Available online at www.sciencedirect.com
ScienceDirect
Journal of Volcanology and Geothermal Research 172 (2008) 189–198
Journal of volcanology and geothermal research
www.elsevier.com/locate/jvolgeores

Research paper

Living with volcanoes: The sustainable livelihoods approach for volcano-related opportunities

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Available online 16 January 2008

Abstract

Although the negative impacts of volcanism on society are well documented and accepted, many possible benefits from volcanoes are not always fully considered. This paper provides suggestions for understanding and implementing volcanoes' benefits by suggesting further application of existing risk management frameworks to volcanology: living with risk by using the sustainable livelihoods approach at the local level. This paper presents an overview bringing established paradigms into volcanic risk management where they are sometimes absent despite their advantages. The sustainable livelihoods approach is important in its application to volcanic scenarios in four ways:

(i) Understanding, communicating, and managing vulnerability and risk and local perceptions of vulnerability and risk beyond immediate threats to life.
(ii) Maximising the benefits to communities of their volcanic environment, especially during quiescent periods, without increasing vulnerability.
(iii) Managing crises.
(iv) Managing reconstruction and resettlement after a crisis.

An overview of case studies is provided showing how volcanic opportunities could be used for sustainable livelihoods. The approach of living with volcanic risks and benefits could be adopted and implemented as an integral part of changing perceptions of volcanoes and of managing volcano-related crisis and non-crisis situations. However, the sustainable livelihoods approach is not a panacea, so limitations are discussed along with why living near a volcano cannot solve all livelihood concerns. In particular, livelihood diversity and livelihood transferability to other locations assists in living with volcanoes.

Keywords: livelihood; community-based; disaster risk reduction; sustainability

1. Introduction: volcanoes as opportunities

The destructive forces of volcanoes are well-known, from the local to global levels. Examples of local volcano-related devastation are the 8 May 1902 pyroclastic density currents from Mount Pelée, Martinique which killed between 28 000 and 30 000 people in St. Pierre (Blong, 1984; de Boer and Sanders, 2002) and the 13 November 1985 lahars from Nevado del Ruiz, Colombia which killed approximately 25 000 people, mainly in Armero (Voight, 1990; Mileti et al., 1991). National and regional impacts are represented by the 1783–1784 eruptions of Laki, Iceland which killed 24% of Iceland's population along with thousands of deaths elsewhere in Europe (e.g., Witham and Oppenheimer, 2004). Global volcano-related impacts have been seen through weather alteration, such as the years following the 1815 Tambora, Indonesia eruption (e.g., de Boer and Sanders, 2002) and the 1991 Mount Pinatubo eruption in the Philippines (e.g., Self et al., 1996). Some global climatic impacts of volcanic activity are still disputed, as demonstrated by the debate over Toba's possible climate impacts (Oppenheimer, 2002). Global climatic impacts have likely happened in the past through episodes of basaltic flood volcanism (e.g., Self et al., 2006).

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doi:10.1016/j.jvolgeores.2007.12.007

So far, human fatalities linked to volcanoes have been relatively few. The death toll attributed to volcanoes since AD 1 is approximately 275 000 (Simkin et al., 2001; see also Tanguy et al., 1998). This toll is lower than the toll from single environmental hazard events such as the 1918–1919 flu pandemic which killed at least 20 million people (Noble, 1982; Taubenberger et al., 1997) and the 28 July 1976 Tangshan earthquake which killed over 500 000 people (Bolt, 1978; Hough, 2004). As with many disasters, volcano-related disasters also have mental health impacts (e.g., Ronan, 1996; Kokai et al., 2004). Volcanic disasters are likely to continue in the future with cities including Auckland, Tokyo, Naples, Quito, and Seattle located near active volcanoes. Each city contains a threatened population larger than the human death toll attributed to volcanoes since AD 1.

Becker et al. (2001), Haynes (2005), and Johnston et al. (1999) provide overviews of the volcanic risk perception literature. The studies tend to focus on threats and dangers from, or worries and concerns about, volcanoes along with possible preparation measures for countering dangers from and increasing resilience to volcanic threats. Data regarding perceptions of volcano-related benefits or opportunities are more limited. In many instances, positive aspects or positive perceptions might be minimal; for example, health consequences of gas emissions at Mount Aso, Japan (Nomura et al., 2004) or lahar and ash impacts on skiing at Mount Ruapehu, New Zealand from the perspective of ski resorts (Miller et al., 1999; Paton et al., 2001). Nevertheless, questions added to surveys could potentially cover expected benefits from taking the risks or whether the perceived benefits dominate decision-making (e.g., Starr and Whipple, 1980; Slovic, 2000).

Volcanoes' contributions to society are discussed in some literature. Duncan et al. (1981) note that "the Mount Etna region represents just under 7% of the land area of Sicily, yet contains over 20% of the population" (p. 165) and "Reasons for this intense human activity on the lower slopes of the volcano are not difficult to find" (p. 165), including Etna-related factors of fertile soils and a reliable freshwater supply. Robertson (1995) describes the agricultural, mining, quarrying, and tourism benefits to St. Vincent and the Grenadines of the country's active Soufrière Volcano. For Mount Ruapehu, New Zealand, Becker et al. (2001; see also Paton et al., 2001) balance the economic losses to ski resorts with the agricultural and tourism benefits along with the opportunity to gain volcanic eruption management experience which can be applied to other crisis management scenarios.

Sigurdsson et al. (2000, Part IX) summarise literature espousing volcanic benefits, covering geothermal resources, the agricultural benefits of volcanic soils, the use of volcanic materials such as basalt hammers and pumice in soap, and tourism along with the archaeological and artistic gains from volcanism. Volcanic processes also yield many precious metal and gemstone deposits (e.g., Erickson, 1988; Decker and Decker, 1991) along with beneficial landscapes, for instance the natural auditorium Auditorio Jameos del Agua on Lanzarote, Canary Islands, Spain.

This overview of the literature demonstrates that positive and negative perceptions of volcanoes and volcanism exist and that volcanoes' positive and negative impacts on society are documented and accepted. Yet it also shows that a gap exists in that all the possible benefits from volcanoes are not always fully considered, although many textbooks address aspects of volcanoes' benefits (e.g. Fisher et al., 1997; Schmincke, 2004). In contrast, approaches used in other fields promote and accrue benefits from potential environmental hazards and these approaches could be applied to volcanoes.

This paper contributes to understanding and implementing volcanoes' benefits by suggesting the application of existing risk management frameworks to volcanology: living with risk through sustainable livelihoods. New data are not presented. Instead, established development and sustainability approaches with respect to disaster risk reduction are connected with volcanic risk management as a contribution towards filling in the gap noted in the critique of the dominant discourse of volcanic risk management by Gaillard (2008-this issue).

