producing larger more dangerous eruptions that is not possible to predict. However, enhanced knowledge about the volcano enables people to make better informed decisions about their livelihoods and their wellbeing. How much risk and uncertainty they are willing to take differs from family to family and is mediated by opportunity elsewhere, attachment to land and the different emergency risk communication strategies put in place in the area.

4.2. Livelihood impacts and transitions

Changes in livelihoods that have taken place around Tungurahua since 1999 are naturally complex, reflecting wider economic transitions, as well as shocks other than volcanic eruptions. For example, the majority of survey respondents reported their household income being impacted over that period by fluctuations in market prices and losses from extreme weather events. Nevertheless, evidence from interviews indicates several aspects of livelihood change in the area that are associated to large extent with the effects of volcanic activity. Here we focus on the two key economic sectors of agriculture and tourism.

4.2.1. Farming

The land around Volcán Tungurahua used for agricultural activities is characterised by smallholding farms for crop cultivation and livestock production. Most of the farms are 1–10 ha in size (Chiriboga, 2009; Sword-Daniels et al., 2011:38). Due to the different altitude zones used for agricultural production in the influence area of the volcano, ranging from 1500 to 4000 m above sea level, a large variety of crops are produced, including maize, potatoes, beans, peas, onions, tomatoes, citrus fruits, apples, plums, tamarillo and sugar cane. Livestock production in the area focuses on dairy and beef cattle and there is also intensive chicken farming. In addition, most households own chickens, guinea pigs and pigs for own consumption, which are occasionally sold in the market (Valencia, 2010).

Since the reactivation of Tungurahua in 1999, the agricultural landscape of the area has undergone major changes, attributed by interviewees at least in part to the impacts of the eruptions. Although, agriculture remains the main activity of most households (the principal occupation for 60–70% of adults surveyed in the rural areas), the amount and types of crops and the numbers of livestock have decreased. Before 1999, the slopes adjacent to the volcano were considered one of the main sources of produce for the markets in Ambato and Riobamba (the capital cities of the Tungurahua and Chimborazo Provinces). Following the reactivation of the volcano, the mass evacuation of 1999, repeated ash fall and other hazards, such as lahars cutting transportation routes to markets, agricultural production has been repeatedly disrupted as has the supply of produce to the nearby markets (Chiriboga, 2009; Lane et al., 2003; Valencia, 2010).

Almost all the survey respondents in the rural sites and resettlements, where many livelihoods are still based on agriculture, noted that they had been repeatedly affected by ash. Up to 2015, an estimated 0.13 cubic km of tephra has been released by the volcano (Bustillos et al., 2016) from 12 major periods of activity and smaller explosions in intervening periods. In the largest eruption in August 2006, villages close to the volcano received 6 cm or more depth of ash deposits. The effect of ashfall on agriculture depends on the type of crop, its stage of maturity, the amount of ashfall and the type of ash – the last two of which vary across space and time according to the characteristics of the eruption and meteorological conditions (Ayris and Delmelle, 2012; Guevara et al., 2009). Since the reactivation of Volcán Tungurahua, local farmers who have lost crops and animals have gained significant knowledge about the different types of ash and their effects on different crops. Through experience and long-term exposure to volcanic ash, they have also been able to experiment and identify the crops that are able to resist ash fall (Valencia, 2010).

Farmers remaining on the slopes of Tungurahua have responded by focusing their agricultural production on maize and by harvesting it earlier. Instead of waiting for the maize to ripen and dry, farmers harvest and sell the crop when it is young (the longer a single crop is left to mature the more chance that crop could be lost or damaged by ashfall). This change was also permitted by an existing market demand for fresh maize. However, this adjustment itself brings problems. It denies the farmer both a source of subsistence and a source of seed for replanting, and obliges farmers to buy seed, which increases production costs and brings a risk of purchasing seed poorly adapted to the local climate.

A more fundamental change has taken place in the adjacent areas where farmers occupy higher-altitude land on the regular path of ash emissions due to prevailing winds around Tungurahua (Ramón, 2009). Over 84% of survey respondents in this population group stated that they 'always' or 'almost always' receive ashfall when the volcano generates ash plumes. According to the survey, there has been a significant shift in cash crop production from potato to the spring onion crop *Allium fistulosum*. In 1999, potato was the most important crop for 24% of households, while this figure had dropped to 10% in 2014. The equivalent figures for spring onion show a change from 5% to 27%. Interviewees explained that the shape of the spring onion plant's leaves make it less likely to retain ash and thereby less susceptible to ash damage than potato.

Since the reactivation of the volcano in 1999, farmers on the slopes of Volcán Tungurahua have also had to deal with the effects of volcanic hazards on their livestock (Mothes et al., 2015; Sword-Daniels et al., 2011; Valencia, 2010). In the survey, 66% of households that own animals in the rural study areas said that today they have fewer animals than in 1999. Three factors were identified as being the most important reasons why farmers have fewer livestock than before 1999: all are related to the volcano.

