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19 Vulnerability analysis in geomorphic risk assessment

Gabi Hufschmidt and Thomas Glade

19.1 Rationale

The application of vulnerability concepts within the discipline of geomorphology is relatively new. Due to the lack of a theory of its own, the usage of these concepts for geomorphic risk assessments is not without pitfalls. A first step towards avoiding these pitfalls is to recognise and appreciate the theoretical backgrounds and meanings in other fields of research. Consequently, it is fundamental to review these concepts carefully and to link them – where possible – to our own discipline of geomorphology. Indeed, some of the reviewed concepts are distant to geomorphic applications. However, it is important to acknowledge their meanings in order to distinguish different aspects linked to various scientific roots. The major aim of this contribution is to review these scientific roots and their vulnerability concepts, to provide ideas for applying these concepts within geomorphology and to give some examples to illustrate advances, but also pitfalls.

The first part of this chapter outlines the series of key developments in vulnerability research, and then builds the (historical) framework for vulnerability analysis in geomorphic risk reduction strategies. The common approach and methodology of vulnerability analysis from a geomorphic (i.e. natural science) perspective is reviewed and discussed in the context presented.

19.2 Different vulnerability approaches towards risk reduction

Research in the fields of natural hazard and risk research has diversified substantially during its relatively short history. A series of key developments can be identified:

1. the notion of risk changed from expressing the likelihood of geophysical processes occurring, such as a landslide, to a concept that includes the possible overall adverse effects on people and their (built) environment;
2. the shift from defining 'hazard' as a natural process only towards a concept that includes the frequency–magnitude relationship of the process;
3. the recognition that measures of loss reduction based on achievements in the field of science and technology only are insufficient for effective and sustainable loss reduction;
4. the importance of human adjustment;
5. the emergence of the vulnerability concept and its development into a research field of its own, where multiple dimensions (space, time, cultural, environmental, political, economic) for understanding and measuring the type and degree of damage inflicted on people, societies or economies are included.

Geomorphic risk reduction only reluctantly acknowledges and responds to the role of this 'social' vulnerability (i.e. living environment of social groups, e.g. Wisner *et al.*, 2004) as opposed to 'physical' vulnerability (i.e. structures of the built environment, e.g. Quarantelli, 2003).

19.3 Science and technology

In the early half of the twentieth century, the Western world became slowly but increasingly aware of the damage and resulting financial losses following the exploitation of their own environmental resources. For example, in the late nineteenth century, US agriculturalists, supported by technological innovation as well as the railway and government policy, had pushed the margin of production into a region of highly variable climate. As a result, great droughts occurred in the subsequent decades, vividly remembered in the images of the 1930s dust bowls

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FIGURE 19.1. Location of a petrol station on a bridge over a currently not active debris flow channel in Bildudalur, Iceland. (Photograph: Rainer Bell.) It is obvious that the vulnerability of the 'elements at risk' (i.e. bridge, road, petrol station, power supply, etc.) towards large debris flows is very high.

covering the Great Plains of North America (Warrick, 1983). Additionally, major floods which occurred in the USA of the 1940s and 1950s clearly demonstrated that somehow not the flood as a natural process, but society with inappropriate development and adaption strategies is the main driver for the consequences suffered following these 'natural' events (Burton *et al.*, 1968; Kates, 1970). Even today, more recent examples of inappropriate development are ubiquitous (Figure 19.1).

Attempts at controlling and predicting natural processes such as soil erosion and floods, usually with engineering measures, dominated within the scientific community. Simultaneously, the pressure to utilise natural resources increased, and so did the amount of money potentially assigned for public engineering works (Mitchell, 1990; Smith, 2004). Nationally and internationally, solutions for reducing losses incurred from natural hazards continued to fall predominantly into the realm of science and technology. In 1972, the United Nations stated:

> It is believed that not only the causes of … disasters fall within the province of science and technology, but also, in some cases their prevention, as well as the organizational arrangements made for forecasting them and reducing their impact when they occur. (United Nations Department of Economics and Social Affairs, 1972, p. 1).

Consequently, the United Nations Advisory Committee on the Application of Science and Technology to Development promoted research in the fields of physical processes, forecasting, technological measures for protection and warning systems (Burton *et al.*, 1978). This research stream continues today, and against the background of recent disasters has intensified on an international scale.