2. Living with risk through sustainable livelihoods

2.1. Dealing with environmental hazards

As exemplified by Mount Etna in Italy (Duncan et al., 1981) and Mount Mayon in the Philippines (Heijmans, 2001), people have solid reasons for living near or on volcanoes, including good farmland and reliable water supplies (e.g., see also Uehara, 2005). This sometimes yields dangers, despite the rewards. To balance the dangers or potential dangers with the gains or potential gains from environmental hazards, including volcanoes, a four-option framework is presented here (Table 1) which has been developed based on the literature (e.g., Hewitt and Burton, 1971; Lewis, 1999; Wisner et al., 2004). Below we discuss some of the issues surrounding each of these four options.

2.1.1. Do nothing

The first option is to do nothing, accepting that volcanic disasters will happen. Depending on the volcano, this option might be more viable or less viable. Mount Etna in Italy and White Island in New Zealand frequently erupt, so doing nothing could lead to a disaster depending on the extent and characteristics of an eruption. In contrast, Edziza, Canada and Mount Jefferson, USA have not erupted in several centuries yet had Holocene eruptions (GVP, 2006). With the risk known and the willingness to accept the consequences of taking that risk, doing nothing could arguably be an appropriate choice for a certain timeframe.

Table 1
Options and consequences for dealing with environmental hazards

Option for dealing with environmental hazards	Main implications
1. Do nothing.	Disasters occur.
2. Protect society from hazards.	Not always feasible and leads to risk transference which augments vulnerability.
3. Avoid hazards.	Not always feasible and can exacerbate other problems, augmenting vulnerability.
4. Live with the hazards and risks.	Livelihoods are integrated with environmental threats and opportunities.

2.1.2. Protect society from volcanic hazards

The second option is to try to protect society from volcanic hazards, such as by strengthening roofs against tephra fall (e.g., Spence et al., 2005a) and building structural defences against lahars (e.g., Tayag and Punongbayan, 1994). Some instances are controversial such as pumping sea water onto lava which threatened to cut off Heimaey's harbour in 1973 (Chester, 1993; Fisher et al., 1997). Other examples are seen as more effective, such as diverting lava from Mount Etna, Italy (Barberi et al., 1993; Chester, 1993) or slowly degassing Lake Nyos, Cameroon to avert a repeat of the sudden gas release which killed over 1700 people in 1986 (e.g., JVGR, 1989). In the Cameroon case, a hazard-altering system was selected as being more effective than other approaches; for example, (i) moving the population from their livelihoods in the gas-vulnerable areas, which could expose them to other hazards and (ii) relying on a tight timeframe for a gas release warning system.

This protection option is not always feasible. Not all gas releases could be averted through degassing. Large pyroclastic flows and lava flows are challenging to stop or even to redirect, although structures could be designed to afford some level of protection to these hazards (Blong, 1984). More fundamental concerns exist which are documented more for floods than for volcanic phenomena, but the discussion applies directly to volcanoes due to lahars and volcano-related floods including jökulhlaups.

Protection which increases risk over the long-term has been illustrated for major floods such as in the Mississippi basin in 1993 (Mileti et al., 1999) and in flood-vulnerable areas such as London, UK (Ward and Smith, 1998). Criss and Shock (2001) document "flood enhancement through flood control" for American rivers. Fordham (1999) and Kelman (2001) further demonstrate how the protective approach for floods, through reliance on structural defences, encourages overconfident settlement in flood-prone locations while discouraging adequate precautions against floods. Other critiques of reliance on structural measures are that they are frequently one of the most expensive options, they tend to be implemented in a top-down manner which contravenes the local approach to living with risk, and they do not address the root causes of the vulnerabilities which the extreme hazard event exposes (see also Hewitt, 1983; Lewis, 1999; Wisner et al., 2004).

The explanation from this work is that hydrological engineering frequently seeks to control river flow including dampening out flow extremes, such as from spring snow melt or the dry season. Riverside inhabitants thus tend to become inured to the absence of regular flood and drought cycles. Because few extremes occur, mitigation and preparedness activities tend to lapse. There is decreased awareness of the potential flood and drought hazards, decreased understanding of how to predict and react to floods and droughts, and decreased ability to cope with floods and droughts. Eventually, a large flood or drought event must occur, yielding damage which is far greater than would have occurred if the affected community were used to regular, smaller-scale floods and droughts. This phenomenon is termed "risk transference" (Etkin, 1999) because the risk is transferred onto future events, yielding potential short-term gain for definite long-term pain.

Reliance on protective measures for flood and non-flood volcanic hazards could similarly lead to risk transference and a dangerous false sense of security without tackling the root causes of vulnerability. Leone and Gaillard (1999), for instance, detail the challenges with the technocratic approach to addressing Pinatubo lahars (but see also Rodolfo, 1995).

2.1.3. Avoid volcanic hazards

The third option is to avoid volcanic hazards, but that is not always feasible. As noted in Section 1, volcanic impacts are frequently non-local and are sometimes global, hence all places on earth have the potential for being severely affected by volcanic activity. Additionally, with global population increasing, constraints on land and resources frequently leave little option other than to inhabit areas potentially affected by volcanic hazards.

Moreover, avoiding volcanic hazards could cause further problems. First, as further described throughout this paper, volcanic activity can yield advantages which might outweigh the problems, although conclusions from analysing the trade-offs frequently depend on the perspective selected for decision-making. Second, moving away from volcanoes could yield other concerns, perhaps exposure to other environmental hazards or perhaps social challenges. After Montserrat's volcano started erupting in 1995, some Montserratian families moved to England in order to ensure that their children would still have appropriate schooling, only to be disappointed at the low standard of education in English schools which they felt would harm their children's future prospects (Windrass and Nunes, 2003). Montserratians were also shocked at the level of crime risk to which they were exposed on neighbouring Caribbean islands (Haynes, 2005).

2.1.4. Live with volcanic risk

The fourth option, living with risk (e.g., UNISDR, 2004), means accepting that environmental hazards are a usual part of life and productive livelihoods. Rather than "environmental hazards", perhaps they should be termed "environmental events" or "environmental phenomena".

For example, many cities in Asia's deserts are sited near earthquake faults because the tectonic activity makes freshwater available (Jackson, 2001). Farmers in the African Sahel use "flood retreat farming" in which seeds are planted in floodplains as annual floodwaters recede in order to capture the moisture before it evaporates (Matlock and Cockrum, 1976). Rather than just surviving in the face of adversity or reacting to extreme events when they occur, living with risk means creating and maintaining habitats and livelihoods by using available resources without destroying those resources. These resources include environmental hazards, which might thereby become less of a danger and more integrated into day-to-day life and livelihoods. For volcanoes, not all potential hazards can be resources and not all resources can have their dangers reduced, but this paper highlights some which could be used.