First, during the evacuation in 1999 many farmers were forced to sell their animals, as they did not have a place to take their livestock. As the possibility of a major eruption grew and authorities began to consider mass evacuation from the area, merchants from different parts of the country, travelled to the slopes of Tungurahua during September and October 1999 to buy livestock and other property. Concurrently, a severe political and economic crisis was under way in Ecuador which ended with the dollarization of the economy in 2000 (Lane et al., 2003; Tobin and Whiteford, 2002a). Hence, when people returned to their homes on the slopes of the volcano in early 2000 they found that livestock prices, now in dollars, had increased to such an extent that they were unable to replace their previous stocks. According to one interviewee:

"I left and sold my cows at 800, 600, 500 thousand sucres each. They were good cows with calves and producing milk. I used to live out of that before 1999. A few months later, when we started using dollars, the 10 million sucres that I went to exchange became 400 dollars. With that money, I went to buy a cow but they would cost 800, 1000, 1200 dollars each. That

is when, how can I put it... I was left in the street. The volcano hit us on the one side and the dollarization on the other."

[Victor from Manzano]

Second, and similarly as with crops, the most damaging hazard to livestock has been ash. The main problem caused by ash is that the feed, mostly grass fields, is contaminated with ash (Valencia, 2010). The general perspective among interviewees was that when cattle, sheep and guinea pigs eat this grass, they are prone to general illness, teeth abrasion, loss of weight and death. Reduced productivity and increased costs of caring for livestock were therefore cited as a major reason for destocking. The third factor mentioned by farmers is that land on the higher slopes of the volcano previously provided pasture for cows and sheep. Because of high risk from pyroclastic flows and ballistics, this has either been sold to the state or is simply not in use anymore. Having fewer animals means that today, local farmers, who have traditionally relied on selling livestock during times of need, have fewer assets to help them manage in an emergency, and are therefore more vulnerable to shocks and abrupt changes to the household economy.

4.2.2. Tourism

In Baños many of the commercial activities and services are geared towards tourism (MCPEC, 2011). The town's natural surroundings, hot springs and religious heritage draw foreign and national visitors all year round. Hotels, restaurants, transport companies and tourism agencies, constitute the main economic activity in Baños. By 1999 Baños was already among the top five tourist destinations in Ecuador (Lane et al., 2003).

The reactivation of Volcán Tungurahua had a direct impact on the tourism industry in Baños (Lane et al., 2003). Although tourists began to visit the town after the evacuation and return of its residents in 2000, the numbers were initially much lower than the 1999 level resulting in a slow recovery for this sector. However, by 2009 the volcano was being re-portrayed as a tourist attraction, and today Baños is once again one of the main destinations of foreign tourists visiting Ecuador.

Unlike Baños, where tourism and other activities have been able to recover and even prosper (MCPEC, 2011), residents of other areas surrounding the volcano who also depended on tourism have not been able to attract tourists as they did before 1999. For instance, Pondoa was used as a base for climbing Tungurahua, but climbing became illegal after the reactivation of the volcano, and this village lost the revenues it used to receive from guiding tourists and selling products to tourists. Similarly, the village of Puela used to receive many domestic tourists who visited restaurants that served traditional Ecuadorian food. After 1999 all restaurants in Puela closed and tourism revenue has collapsed throughout Penipe canton (Chiriboga, 2009).

4.3. Social disruption and settlement changes

Since the reactivation of Tungurahua in 1999, residence patterns and population numbers have dramatically changed in the areas surrounding the volcano. The events with the most lasting effect on residence patterns and population numbers have been the evacuation of more than 25,000 people from the area in 1999, and the 2006 eruption and subsequent evacuation and relocation of thousands of local residents. After these two events many of those who evacuated did not return to their homes and instead migrated to other provinces and other countries, particularly to Spain where many Ecuadorians from other areas moved during the economic crisis of 1999.

Again, different long-term effects can be observed in Baños and elsewhere. In 1999 Baños had a population of approximately 16,000 but by 2003 only 10,000 people had returned (Lane et al., 2003:5). However, by the time of the last population census carried out in 2010, the population in Baños had grown to 20,000 and had surpassed pre-1999 levels (INEC, 2010). There are many reasons for this, but evidence from interviews and other sources suggest that organisations and citizen groups who were at the forefront of the 'return' to Baños have been influential in negotiating with the authorities permits to conduct tourism activities in the area, and most of all, to be allowed to live in Baños (Tobin and Whiteford, 2002b; Vieira, 2003). Despite its location in designated risk zones on the official hazard exposure map, Baños' residents were successful in negotiating their return to their homes and re-establishing their activities in the period since January 2000.