From the perspective of this research stream, damage is predominantly seen as proportional only to the magnitude, frequency and type of the natural process (Hewitt, 1983; UNDP, 2004). What is more, in the 1970s and 80s 'risk' was used by natural scientists to express the likelihood of an event occurring (frequency and magnitude). The focus was very much on the natural process itself, without including damage or loss estimates (Timmerman, 1981; Cardona, 2004). The process-focused understanding of risk has now mostly shifted towards including the probability of damage and loss; this means adverse consequences for humans and their environment. Some examples include studies on landslides (Ragozin and Tikhvinsky, 2000; Glade, 2003; Alexander, 2005), debris flows (Fuchs *et al.*, 2007; Lu *et al.*, 2007), volcanic eruptions (Aceves-Quesada *et al.*, 2007), or snow avalanches (Fuchs and Bründl, 2005) (refer also to Chapter 5 by Bründl *et al.* in this book), to name a few examples and exemplary references only.

Additionally, 'hazard' applied today usually implies that someone or something is threatened (e.g. Glade *et al.*, 2005), while in the 1980s, 'hazard' was frequently used to describe the natural process only (Hewitt, 1983). This shift in terminology reflects the development of natural hazard and risk research, as will be seen in the following.

19.4 The human ecology approach

In his dissertation, published in 1945, Gilbert F. White clearly placed the responsibility for flood damage into the realm of human action, not 'nature' (White, 1945). White, who had worked with H. Barrows, questioned the efficacy of solutions based on science and technology only, such as large flood-control measure expenditures for dams, channel modification and levees (White *et al.*, 1958; White, 1961). This questioning can indeed be transferred to various hazardous processes such as landslides and snow avalanches.

White and colleagues concluded that reducing loss by technology-driven strategies only proved to generate even more rather than less damage. Avoiding smaller losses in the short term turned out to increase losses in the long term (Burton *et al.*, 1968, 1978; Kates, 1970; Burton and Hewitt, 1974). While, for example, the construction of dams reduces flood damage of a specific magnitude, 'protected' areas are still exposed to higher-magnitude events. Furthermore, by constructing levees human settlement is encouraged in a supposedly flood-protected area, which creates a false sense of security and increases the damage potential. Urban growth outside the range of levees raises the damage potential further (Hewitt and Burton, 1971; White, 1974).

Against the background of a common aim to optimise the cost–benefit ratio of mitigation measures (e.g. engineering flood protection works), White (1973, 1974) criticised that the knowledge of physical processes and their behaviour is 'imperfect' and therefore mitigation measures were not as successful as envisaged. Today, the problem of uncertainty in prediction has still not been resolved for many hazards, especially for landslide hazards as Crozier and Glade (2005) pointed out.

Hewitt and Burton (1971) advocated White's human ecology perspective on hazards. They identified beneficial outcomes of the dualism of 'man' and 'nature' i.e. resources and goods, and negative outcomes, such as hazard and risk (see also Kates, 1970, and Burton *et al.*, 1993). White (1974, p. 3) emphasised that 'natural' hazards are not generated by 'nature': 'By definition, no hazard exists apart from human adjustment to it. It always involves human initiative and choice. Floods would not be hazards were not man tempted to occupy floodplains …'. This statement implies that humans can take action to reduce these losses, and therefore bears a strong possibilistic, not a deterministic, connotation.

Human adjustment to natural hazards is the central topic of the human ecologist school, which is also sometimes labelled the 'Chicago School' (Tobin and Montz, 1997) or the 'behavioural paradigm' (Pelling, 2003; Smith, 2004). White (1974, p. 4) defined adjustment as 'a human activity intended to reduce the negative impact of the event'. It is when the impact of a natural process exceeds the adjustments in place that damage and loss unfold. This entails 'a continuing effort to make the human use system less vulnerable to the vagaries of nature' (Kates, 1970, p. 1).

From a human ecology perspective, a combination of the magnitude of a geophysical variable, like water discharge, and human adjustment delineates a zone where damage is not significant, i.e. does not cross a threshold above which the positive effects of resource utilisation flip into adverse effects creating 'negative resources' (hazards) (Hewitt and Burton, 1971; Burton and Hewitt, 1974). This damage threshold is closely interlinked with human adjustment strategies which can alter the threshold, and hence widen or lessen the zone of insignificant damage. The zone of insignificant damage is adjusted to buffer 'normal' events of a certain frequency–magnitude relation. 'Extreme events' exceeding the damage threshold, however, are not covered and damage is incurred. It is important to recognise that such damage thresholds vary in time. This variation is related not only to changes in the geo(morphological) system, but also within the social realm, for example the implementation of new urban development strategies or changes in land use.