A component of living with risk is localising disaster risk reduction. Disaster risk reduction, including pre-disaster activities such as preparedness and mitigation and post-disaster activities such as response and recovery, is best achieved at the local level with community involvement (e.g., Lewis, 1999; Wisner et al., 2004). Top-down guidance is frequently helpful, such as through legislation or for providing resources. Nonetheless, the most successful outcomes are seen with broad support and action from local residents, rather than relying on external specialists or interventions.

Examples of community involvement and leadership for disaster risk reduction are Townwatch (Ogawa et al., 2005), Community Fire Units (Lowe et al., in press), and Future Search (Mitchell, 2006). Even for post-disaster activities, many manuals suggest that individuals and families must be prepared to take care of themselves for at least 72 h without external assistance (e.g., EMA, 2003; FEMA, 2004) although recent discussions with practitioners have suggested 1–2 weeks or more. Community teams are increasingly being trained for such purposes; for example, Community Emergency Response Teams in the USA (Simpson, 2001).

Although volcanoes' long dormancy periods and significant uncertainties about eruptive pathways might make community interest in disaster risk reduction wane, few communities are vulnerable to only volcanic hazards. Day-to-day and year-to-year threats could be used to establish and maintain community-based initiatives which would also be useful when volcanic threats manifest. The result is localising living with all disaster risks.

2.2. The sustainable livelihoods approach

To apply in practice the principles of localising living with risk, the sustainable livelihoods approach has often been adopted for disaster risk reduction and it applies to volcanoes too. Chambers and Conway (1992) propose:

> "A livelihood comprises the capabilities, assets (stores, resources, claims and access) and activities required for a means of living: a livelihood is sustainable which can cope with and recover from stress and shocks, maintain or enhance its capabilities and assets, and provide sustainable livelihood opportunities for the next generation; and which contributes net benefits to other livelihoods at the local and global levels and in the short and long term."

Despite some circularity and the absence of explicit mention of social networks, this definition is useful operationally. The ideas can be summarised by defining sustainable livelihoods to be creating and maintaining between generations means of individual and community living which are flexible, safe, and healthy.

The sustainable livelihoods approach, sometimes termed the livelihoods approach or the livelihoods security approach, frames problems from the perspective of focusing on livelihoods and livelihood indicators (Chambers and Conway, 1992; Chambers, 1995). Applications include the contribution of human rights to supporting sustainable livelihoods (Moser et al., 2001) and adapting the approach for specific regions such as Pacific islands (Cahn, 2002).

Cannon et al. (2003) and Twigg (2004) are examples of using the sustainable livelihoods approach for disaster risk reduction, connected to the living with risk approach described in Section 2.1.4. Two specific examples of sectors which integrate the sustainable livelihoods approach into their programs are:

1. Refugee shelter, termed "transitional settlement and shelter" (Corsellis and Vitale, 2005).
2. Warning systems (Carney et al., 1999; Turton, 2000).

Although not named as livelihoods, these themes are present in earlier literature; for instance, Burton et al.'s (1978) statement that "people not only locate in areas of high, recurrent natural hazard; they survive and prosper there" (p. 4).

Application of the sustainable livelihoods approach to volcanoes has been more limited in the literature, although the concepts are applied without formally mentioning the approach (Table 2). As further support for applying the sustainable livelihoods approach to volcanoes, Mileti et al. (1991) describe how the lack of livelihoods prior to 1985 lahars from Nevado del Ruiz, Colombia exacerbated poverty following post-lahar displacement. Supporting livelihoods before a crisis assists in managing a crisis. For Pinatubo, Gaillard (2006) notes that livelihood diversification assisted community recovery while Gaillard and Leone (2000) emphasise livelihood adaptation as a successful coping strategy for the Aeta, an indigenous group. Many indigenous peoples around the world have varying levels of "positiveness" in the manner in which they view volcanoes and potential gains from living on or near a volcano. Scope exists for formal application of the sustainable livelihoods

Table 2
Examples of studies using livelihoods concepts for volcanic risk management (see also Section 1)

Studies	Location	Livelihoods material
Crittenden (2001)	Bacolor, the Philippines	Residents made efforts to keep the community functioning despite lahar inundations following the 1991 Pinatubo eruption.
Dibben and Chester (1999)	Furnas, Saõ Miguel, Azores, Portugal	Livelihoods were part of analysing human vulnerability to the area's volcanic threats.
Gaillard (2003)	Mount Pinatubo, the Philippines.	Evacuees returned to their homes for agriculture-related livelihoods after the 1991 eruption.
Glaser (1996)	Global	Volcanic effects on agricultural livelihoods are discussed along with agricultural livelihoods exposing people to volcano-related health effects.
Lane et al. (2003) Tobin and Whiteford (2006)	Mount Tungurahua, Ecuador	After being evacuated due to a volcanic threat in 1999, many residents returned against government advice to pursue their tourism-related livelihoods.
Rozdilsky (2001)	Montserrat	Concepts of sustainability are discussed incorporating "economic and social resiliency" (p. 66) but with only passing reference to livelihoods.

approach in order to implement "living with volcanic risks"—and volcanic benefits.

This paper does so, providing an overview of case studies where volcano-related opportunities could be used for sustainable livelihoods. These examples illustrate that the local approach of living with volcanic risks and benefits could be adopted and implemented as part of changing perceptions of volcanoes and of "living with volcanoes". We suggest that the sustainable livelihoods approach is important in its application to volcanic scenarios in four ways:

(i) Understanding, communicating, and managing vulnerability and risk and local perceptions of vulnerability and risk beyond immediate threats to life.
(ii) Maximising the benefits to communities of their volcanic environment, especially during quiescent periods, without increasing vulnerability.
(iii) Managing crises.
(iv) Managing reconstruction and resettlement after a crisis.

These four points are now illustrated in practice.

3. Applying the sustainable livelihoods approach

3.1. Managing vulnerability and risk

The first application of the sustainable livelihoods approach to volcanoes is understanding, communicating, and managing vulnerability and risk along with local perceptions of vulnerability and risk beyond immediate threats to life. Newhall and Hoblitt (2002), for instance, calculate individual risk to life for volcanic scenarios, noting that estimating "community risk (probable losses of lives and property in a specified area) is beyond the scope of this paper". Spence et al. (2005a,b) detail methods for calculating community risk from individual lives and properties. Such studies are an essential component of volcanic disaster risk reduction, but the sustainable livelihoods approach introduces an equally essential component.