Depopulation is most severe on the slopes of the volcano, where some of the communities have been partially or completely abandoned. People still live in most former villages but the activity and number of residents has dramatically decreased. The town of Puela, which is the head of a Parish, now has only 7 permanent residents (though Puela occupies the same hazard zone category as most of Baños). Choglontus, in the same parish, used to have 48 residents, but today there are only two families living permanently there, with between 6 and 8 people in total. Pondoa, which is close to Baños, used to have 46 families, but today only 20 live there permanently. Though precise figures are difficult to establish for reasons that follow, similar trends are possible to see across the communities. Many of those who have relocated have moved either to resettlement sites or elsewhere outside what is considered the high-risk zone.

Following the 2006 eruption, between 2007 and 2014 the Ecuadorian state and some non-profit organisations have built a number of resettlement areas in Tungurahua and Chimborazo Provinces. In total there are more than 750 homes located across the different relocation sites. However, many of those we interviewed who accepted houses in these locations have struggled to find jobs in the nearby towns or to resume agriculture outside the risk zone areas.

In fact, a pattern has emerged in which many 'relocated' households actively retain land and houses in the villages at the volcano. In both Tungurahua and Chimborazo provinces commuting between sites on a daily basis is part of the livelihood strategy of resettled households. For some families this has even become a way of expanding and diversifying their investment in agriculture. Many, in addition to working the land they owned or worked before 1999, have rented land in areas where local farmers have moved out, and are planting more crops, generally maize, to sell in the markets. Interviews suggest that it has been culturally and economically difficult for many of those who accepted the resettlement home to sustain a livelihood not based on agriculture:

"Even if the volcano gives us a lot of work, and affects us a lot, our source of pride is the work we put into our land. How are we going to abandon this land, if it is what maintains us? Even if they make us go to the resettlement in La Paz, they pressure us, but we do not have the necessary economic resources to live there. Over there, there is nothing for us to do..."

[Josefina from Chacauco]

However, commuting is costly and therefore some who work the land stay in their old homes at the volcano as they have limited funds to commute on a daily basis. As a result of this situation, many households have resolved to occupy both their new and old homes: different household members reside separately, some in the resettlements (and other areas outside the risk zones) and some in their homes at the volcano. For the households surveyed in the villages on the volcano's slopes almost 25% of the combined households' members only spend part of the week in the villages or never sleep in these houses.

The rationale for domiciliary division of households is particularly strong for those living in resettlements built by the Ministry of Housing in Penipe, Guano, La Paz and Rio Blanco. One of the conditions of acquiring a house in these locations is for their owners to live permanently in their new homes, and officials from the Ministry of Housing make unannounced visits to verify their occupation. Thus many families have decided to split their residence, with some family members living in the resettlement and others living in their homes close to their agricultural land. Several interviewees described the deleterious impact this has on family relations and especially on older children who commonly spend long periods without adult supervision in the resettlement sites where they go to school.

However, many of those who do not use their resettlement homes on a permanent basis argue that having these places makes them less vulnerable to volcanic crisis, as they are able to use them when the volcano enters moderate levels of activity, even before the authorities have called for an evacuation. .

4.4. Changing services and infrastructure

Parallel to population loss in most of the rural communities on the slopes of Tungurahua, service provision and infrastructure has been severely affected by volcanic activity through the mass evacuation in 1999, the long-term depopulation of the area, the identification of risk zones adjacent to the volcano, and regulations on state investment in infrastructure in high-risk areas. The most affected services have been schools and rural health posts, some of which disappeared immediately after the 1999 reactivation of the volcano and the mass evacuation of the local population. Houses, roads, drinking water systems, irrigation channels, community centres and electricity infrastructure have also been affected (Sword-Daniels et al., 2011).

While some schools temporarily closed after the 1999 evacuation, others never reopened. This was the case for the schools in Pondoa, Juive and Cusúa, which closed at the beginning of the school year in 1999 and never reopened. Another school in Chacauco closed after the 2006 eruption. Other recent school closures in Pachanillay and Pillate were less explicitly related to the volcano, and were indicated to be part of a nationwide project that aims to build or expand schools in centralised locations (MinEduc, 2012).

An important effect of school closure is that some of the students who live on the slopes of the volcano have to travel to schools in nearby towns on a daily basis or live part of the week in the resettlements sites from where schools are more easily accessed. This is the case for children from Cusúa who travel on a daily basis to Baños, and children from Chacauco who travel to Cotaló or stay at the resettlement of La Paz in the town of Pelileo. For many local residents, school closure also translates into losing one of the main centres of activity and cohesion for the community. A resident of Puela expressed profound concern over the possibility of school closure:

> "The school makes the village, it improves the village, but if it is gone, everything is finished, Puela will be buried. At least the school makes the Parish feel alive, but once it is finished, the entire Parish will be finished."
>
> [Irene from Anaba]

In terms of infrastructure, significant damage has been caused to roads, particularly the road connecting Baños to Penipe, which has been impacted by lahars and pyroclastic density currents on numerous occasions. This road serves many of the rural communities on the slopes of the volcano between Juive and Cahauaji and has been vital for their access to markets and other services. Although the local municipalities have made an effort to keep the road open most of the time, the state has not invested in improving the road in many years. Instead a new north-south trunk road has been built over to the west of the river Chambo, on land designated as at lower risk from volcanic hazards. Local government interviewees cited national policy provisions countering investment in areas identified as high risk, which subsequently became clarified in the legal Code on Territory, Autonomy and Decentralisation (COOTAD, 2014).

4.5. Synthesis

The foregoing pages have described a series of changes for the populations living around Tungurahua since the reactivation of the volcano in 1999. Together they have created complex effects on people's livelihoods and wellbeing: complex not just because hazard impacts and responses to risk may have positive and negative aspects for the same group over time, but also because the social, environmental and governance changes have overlaid and interacted with one another. This has created a highly dynamic situation in which the social outcomes of the long-lived eruptive phase have modified during its course, and in ways that may not necessarily match simple expectations of hazard impact.

4.6. Differences over time

Individual eruptive episodes of Tungurahua can each produce a set of impacts that unfold over time. The significant eruptive events that generate heavy ashfall, pyroclastic density currents, and ballistics can lead immediately to evacuation and direct damages to assets including homes, crops and livestock (Guevara et al., 2009; Mothes et al., 2015; Valencia, 2010). In the days and weeks following elevated eruptive activity, rainfall may create secondary hazards by mobilising volcanic debris and generating lahars that cut road communications. Any prolonged evacuation and disruption of livelihood activities starts to impact on income and wellbeing of the displaced population. In order to address loss of assets a household may need to go into debt or divert income from other uses. Hence repercussions can emerge and develop over time beyond the immediate impact of the event.

But impacts from a single eruption tell us only a small part of the story of change. Tungurahua's recent history is one common to many volcanoes in that the volcano has entered a prolonged active period following decades of quiescence. During this period there have been phases of higher and lower activity levels, punctuated by major eruptive events occurring with differing frequency. What is key to recognise here is that, though the hazards may emerge episodically, the impacts of being in a period of activity not only evolve beyond hazard events but can be cumulative in their effects to bring about larger social change. But, importantly, the nature of these dynamics is that they can also shift direction, in both positive and negative ways. Ultimately the impacts of an event may contribute to structural changes in society such as understandings of risk, adaptive activity, economic change, alteration in the pattern of services, and population resettlement. Fig. 3 summarises some of the changes observed during the course of Tungurahua's contemporary eruptive period, noting especially the importance of the 2006 eruption as a catalyst within the overall dynamic.

The figure indicates how changes broadly relate to the three phases of volcanic activity identified earlier. However, it should be underlined that this association is neither precise in timing nor deterministic in its operation. The behaviour of the volcano itself may provide the framing for these changes, but its hazard dynamics have only partial power to shape changes in risk because at the same time the long-duration eruptive period has generated