Cronin et al. (2004a,b) illustrate how to bring livelihoods into pre-eruption vulnerability and risk management by using Participatory Rural Appraisal approaches to understand how small island communities wish to view and manage volcanic disaster risk reduction. Traditional and scientific knowledge are combined yielding insights into how nearby volcanoes assist and threaten the communities and how the communities could be more involved in the vulnerability and risk management. The process effectively examines living with volcanic risk based on decisions at the local level.

Livelihoods are explicitly considered. Cronin et al. (2004b, p. 108) note "the sites of greatest hazard, primarily from pyroclastic flows and lahars…support the most productive soils and agriculture, the gentlest island terrain and the highest population densities." Understanding the livelihood reasons for vulnerability is an essential step towards managing that vulnerability—as noted by Cronin et al. (2004b) by having one of their work's objectives being to reduce livelihood vulnerability. Cronin et al. (2004a) describe the challenge of balancing livestock survival with protecting subsistence gardens during an evacuation. Both are essential livelihoods in the area examined. Recognising the roles of each livelihood, trying to maintain those roles for post-eruption return, and reducing the livelihoods' vulnerabilities in different evacuation scenarios introduces the sustainable livelihoods approach into volcanic disaster risk reduction.

Thinking ahead of the event ensures that (i) local livelihoods are preserved, meaning that the population has an easier post-disaster recovery except for cases of extreme destruction and (ii) the affected population is confident that their livelihoods will remain, so they will be more willing to shelter and evacuate without putting their lives at risk for the sake of livelihoods. The population is better able to live with the risk knowing that their livelihoods are being considered, particularly since many decisions were made at the local level with outside guidance where requested.

Examples of syn-eruption consideration of livelihoods are the attempts to prevent lava blocking Heimaey's harbour (Chester 1993; Fisher et al., 1997) and balancing ski access to Ruapehu during active episodes and especially the continuing lahar threat (Miller et al., 1999; Becker et al., 2001). In these instances, it was decided that saving only lives without considering livelihoods was unacceptable. Risk and vulnerability have been managed to achieve a balance between lives and livelihoods: living with volcanic risk.

3.2. Maximising community benefits sustainably

The second application of the sustainable livelihoods approach to volcanoes is maximising the benefits to communities of their volcanic environment, especially during quiescent periods, while decreasing vulnerability. These suggestions are not for supporting economic growth, because "sustainable economic growth" is infeasible (e.g., see Bartlett, 2004 for mathematical and environmental justifications of this statement). Instead, they support the sustainable livelihoods approach and suggest, not recommend, further options. All the provisos should be considered before implementing any of these options in order to avoid vulnerability increasing, especially over the long-term.

The livelihood benefits of volcanoes discussed in Sections 1 and 2 can be placed into three main categories: physical resources (e.g., mining), energy resources (e.g., heat), and social resources (e.g., tourism). In explicitly placing long-term issues and inter-generational sustainability above short-term economic gain, the sustainable livelihoods approach accepts the limitations of many livelihoods and acknowledges the lack of realism of some suggested livelihoods futures. The challenges of exploiting the full potential of volcanic environments are examined by looking at the illustrative examples of mining and energy.

Although it may require hydrothermal alteration and erosion over long time scales to form and expose them, volcanoes play an important role in the formation of precious metal ores (e.g., Francis, 1976; Fisher et al., 1997). Despite the possible economic gains, mining in volcanic regions presents challenges for the sustainable livelihoods approach in that it yields relatively short-

term spikes in local income which are rarely sustainable and which often damage the local society and environment, inhibiting other livelihoods.

Thinking more speculatively about volcanoes as a future resource particularly in the context of terrestrial reserves of precious metals becoming increasingly depleted, persistently active volcanoes continuously emit precious metals in their gases and hydrothermal fluids, although it is difficult at present to exploit them economically. For example, the atmospheric flux of copper from volcanoes is estimated at 1–22 Gg/yr (Mather et al., 2003) compared to global copper mining production of 13.63 Tg in 2003 (Mbendi, 2004) and anthropogenic emissions to the atmosphere in 1983 of 35 Gg (median value; Nriagu, 1989). Could these persistent emissions yield viable livelihoods in the future? The technology does not exist today and an additional risk factor is that if the volcano's activity increases, the mining resources, equipment, and expected income could be jeopardised.

As well, dangers might result from mining. Davies et al. (2007) propose that the 29 May 2006 eruption of a "mud volcano" in eastern Java, which was highly destructive to local livelihoods, resulted from borehole drilling. As well, the external financing, expertise, and equipment often needed for mining might not be conducive to localisation and other community-based risk-related decision-making.

Similarly, volcanic areas can be important sources of energy for local use, but more extensive application tends to be stymied. For rotating turbines to produce electricity for transmission over large distances, high pressure and non-corrosive steam sources are most useful. Many volcanic gas emissions do not fit these criteria. Moreover, locations with significant potential for electricity generation are often remote from large areas of population, for instance the El Tatio geyser field in Chile, and using those areas for energy can compromise their tourism potential (Francis, 1976). However, livelihoods can be combined to turn the energy source into a tourist attraction, such as at New Zealand's Wairakei Geothermal Power Station. Alternatively, the energy potential could be used locally only, to power the tourist facilities—a true localisation approach to living with volcanic risk.

Yet most volcanic thermal energy is not released as hot steam suitable for use. In theory, the total heat energy dissipated by the 1952 Kīlauea, Hawai'i eruption could have provided enough energy to supply 40% of the power requirements of the entire USA during the eruption's timeframe. Despite some dramatic proposals for how to tap such energy (Francis, 1976), it is not currently feasible (see also Wright and Flynn, 2004). Furthermore, relying on energy from volcanic sources could increase the vulnerability of communities to volcanic eruptions if the energy infrastructure were damaged by an eruption.

3.3. Managing crises

The third application of the sustainable livelihoods approach to volcanoes is managing crises. Emergency response and humanitarian relief are adopting the sustainable livelihoods approach, such as for the sectors of transitional settlement and shelter (Corsellis and Vitale, 2005) and food security (Young et al., 2001), by ensuring that these sectors' programs support livelihoods as well as directly saving lives. The consequence is that dignity and self-respect of evacuees are maintained while reducing the chance of developing a culture of dependency. More durable reconstruction and resettlement are therefore promoted from the beginning of the crisis. Living with the risk has been achieved because the volcanic crisis did not become a volcanic disaster.