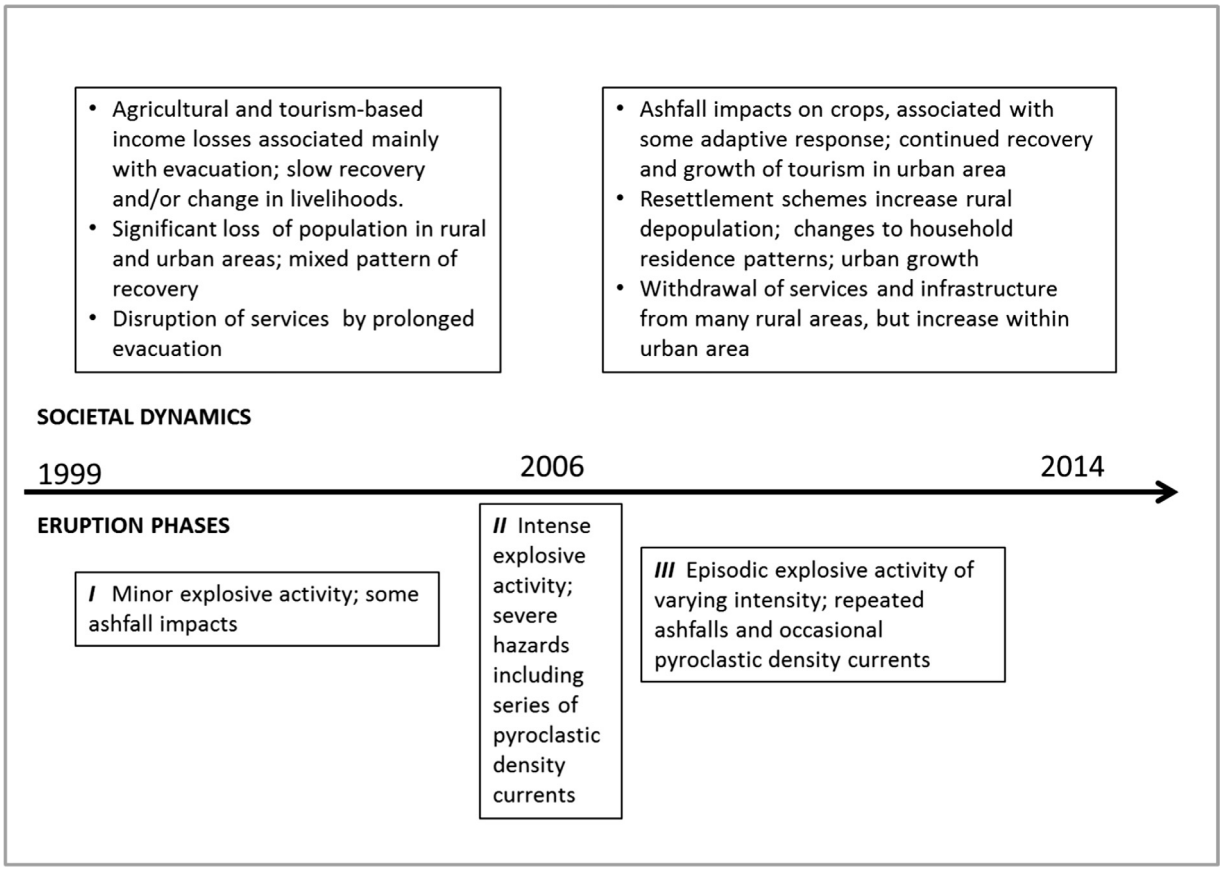

Fig. 3. Overview of physical and social dynamics.

changes in social vulnerability. And, as the following sub-section describes, these dynamics have played out differently for different population groups.

4.7. Differences over space and time

The complex nature of changes associated with Tungurahua's current active phase is evidenced especially by differences in the relative outcomes over time for three population groups: (a) villagers originally occupying the slopes of the volcano and those displaced from there to resettlement sites; (b) villagers in the adjacent high-ashfall zones; and (c) the urban population of Baños. (It should be recognised that there are of course differences within these groups – between specific communities, households and individuals – however, analysis of this finer scale of differentiation is beyond the scope of this present paper).

(a) The rural populations from the slopes of the volcano have faced severe hazard threat during eruptions and have experienced the most fundamental social changes and challenges since 1999. Their prolonged evacuation triggered by the 1999 reactivation led to disruption of livelihoods, loss of harvest, and a loss of livestock from which even today there appears only to have been partial recovery. Tourism in the rural areas, which contributed a minor share of the economy but was a major part of certain households' livelihood, took a severe impact from which it is also only recently starting to recover. The 2006 event then brought a further step-change in social impacts, causing direct deaths of people and livestock, some destruction of assets and disruption of communication. A depopulation trend for the villages increased, and those who remained began to experience loss of services such as schools and health posts, and investment in roads. Further eruptions may have accentuated this withdrawal of state support for the communities, although such change was also seemingly influenced by both national policy trends and local plans for land management. The introduction of resettlement programmes for most of these communities provided an opportunity for permanent refuge from the dangers presented by the volcano. Lives changed for the resettled households, in some cases providing new economic opportunities, but reducing their ready access to productive land and generating a high degree of social disruption. Some households retained their original properties and effectively became functionally divided between the old and new homes. Set against these problems, public knowledge about hazards and their precursors and improvements in the emergency communication process have risen over time, which, along with the ready accessibility of private refuge, may be reducing the threats to life for those who still reside on the flanks. However, two aspects of hazard counter this assumption: an unpredictability of eruptive behaviour in recent years, and the limited preparedness for a high VE event that would greatly increase the level of risk.

(b) Across the Rio Chambo, in the mountains to the west of the volcano, the story of vulnerability is more simple, but to large extent unreported. Since the reactivation of the volcano farming villages in this area have been repeatedly affected by ashfall hazards sufficient to damage crops and threaten the health and productivity of livestock. External assistance for the economic livelihood problems the ash has caused has been relatively low, but the farmers have

themselves tried to adapt to the recurrent hazard, including switching to crop varieties that are less susceptible to ash damage. This adaptation, essentially derived from experience accumulated over the active phase of the volcano, has been successful in terms of establishing a more secure revenue from crop production (Valencia, 2010). However, the shift has demanded extra work and investment, and does not nullify the continuing effect of ash on crops, as well as on livestock.

(c) As an urban settlement, the diversity of livelihoods and income levels in Baños makes it more difficult to generalise about vulnerability and its dynamics. Nevertheless there is a broad pattern of change that emerges for the town that is quite contrasting to the mixed outcomes evident for the other two population groups. Initially, following the prolonged 1999 evacuation, the tourism base of the economy suffered a major decline. Loss of revenue was high, and recovery of the tourism sector was again reversed by the severe hazards and transport disruptions of 2006, although for a briefer period. Some depopulation initially occurred through migration, but the numbers steadily rose again and the town has grown beyond its former size, together with its tourism economy, its services and its infrastructure. This increased development has taken place despite the location of the town in a risk zone – and it is important to note that a section of the town is classed in the same high risk category as the villages on the flanks. However, after 1999 people of Baños have generally been reluctant to evacuate, and this pattern of risk behaviour may prove to be an issue if the volcano moves into a more dangerous state.

All three populations have therefore seen shifts in impacts and in both social and physical vulnerability to hazards from eruptive events over time, including changes that are both negative and positive, but with a differing balance between the two. The triggers for these changes are a combination of physical and broadly socio-economic drivers. If we take the current active phase as a whole – viewing the post-1999 period of eruptive activity as constituting a single, complex 'hazard' – then we can see that vulnerability to the period cannot be read off simply as a static state. It has shifted and reconfigured during the course of 17 years.

Most striking in relative terms has been the contrasting fortunes for the rural communities and the urban community of Baños. The villages on the slopes of the volcano and in the high ashfall area continue to experience predominantly negative impacts from the eruptive phase. For the villages on the slopes, the post-1999 story has essentially been one of net withdrawal from the communities – of population, services and infrastructure, with the settlements articulated as at high-risk, and residents encouraged to resettle elsewhere. For the neighbouring high-ashfall communities, rather than them being actively targeted by the state's risk management mechanisms, they have received limited external support or recognition of their vulnerability. Both sets of communities have developed endogenous responses to the new challenges that reduce impacts on their livelihoods but that in turn may raise additional strains on wellbeing: functional division of households between original and resettlement sites on the one hand, and modification of crop type and increased workload on the other.

The Baños experience, by contrast, has turned out to be one of resurgent development combined with a partial negation of risk. Within several years of the reactivation of Tungurahua, the town was receiving continued public investment, economic development and population growth, despite much of it being located within designated risk zones. That the town's status is more significant in national economic and political terms is undoubtedly a factor in this: Baños is a major tourism centre, along a key highway connecting the highlands to the Amazon region. Here, also, a powerful endogenously-generated response to risk emerged in the aftermath of the 1999 evacuation, through which at least some people in the town have effectively articulated a demand to minimize disruption to its economic base, in part through resisting evacuation. Notably, some tourism businesses simultaneously promote graphic imagery of the volcano as an icon to attract visitors.

5. Conclusion

The research reported in this paper set out to study the dynamic aspects of risk and long-term effects of volcanic activity across different locations with distinct exposure to hazards around Volcán Tungurahua. It required analysis of dynamics throughout the period – in times of emergency and times of relative volcanic calmness – to unveil how impacts emerged and transformed during the course of time.

Tungurahua's period of activity frames the story of change, but tracking the associated changes in society reveals a process that is neither linear in terms of causation nor uniform in terms of its social effects. During the period since reactivation of the volcano in 1999, economic livelihoods, settlement and residence patterns, services and infrastructure, and risk communication and behaviour have all undergone shifts that have varied in space and time, while the physical nature of the hazard itself has also undergone change. A strong rural-urban differentiation can be seen in how the impacts of the eruptive phase have played out over time around the volcano, with clear contrast overall between the demographic decline or relative neglect of the agricultural villages and the resurgent development of the main urban area with its tourism-led economy (though the town remains at risk, especially from any additional elevation in the level of volcanic activity). This broad distinction reveals the importance of understanding social, economic and political changes associated both with the volcano and with wider societal changes, dynamics of the hazard itself and shifts in responses to risk.

We can view the changes as constituting a long-term dynamic that defies static (exposure-based) descriptions of vulnerability, echoing and extending the findings on trajectories of vulnerability for Montserrat reported in Hicks and Few (2015). At the time a volcanic hazard occurs it may seem that exposure is the key determinant of impact. Yet we know from a wide range of hazard types not only that exposure itself is in part socially determined but that the way impacts subsequently play out for those exposed or affected rests a great deal on access to resources and support (see e.g. Pelling, 2003, Eriksen et al., 2005, Chhotray and Few, 2012). This dimension of vulnerability takes on stronger significance when one looks at impacts through the lens of livelihoods and wellbeing of those affected by hazards, rather than solely focussing on the immediate physical threat to public safety. For long-duration hazards and crises, such as a long-lived eruptive phase, the social, economic and political dimensions to vulnerability take on even more prominent roles as both physical and social dynamics occurring within the hazard phase itself come into play. This means that identification of underlying vulnerability requires a longitudinal element of analysis, underlining the importance of tracking the unfolding trajectories of livelihoods and wellbeing, and analysing how these differ between social groups.

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References

Arellano, S., Hall, M.L., Samaniego, P., Le Pennec, J.L., Ruiz, G., Molina, I., Yepes, H., 2008. Degassing patterns of Tungurahua volcano, Ecuador, during the 1999–2006 eruptive period deduced from spectroscopic remote measurements of SO_2 emissions. J. Volcanological Geothermal Res. 176, 151–162.

Ayris, P.M., Delmelle, P., 2012. The immediate environmental effects of tephra emission. Bull. Vulcanol. 74, 1905–1936.

Bachri, S., Stötter, J., Monreal, M., Sartohadi, J., 2015. The calamity of eruptions, or an eruption of benefits? Mt. Bromo human–volcano system a case study of an open-risk perception. Nat. Hazards Earth Syst. Sci. 15, 277–290.