3.4. Managing reconstruction and resettlement

The fourth application of the sustainable livelihoods approach to volcanoes is managing reconstruction and/or resettlement after a volcanic crisis. Following the 1991 Pinatubo eruption, Gaillard (2006) noted for the Aeta that a predominant factor in their capability to overcome disaster was diversity of pre-disaster livelihoods. Where that diversity could not be maintained, viable resettlement was difficult. Seitz (1998, p. 82) states that "The main problem remains earning a living" regarding the Aeta's resettlement. Aeta lives were saved by timely evacuation, but those lives were put at risk again by not fully considering livelihoods in resettlement. The sustainable livelihoods approach ensures that lives are not lost through poorly-managed post-eruption activities.

Montserrat provides another example. Resettlement in the island's north, away from the most dangerous zones due to volcanic activity, included housing construction which was completed without sufficient attention to local culture, other hazards, or livelihoods (Pattullo, 2000; Rozdilsky, 2001; Mitchell, 2002; Rozdilsky, 2002; Mitchell, 2006). The resettlement saved lives, but did not adopt a local approach to living with risk. Long-term problems emerged which the sustainable livelihoods approach might have prevented.

3.5. Disadvantages

The examples here show the importance of the sustainable livelihoods approach to volcanic disaster risk reduction, yet they do not display the entire picture. For example, volcano-related evacuations have sometimes forced people to choose between staying in poorly-managed shelters with no livelihood prospects and returning home to their livelihoods despite a high risk of injury or death from the volcano. This issue was witnessed in Montserrat, exacerbated by economic structures which encouraged farming in the exclusion zone (Pattullo, 2000), and around Tungurahua volcano in Ecuador (Tobin and Whiteford, 2006). Arguably, such behaviour is each individual's and community's choice and they should be permitted to make that choice as long as they know and accept the consequences of their decision. The challenge is ensuring that people do understand the risks and are making informed choices—while having adequate options which means proper treatment, shelters, and livelihood opportunities in the evacuee settlement. Loughlin et al. (2002) discuss this point for Montserrat while Corsellis and Vitale (2005) discuss it for transitional settlement and shelter in general.

Newhall and Hoblitt (2002) seek to overcome some risk communication difficulties by providing their Table 5 (p. 16) listing annual risks of death by age group, occupation, disease, and accidents. These annual risks of death may be compared to the annual risk of death from certain behaviour during a volcanic crisis, such as evacuating to different locations or not evacuating. This approach makes the risk somewhat subjective and relative to each person's experience and livelihoods which is a boon for communication purposes, but which could have unintended consequences in addition to the provisos detailed by Newhall and Hoblitt (2002, pp. 17–18).

For example, if a person is informed that the risk is so high that it is equivalent to smoking two packs of cigarettes a day, s/he could respond that s/he smokes three packs of cigarettes a day and feels fine, so the volcano could not be too dangerous. Similarly, an occupational comparison such as logging which Newhall and Hoblitt (2002, p. 16) term "high-risk" could produce a response that several relatives have that occupation and have never had problems, so the volcano could not be too dangerous. These responses are not necessarily detrimental, but could yield risk-related behaviour different from the expected reaction. Focusing on livelihoods and making the message locally relevant might not convey the intended risk message; however, "living with risk" objectives have nonetheless been achieved.

The sustainable livelihoods approach is necessary for volcanic disaster risk reduction, but it is not a panacea and it might not be sufficient for all circumstances.

4. Towards reducing volcanic impacts

This paper shows that considering livelihoods is important in successful volcanic disaster risk reduction through the four ways discussed because they contribute to living with volcanic risk based on a localised approach. Living with volcanoes at the local level requires changes of perception and action resulting in advantages for volcanic disaster risk reduction, although potential disadvantages can also occur. With the local population involved in monitoring, understanding, communicating, making decisions, and taking responsibility for aspects of volcanic disaster risk reduction—with external guidance and assistance where requested—disadvantages can be minimised.

Three points emerge from applying the sustainable livelihoods approach to localised living with volcanic risk. First, not all livelihoods near volcanoes are volcano-related. Productive agriculture could be due to regular, slow-moving floodwaters rather than volcanic deposits—or due to a combination of factors. Landscape resources such as harbours can exist as much due to erosion processes as due to volcanic building processes. The sustainable livelihoods approach encompasses all livelihoods without necessarily identifying each livelihood's origin.

Second, not all volcanic activity necessarily yields livelihoods or livelihoods which should be encouraged. The sustainable livelihoods approach is essential but it complements, not supplants, individual and community risk analyses. Tourism and research activities in active craters, for example, tend to be discouraged in volcanology (IAVCEI, 1994, 1999). That level of risk taking could also make the livelihood vulnerable. For example, if tourists were killed by a volcano, the area's tourism could suffer.

The sustainable livelihoods approach also entails livelihood diversity and transferability. Relying on only volcanic processes for livelihoods creates vulnerability in (i) resettlement cases, as implied in Section 3.1 in the statement "the population has an easier post-disaster recovery except for cases of extreme destruction" and (ii) cases where needed volcanic processes diminish or otherwise change. Communities should seek livelihoods beyond the volcano to ensure livelihood diversity and transferability of livelihoods to different locations.

Third, resource availability does not always imply resource use. Mining could be deemed too externally-dependent or too environmentally and socially destructive to be worthwhile pursuing. As well, many indigenous cultures place higher value on preserving land than they would on income derived from possibly sacrilegious activities such as mining and tours. In volcano-related attitudes and values mirrored amongst other indigenous peoples from Réunion to Hawai'i, the Aeta around Pinatubo believed that the mountain was their divine protector. Pinatubo's 1991 volcanic activity indicated that the Aeta, or perhaps non-Aeta loggers and geothermal energy explorers, had angered the volcano (Goertzen, 1991). To the Aeta, certain livelihoods would not have been acceptable while they were living on the volcano's slopes. Some societal needs transcend individual risk, community risk, and livelihoods.

Communities face non-volcanic hazards too and linking wider disaster risk reduction with volcanic disaster risk reduction would be needed. For example, as witnessed by one of the authors (IK) in 2006, a school near one of Ecuador's volcanoes does an exemplary job of educating its pupils and its community about volcano-related hazards, warning signs, and appropriate behaviour, yet some of the school's design features could have better accounted for fire risk. The all-hazards approach—considering all hazards for disaster risk reduction—along with an all-vulnerabilities approach—trying to reduce overall vulnerability rather than only one component (see also Lewis, 1999; Wisner et al., 2004)—should be implemented for volcanic disaster risk reduction.