Bankoff, G., Frerks, G., Hilhorst, D., 2004. Mapping Vulnerability: Disasters. Development and People, Earthscan, London.

Bernard, B., 2013. Homemade ashmeter: a low-cost, high-efficiency solution to improve tephra field-data collection for contemporary explosive eruptions. J. Appl. Volcanol. 2 (1), 1–9.

Biggs, J., Mothes, P., Ruiz, M., Amelung, F., Dixon, T.H., Baker, S., Hong, S.-H., 2010. Stratovolcano growth by co-eruptive intrusion: the 2008 eruption of Tungurahua Ecuador. Geophys. Res. Lett. 37, 1–5.

Bustillos, J.A., Romero, J.E., Troncoso, L., Guevara, A.G., 2016. Tephra fall at Tungurahua Volcano (Ecuador)–1999-2014: an example of tephra accumulation from a long-lasting eruptive cycle. Geofísica Internacional 55, 55–67.

Cevallos, V.H., 2006. El Tungurahua riega muerte y destrucción, El Universo, 18/08/2006 ed, Guayaquil.

Chiriboga, E., 2009. Desarollo Territorial del cantón Penipe: previniendo las consecuencias de la activacíon del Volcán Tungurahua, Ecuador, experiencias significativas de desarrollo local frente a los riesgos de desasteres. Secretaría General de la Comunidad Andina, Lima.

Chhotray, V., Few, R., 2012. Post-disaster recovery and ongoing vulnerability: Ten years after the super-cyclone of 1999 in Orissa, India. Global Environ. Change 22 (3), 695–702.

COOTAD, 2014. Código Orgánico Territorial. Autonomía y Decentralización, Asamblea Nacional, Quito.

Cutter, S.L., 1996. Vulnerability to environmental hazards. Prog. Hum. Geogr. 20, 529–539.

De Bélizal, É., Lavigne, F., Gaillard, J.C., Granchera, D., Pratomoc, I., Komorowskid, J.-C., 2012. The 2007 eruption of Kelut volcano (East Java, Indonesia): phenomenology, crisis management and social response. Geomorphology 136 (1), 165–175.

Dove, M., 2008. Perception of volcanic eruption as agent of change on Merapi volcano, Central Java. J. Vulcanol. Geothermal Res. 172, 329–337.

Eriksen, S., Brown, K., Kelly, M., 2005. The dynamics of vulnerability: locating coping strategies in Kenya and Tanzania. Geogr. J. 171, 287–305.

Gaillard, J.-C., 2008. Alternative paradigms of volcanic risk perception: the case of Mt. Pinatubo in the Philippines. J. Vulcanol. Geothermal Res. 172, 315–328.

Gaillard, J.-C., Dibben, C.J., 2008. Volcanic risk perception and beyond. J. Volcanol. Geoth. Res. 172, 163–169.

Guevara, A., De la Torre, E., Criollo, E., Valencia, L., Gallegos, B., Mena, F., 2009. Evaluación de la influencia de la ceniza volcánica sobre suelos agrícolas aledaños al Volcán Tungurahua. Gestión del Riesgo: Revista Informativa de la Secretaria Técnica de Gestión de Riesgos 4 (6), 20–23.

Hall, M., Steele, A., Bernard, B., Mothes, P., Vallejo, S., Douillet, G., Ramon, P.A., Aguaiza, S., Ruiz, M., 2015. Sequential plug formation, desintegration by vulcanian explosions, and the generation of granular pyroclastic density currents at Tungurahua Volcano (2013–2014), Ecuador. J. Volcanol. Geoth. Res. 306, 90–103.

Hall, M., Steele, A., Mothes, P., Ruiz, M., 2013. Pyroclastic density currents (PDC) of the 16–17 August 2006 eruptions of Tungurahua volcano, Ecuador. J. Volcanol. Geoth. Res. 265, 78–93.

Hall, M.L., Robin, C., Beate, B., Mothes, P., Monzier, M., 1999. Tungurahua Volcano, Ecuador: structure, eruptive history, and hazards. J. Volcanol. Geoth. Res. 91, 1–21.

Hewitt, K., 1983. Interpretations of Calamity: from the Viewpoint of Human Ecology, Allen and Unwin, Boston.

Hicks, A., Few, R., 2015. Trajectories of social vulnerability during the Soufrière Hills volcanic crisis. J. Appl. Volcanol. 4 (10).

INEC, 2010. Censo de Población y Vivienda 2010. Statistical Database of the Instituto Nacional de Estadística y Censos.

Jones, E., Faas, A., Murphy, A., Tobin, G., Whiteford, L., McCarty, C., 2013. Cross-cultural and site-based influences on demographic, wellbeing, and social network predictions of risk perception in hazard and disaster settings in Ecuador and Mexico. Human Nature 24, 5–32.