The all-hazards and all-vulnerabilities approach means that living near a volcano and living with volcanic risk does not necessarily dominate a community or its livelihoods. Volcanic risk perception and communication studies (referenced throughout this paper and this special issue) show that not everyone living by a volcano understands or accepts the actual or potential implications of the volcano. That statement has usually focused on volcanic risks, but this paper has shown that it also includes volcanic benefits through livelihoods, especially when balancing the importance of life versus livelihoods (see also Gaillard, 2008-this issue). Risk and disasters emerge from volcanoes, but livelihood opportunities emerge from volcanoes too. Those opportunities form an integral part of volcanic disaster risk reduction. Promoting livelihoods prior to a disaster and explicitly considering livelihoods within disaster risk reduction and crisis management plans assist when a threat manifests, helping to prevent a crisis from becoming a disaster.

Yet despite volcanic benefits, living with volcanic risk is not always feasible and volcanoes should not be relied on for livelihoods without careful consideration of potential drawbacks. Other approaches—do nothing, protect, and avoid—should be considered, as well as appropriate combinations of the approaches for different combinations of volcanic risks, volcanic benefits, and societal desires.

Acknowledgements

The National Center for Atmospheric Research is supported by the National Science Foundation. TM is funded by the Royal Society. David Pyle, Tom Mitchell, Kat Haynes, and Kate Donovan provided useful discussion. Terry Cannon, Linda Whiteford, an anonymous reviewer, and the editors provided helpful comments.

References

Barberi, F., Carapezza, M.L., Valenza, M., Villari, L., 1993. The control of lava flow during the 1991–1992 eruption of Mt. Etna. Journal of Volcanology and Geothermal Research 56 (1–2), 1–34.

Bartlett, A.A., 2004. The Essential Exponential! University of Nebraska, Lincoln, Nebraska.

Becker, J., Smith, R., Johnston, D., Munro, A., 2001. Effects of the 1995–1996 Ruapehu eruptions on communities in central North Island, New Zealand, and people's perceptions of volcanic hazards after the event. Australasian Journal of Disaster and Trauma Studies 2001-1, online only http://www.massey.ac.nz/~trauma.

Blong, R.J., 1984. Volcanic Hazards: A Sourcebook on the Effects of Eruptions. Academic Press, London.

Bolt, B., 1978. Earthquakes: A Primer. W.H. Freeman and Company, San Francisco.

Burton, I., Kates, R.W., White, G.F., 1978. The Environment as Hazard. Oxford University Press, Oxford.

Cahn, M., 2002. Sustainable livelihoods approach: concept and practice. Paper from DevNet Conference 2002—Contesting Development: Pathways to Better Practice, Institute of Development Studies, Massey University, Palmerston North, New Zealand, 5–7 December 2002.

Cannon, T., Twigg, J., Rowell, J., 2003. Social vulnerability, sustainable livelihoods and disasters. Conflict and Humanitarian Assistance Department and Sustainable Livelihoods Support Office. Department for International Development, London.

Carney, D., Drinkwater, M., Rusinow, T., Neefjes, K., Wanmali, S., Singh, N., 1999. Livelihood Approaches Compared. Department for International Development, London.

Chambers, R., 1995. Poverty and livelihoods: whose reality counts? Environment and Urbanization 7 (1), 173–204.

Chambers, R., Conway, G.R., 1992. Sustainable rural livelihoods: practical concepts for the 21st century. Discussion Paper, vol. 296. Institute of Development Studies, University of Sussex, Brighton (although dated December 1991).

Chester, D., 1993. Volcanoes and Society. Edward Arnold, London.

Corsellis, T., Vitale, A., 2005. Transitional Settlement: Displaced Populations. Oxfam, Oxford.

Criss, R.E., Shock, E.L., 2001. Flood enhancement through flood control. Geology 29 (10), 875–878.

Crittenden, K.S., 2001. Can this town survive? Case study of a buried Philippine town. Natural Hazards Review 2 (2), 72–79.

Cronin, S.J., Gaylord, D.R., Charley, D., Alloway, B.V., Wallez, S., Esau, J.W., 2004a. Participatory methods of incorporating scientific with traditional knowledge for volcanic hazard management on Ambae Island, Vanuatu. Bulletin of Volcanology 66, 652–668.

Cronin, S.J., Petterson, M.J., Taylor, M.W., Biliki, R., 2004b. Maximising multi-stakeholder participation in government and community volcanic hazard management programs: a case study from Savo, Solomon Islands. Natural Hazards 33, 105–136.

Davies, R.J., Swarbrick, R.E., Evans, R.J., Huuse, M., 2007. Birth of a mud volcano: East Java, 29 May 2006. GSA Today 17 (2), 4–9.

de Boer, J.Z., Sanders, D.T., 2002. Volcanoes in Human History. Princeton University Press, Princeton, New Jersey.

Decker, R.W., Decker, B.B., 1991. Mountains of Fire: The Nature of Volcanoes. Cambridge University Press, New York.

Dibben, C., Chester, D.K., 1999. Human vulnerability in volcanic environments: the case of Furnas, Saõ Miguel, Azores. Journal of Volcanology and Geothermal Research 92, 133–150.

Duncan, A.M., Chester, D.K., Guest, J.E., 1981. Mount Etna Volcano: environmental impact and problems of volcanic prediction. The Geographical Journal 147 (2), 164–178.

EMA, 2003. Preparing for the Unexpected. EMA (Emergency Management Australia), Canberra.

Erickson, J., 1988. Volcanoes and Earthquakes. Tab Books, Blue Ridge Summit, Pennsylvania.

Etkin, D., 1999. Risk transference and related trends: driving forces towards more mega-disasters. Environmental Hazards 1, 69–75.

FEMA, 2004. Are you ready? An In-depth Guide to Citizen Preparedness. FEMA (Federal Emergency Management Agency), Washington, DC.

Fisher, R.V., Heiken, G., Hulen, J.B., 1997. Volcanoes: Crucibles of Change. Princeton University Press, Princeton, New Jersey.

Fordham, M., 1999. Participatory planning for flood mitigation: models and approaches. The Australian Journal of Emergency Management 13 (4), 27–34.

Francis, P., 1976. Volcanoes. Penguin, New York.

Gaillard, J.-C., 2003. Territorial and ethno-cultural implications of a volcanic crisis: the case of the Mount Pinatubo eruption. Alaya: Kapampangan Research Journal 1, 73–88.

Gaillard, J.-C., 2006. Traditional societies in the face of natural hazards: the 1991 Mt. Pinatubo eruption and the Aetas of the Philippines. International Journal of Mass Emergencies and Disasters 24 (1), 5–43.

Gaillard, J.-C., 2008. Alternative paradigms of volcanic risk perception: the case of Mt. Pinatubo in the Philippines. Journal of Volcanology and Geothermal Research 172, 315–328 (this issue), doi:10.1016/j.jvolgeores.2007.12.036.