Kelman, I., Mather, T.A., 2008. Living with volacanos: the sustainable livelihoods approach for volcano-related opportunities. J. Volcanol. Geoth. Res. 172, 189–198.

Lane, L., Tobin, G., Whiteford, L., 2003. Volcanic hazard or economic destitution: hard choices in Baños, Ecuador. Environ. Hazards 5, 23–34.

MCPEC, 2011. Agendas para la transformación productiva territorial: Provincia de Tungurahua, in: Ministerio de Coodinación de la Producción, E.y.C. (Ed.), Agendas para la Transformación Productiva Territorial. Ministerio de Coodinación de la Producción, Empleo y Competitividad, Quitoo.

Meia, E.T.W., Lavignea, F., Picquouta, A., de Bélizala, E., Brunsteina, D., Granchera, D., Sartohadib, J., Cholikc, N., Vidal, C., 2013. Lessons learned from the 2010 evacuations at Merapi volcano. J. Volcanol. Geoth. Res. 261, 348–365.

Mercer, J., Kelman, I., 2010. Living alongside a volcano in Baliau, Papua New Guinea. Disaster Prevent. Manage. 19 (4), 412–422.

MinEduc, 2012. Reordenamiento de la oferta educativa. Ministerio de Educación del Ecuador, Quito.

Mothes, P., Yepes, H., Hall, M.L., Ramon, P., Steele, A.L., Ruiz, M., 2015. The scientific-community interface over the fifteen-year eruptive episode of Tungurahua Volcano, Ecuador. J. Appl. Volcanol. 4 (9).

Myers, M.L., Geist, D.J., Rowe, M.C., Harpp, K.S., Wallace, P.J., Dufe, J., 2014. Replenishment of volatile-rich mafic magma into a degassed chamber drives mixing and eruption of Tungurahua volcano. Bull. Volcanol. 76 (872).

Paton, D., Millar, M., Johnston, D., 2001. Community resilience to volcanic hazard consequences. Nat. Hazards 24 (2), 157–169.

Pelling, M., 2003. The Vulnerability of Cities: Natural Disasters and Social Resilience. Earthscan, London.

Pierson, T., Wood, N., Driedger, C., 2014. Reducing risk from lahar hazards: concepts, case studies, and roles for scientists. J. Appl. Volcanol. 3 (16).

Ramón, P., 2009. Análisis retrospectivo de la evaluación de la amenaza, el monitoreo volcánico y la comunicación de la información durante las erupciones del año 2006 del Volcán Tungurahua. Ciencias y Gestión de la Tierra. Universidad de Nice, Nice.

Ruiz, M., Lees, J.M., Johnson, J.B., 2006. Source constraints of Tungurahua volcano explosion events. Bull. Volcanol. 68 (5), 480–490.

Samaniego, P., Le Pennec, J.L., Robin, C., Hidalgo, S., 2011. Petrological analysis of the pre-eruptive magmatic process prior to the 2006 explosive eruptions at Tungurahua volcano, Ecuador. J. Volcanol. Geoth. Res. 199, 69–84.

Stone, J., Barclay, J., Simmons, P., Cole, P.D., Loughlin, S., Ramón, P., Mothes, P., 2014. Risk reduction through community-based monitoring: the vigías of Tungurahua, Ecuador. J. Appl. Vulcanol. 3 (14).

Sword-Daniels, V., Wardman, J., Stewart, C., Wilson, T., Johnston, D., Rossetto, T., 2011. Infrastructure impacts, management and adaptation to eruptions at Volcán Tunguraha, Ecuador, 1999–2010. University of Canterbury. Geological Sciences.

Thorvaldsdóttir, S., Sigbjörnsson, R., 2015. Framing the 2010 Eyjafjallajökull volcanic eruption from a framing-disaster perspective. J. Natural Hazards 77, 1619–1653.

Tobin, G., Whiteford, L., 2002a. Community resilience and volcano hazard: the eruptions of Tungurahua and evacuation of the faldas in Ecuador. Disasters 26 (1), 28–48.

Tobin, G., Whiteford, L., 2002b. Economic ramifications of disaster: experiences of displaced persons on the slopes of Mount Tungurahua, Ecuador. Appl. Geography Conf., pp. 316–324.

Valencia, J., 2010. Sistematización de prácticas para la gestión del risgo por la erupción del Volcán Tungurahua. Food and Agriculture Organization of the United Nations, Rome.

Vieira, L., 2003. Erupciones del Tungurahua. OFFSET GRABA, Guayaquil.

Wilson, T., Stewart, C., Sword-Daniels, V., Leonard, G., Johnston, D., Cole, J., Wardman, J., Wilson, G., Barnard, S., 2012. Volcanic ash impacts on critical infrastructure. Physics and Chemistry of the Earth, Parts A/B/C 45–46, 5–23.

Wisner, B., 2004. Assessment of capability and vulnerability. In: Bankoff, G., Frerks, G., Hilhorst, D. (Eds.), Mapping Vulnerability: Disasters, Development and People. Earthscan, London, pp. 183–193.