Gaillard, J.-C., Leone, F., 2000. Implications territoriales de l'éruption du Mont Pinatubo pour la minorité autochtone aeta: Cas des bassins-versants des rivières Pasig et Sacobia (provinces de Pampanga et Tarlac, Philippines). Cahiers Savoisiens de Géographie, 1, 53–68.

Glaser, A.N., 1996. Global effects of volcanic eruptions on human health and agriculture: a review. Journal of Agromedicine, 3 (2), 31–44.

Goertzen, D., 1991. Valour under fire (tribe trusted in Mt. Pinatubo's protection). Far Eastern Economic Review 25–26 18 July 1991.

GVP, 2006. Worldwide Holocene volcano and eruption information. GVP (Global Volcanism Program). Smithsonian Institute, Washington, DC. http://www.volcano.si.edu.

Haynes, K., 2005. Exploring the Communication of Risk During a Volcanic Crisis: A Case Study of Montserrat, WI. PhD dissertation, University of East Anglia, Norwich.

Heijmans, A., 2001. Vulnerability: a matter of perception. Disaster Management Working Paper 4/2001. Benfield Greig Hazard Research Centre, London.

Hewitt, K. (Ed.), 1983. Interpretations of Calamity from the Viewpoint of Human Ecology. Allen and Unwin, Massachusetts.

Hewitt, K., Burton, I., 1971. The Hazardousness of a Place: A Regional Ecology of Damaging Events. University of Toronto Press, Toronto, Ontario.

Hough, S.E., 2004. Earthshaking Science: What We Know (and Don't Know) about Earthquakes. Princeton University Press, Princeton, New Jersey.

IAVCEI, 1994. Safety Recommendations for Volcanologists and the Public. IAVCEI (International Association of Volcanology and Chemistry of the Earth's Interior).

IAVCEI, 1999. Professional conduct of scientists during volcanic crises. Bulletin of Volcanology 60, 323–334.

Jackson, J., 2001. Living with earthquakes: know your faults. Journal of Earthquake Engineering 5 (special issue 1), 5–123.

Johnston, D.M., Bebbington, M.S., Lai, C.-D., Houghton, B.F., Paton, D., 1999. Volcanic hazard perceptions: comparative shifts in knowledge and risk. Disaster Prevention and Management 8 (2), 118–126.

JVGR, 1989. Special issue from the International conference on Lake Nyos disaster, Yaoundé, Cameroon 16-20 March, 1987. Journal of Volcanology and Geothermal Research 39 (2–3), 97–275.
Kelman, I., 2001. The Autumn 2000 Floods in England and Flood Management. Weather 56 (10), 346–348,353–360.
Kokai, M., Fujii, S., Shinfuku, N., Edwards, G., 2004. Natural disaster and mental health in Asia. Psychiatry and Clinical Neurosciences 58 (2), 110–116.
Lane, L.R., Tobin, G.A., Whiteford, L.M., 2003. Volcanic hazard or economic destitution: hard choices in Baños, Ecuador. Environmental Hazards 5, 23–24.
Leone, F., Gaillard, J.-C., 1999. Analysis of the institutional and social responses to the eruption and the lahars of Mount Pinatubo Volcano from 1991 to 1998 (Central Luzon, Philippines). GeoJournal 49, 223–238.
Lewis, J., 1999. Development in Disaster-prone Places: Studies of Vulnerability. London, Intermediate Technology Publications.
Loughlin, S.C., Baxter, P.J., Aspinall, W.P., Darroux, B., Harford, C.L., Miller, A.D., 2002. Eyewitness accounts of the 25th June 1997 pyroclastic flows at Soufrière Hills Volcano, Montserrat, and implications for disaster mitigation. In: Druitt, T.H., Kokelaar, B.P. (Eds.), The Eruption of Soufrière Hills Volcano, Montserrat, from 1995 to 1999, vol. 21. Geological Society of London, London, pp. 211–230.
Lowe, T., Byrne, G. and Haynes, K., in press. Promoting Resilience Through Community Action: the New South Wales Fire Brigades Community Fire Unit Approach. In: Handmer, J., Haynes, K., Gledhill, J. (Eds.), Community Wildfire Safety, Bushfire Cooperative Research Centre. CSIRO Publishing, Australia.
Mather, T.A., Pyle, D.M., Oppenheimer, C., 2003. Tropospheric volcanic aerosol. In: Robock, A., Oppenheimer, C. (Eds.), Volcanism and the Earth's Atmosphere. Geophysical Monograph, vol. 139. American Geophysical Union, Washington, DC, pp. 189–212.
Matlock, W.G., Cockrum, E.L., 1976. Agricultural production systems in the Sahel. In: Glantz, M.H. (Ed.), The Politics of Natural Disaster: The Case of the Sahel Drought. Praeger Publishers, New York, USA, pp. 232–255.
Mbendi, 2004. World: Mining—Copper Mining: Commodity Properties and Uses. Online only http://www.mbendi.co.za/indy/ming/cppr/p0005.htm downloaded on 12 September 2006.
Mileti, D., Bolton, P.A., Fernandez, G., Updike, R.G., 1991. The eruption of Nevado del Ruiz Volcano, Colombia, South America, November 13, 1985. Natural Disaster Studies, volume 4, for the Committee on Natural Disasters, Division of Natural Hazard Mitigation, Commission on Engineering and Technical Systems, National Research Council (USA). Washington, DC, National Academy Press.
Mileti, D., et al., 1999. Disasters by Design: A Reassessment of Natural Hazards in the United States. Joseph Henry Press, Washington, DC.
Miller, M., Paton, D., Johnston, D., 1999. Community vulnerability to volcanic hazard consequences. Disaster Prevention and Management 8 (4), 255–260.
Mitchell, T., 2002. Discussion of 'Second hazards assessment and sustainable hazards mitigation: disaster recovery on Montserrat' by Jack L. Rozdilsky. Natural Hazards Review 3 (2), 74–76.
Mitchell, T., 2006. Building a Disaster Resilient Future: Lessons from Participatory Research on St. Kitts and Montserrat. PhD dissertation, University College London, London.
Moser, C., Norton, A., Conway, T., Ferguson, C., Vizard, P., 2001. To Claim our Rights: Livelihood Security, Human Rights and Sustainable Development. Overseas Development Institute, London.
Newhall, C.G., Hoblitt, R.P., 2002. Constructing event trees for volcanic crises. Bulletin of Volcanology 64, 3–20.
Noble, G.R., 1982. Epidemiological and clinical aspects of influenza. In: Beare, A.S. (Ed.), Basic and Applied Influenza Research. CRC Press, Boca Raton, Florida.
Nomura, K., Yamaoka, K., Okano, T., Yano, E., 2004. Risk perception, risk-taking attitude, and hypothetical behavior of active volcano tourists. Human and Ecological Risk Assessment 10, 595–604.
Nriagu, J.O., 1989. A global assessment of natural sources of atmospheric trace metals. Nature 338, 47–49.
Ogawa, Y., Fernandez, A.L., Yoshimura, T., 2005. Town watching as a tool for citizen participation in developing countries: applications in disaster training. International Journal of Mass Emergencies and Disasters 23 (2), 5–36.
Oppenheimer, C., 2002. Limited global change due to the largest known Quaternary eruption, Toba ≈74 kyr BP? Quaternary Science Reviews 21 (14–15), 1593–1609.
Paton, D., Millar, M., Johnston, D., 2001. Community resilience to volcanic hazard consequences. Natural Hazards 24, 157–169.
Pattullo, P., 2000. Fire from the Mountain: The Tragedy of Montserrat and the Betrayal of its People. Constable and Robinson, London.
Robertson, R.E.A., 1995. An assessment of the risk from future eruptions of the Soufriere Volcano of St. Vincent, West Indies. Natural Hazards 11, 163–191.
Rodolfo, K.S., 1995. Pinatubo and the Politics of Lahar: Eruption and Aftermath, 1991. University of the Philippines Press, Quezon City.
Ronan, K., 1996. The effects of a "benign" disaster: symptoms of post-traumatic stress in Children following a series of volcanic eruptions. Australasian Journal of Disaster and Trauma Studies 1997-1, online http://www.massey.ac.nz/~trauma.
Rozdilsky, J.L., 2001. Second hazards assessment and sustainable hazards mitigation: disaster recovery on Montserrat. Natural Hazards Review 2 (2), 64–71.
Rozdilsky, J.L., 2002. Closure to 'Second hazards assessment and sustainable hazards mitigation: disaster recovery on Montserrat' by Jack L. Rozdilsky. Natural Hazards Review 3 (2), 76–77.
Schmincke, H.-U., 2004. Volcanism. Springer-Verlag, Berlin Heidelberg New York.
Seitz, S., 1998. Coping strategies in an ethnic minority group: the Aeta of Mount Pinatubo. Disasters 22 (1), 76–90.
Self, S., Zhao, J.-X., Holasek, R.E., Torres, R.C., King, A.J., 1996. The atmospheric impact of the 1991 Mount Pinatubo Eruption. In: Newhall, C.G., Punongbayan, R.S. (Eds.), Fire and Mud: Eruptions and Lahars of Mount Pinatubo, Philippines. University of Washington Press, London, pp. 1089–1115.
Self, S., Widdowson, M., Thordarson, T., Jay, A.E., 2006. Volatile fluxes during flood basalt eruptions and potential effects on the global environment: a Deccan perspective. Earth and Planetary Science Letters 248, 517–531.
Sigurdsson, H., Houghton, B., McNutt, S.R., Rymer, H., Stix, J. (Eds.), 2000. Encyclopedia of Volcanoes. Academic Press, San Diego, California.
Simkin, T., Siebert, L., Blong, R., 2001. Volcano fatalities—lessons from the historical record. Science 291 (5502), 255.
Simpson, D., 2001. Community emergency response training (CERTs): a recent history and review. Natural Hazards Review 2 (2), 54–63.
Slovic, P., 2000. The Perception of Risk. Earthscan, London.
Spence, R., Kelman, I., Baxter, P., Zuccaro, G., Petrazzuoli, S., 2005a. Residential building and occupant vulnerability to tephra fall. Natural Hazards and Earth Systems Sciences 5, 477–494.
Spence, R., Kelman, I., Calogero, E., Toyos, G., Baxter, P., Komorowski, J.-C., 2005b. Modelling expected physical impacts and human casualties from explosive volcanic eruptions. Natural Hazards and Earth Systems Sciences 5, 1003–1015.
Starr, C., Whipple, C., 1980. Risks of risk decisions. Science 208, 1114–1119.
Tanguy, J.-C., Ribière, Ch., Scarth, A., Tjetjep, W.S., 1998. Victims from volcanic eruptions: a revised database. Bulletin of Volcanology 60 (2), 137–144.
Taubenberger, J.K., Reid, A.H., Krafft, A.E., Bijwaard, K.E., Fanning, T.G., 1997. Initial genetic characterization of the 1918 'Spanish' influenza virus. Science 275, 1793–1796.
Tayag, J.C., Punongbayan, R.S., 1994. Volcanic disaster mitigation in the Philippines: experience from Mt. Pinatubo. Disasters 18 (1), 1–15.
Tobin, G.A., Whiteford, L.M., 2006. Community resilience and volcano hazard: the eruption of Tungurahua and evacuation of the *Faldas* in Ecuador. Disasters 26 (1), 28–48.
Turton, C., 2000. The Sustainable Livelihoods Approach and Programme Development in Cambodia. Overseas Development Institute, London.
Twigg, J., 2004. Disaster risk reduction: mitigation and preparedness in development and emergency programming. Good Practice Review Number, vol. 9. Humanitarian Practice Network at the Overseas Development Institute, London.
Uehara, G., 2005. Volcanic soils. In: Hillel, D. (Ed.), Encyclopedia of Soils in the Environment, vol. 4. Elsevier, London, pp. 225–232.

UNISDR, 2004. Living With Risk. UNISDR (United Nations International Strategy for Disaster Reduction), Geneva.

Voight, B., 1990. The 1985 Nevado del Ruiz volcano catastrophe: anatomy and retrospection. Journal of Volcanology and Geothermal Research 44, 349–386.

Ward, R., Smith, K., 1998. Floods: Physical Processes and Human Impacts. John Wiley & Sons, Chichester.

Windrass, G., Nunes, T., 2003. Montserratian mothers' and English teachers' perceptions of teaching and learning. Cognitive Development 18, 555–577.

Wisner, B., Blaikie, P., Cannon, T., Davis, I., 2004. At Risk: Natural Hazards, People's Vulnerability and Disasters, (2nd ed.). Routledge, London.

Witham, C.S., Oppenheimer, C., 2004. Mortality in England during the 1783–4 Laki craters eruption. Bulletin of Volcanology 67 (1), 15–26.

Wright, R., Flynn, L.P., 2004. Space-based estimate of the volcanic heat flux into the atmosphere during 2001 and 2002. Geology 32 (3), 189–192.

Young, H., Jaspars, S., Brown, R., Frize, J., Khogali, H., 2001. Food-security assessments in emergencies: a livelihoods approach. Humanitarian Practice Network Paper, vol. 36. Overseas Development Institute, London.