The zone of insignificant damage is what the climate change and global environmental change community calls the 'coping range' (Smit *et al.*, 2000; Ford, 2004), which can be extended depending on people's 'adaptive capacity' (Smit and Pilifosova, 2003; Adger, 2006; Smit and Wandel, 2006).

The Chicago School proposes a combination of adjustments such as (1) '*modify the cause*', i.e. keep the hazard away from the population (for example by structural measures such as constructing levees, avalanche fences, or by operations such as snow melting, slope stabilisation); (2) '*modify the loss*' by keeping the population away from the hazard (for example warning systems, building design, land use planning); and (3) '*distribute and adjust to losses*' such as purchasing insurance (Burton *et al.*, 1968, 1993; Kates, 1970; White, 1973; Mitchell, 1990). For a variety of adjustments in relation to different hazard types, see Burton and Hewitt (1974). Especially when 'modifying the cause' is not possible, non-structural management options are rated as increasingly relevant. Therefore, common strategies of loss reduction based on science and technology are not dismissed as such, but rated to be insufficient by themselves and only effective if in combination with other strategies.

Choices of adjustment are seen as mirroring a limited human rationality, or 'bounded rationality' (Kates, 1970; White, 1973; Burton *et al.*, 1978, 1993). Rational behaviour overruled by political or economic power is only marginally recognised within the classical human ecology perspective, which is identified as a major deficit by the emerging criticism of the 'structuralist paradigm'.

One component of a human ecologist approach to loss reduction is to include the socio-economic causes and effects of risk. The human ecology school defines vulnerability as the '*capacity to be wounded*' (Kates, 1985, p. 9). The most vulnerable element, i.e. the one most susceptible to be wounded, is relative. This means it varies with hazard type and community type. Acknowledging the partially context-specific nature of vulnerability is regarded as especially important.

White and Haas (1975) suggested that three interacting elements have to be analysed in order to estimate losses: the 'natural event generator' (for example frequency and magnitude of earthquakes and storms), the 'population-at-risk in each area' (density or distribution of people and buildings), and the 'vulnerability of population-at-risk to loss for a given severity of an event' (p. 123). This work inititated the concept of risk as it is predominantly understood today and synthesised by the United Nations Disaster Relief Office (UNDRO, 1982).

In summary, the emerging human ecology school shifted the focus from human *control* of nature to human *adjustment* to nature. The 'naturalness' of hazards is questioned, as well as the limited effectiveness of purely scientific and engineering approaches to loss reduction. What is more, the human ecology school paved the way for the concept of vulnerability that today is a key to understanding the magnitude of damage induced from natural processes.

In the 1980s, when a *Zeitgeist* of science-scepticism emerged and whole societies perceived themselves as threatened in various ways – labelled 'risk society' by Ulrich Beck (1986) – vulnerability research developed into two different ways of tackling the challenge of reducing losses from natural hazards: one as a continuous development of the human ecology school ('applied sciences'), the other being the 'structuralist paradigm' triggered by criticism of the former and the 'science and technology' approach.

19.5 Vulnerability and the applied sciences

Applied sciences, such as engineering, economics, politics, geography and environmental studies, are increasingly inspired by the human ecologist school of natural hazards. At the end of the 1970s, the vulnerability concept was fostered and implemented in guidelines for future research in the fields of energy, risk management and climate impact assessment. Models of social collapse and ecology were combined under the vulnerability umbrella (Timmerman, 1981).

Applied sciences define vulnerability as the degree of loss, which can be expressed as a damage ratio (for example from 0 to 1). This understanding is based on definitions suggested by the United Nations Disaster Relief Organisation (UNDRO, 1982). Hollenstein *et al.* (2002) presented a comprehensive compilation and evaluation of approaches to vulnerability within the applied sciences, covering a range of natural hazard types. Within these, Hollenstein (2005) detected a dominance of earthquake- and wind-related vulnerability models.

Analysing vulnerability can be done qualitatively, semi-quantitatively or quantitatively. Whatever the way, the construct is expressed as a condition. In the overall context of risk assessment, qualitative descriptions are often used as a first assessment to identify different vulnerability aspects, or when numerical data are not available (AS/NZS, 2004). Wisner (2006) for instance discussed and exemplified the advantages of participatory approaches that are qualitative self-assessments. Semi-quantitative methods assign values to qualitative ranks in order to introduce a more expanded scale. These values are, however, not 'real' values and are usually expressed on an ordinal scale that bears limited mathematical possibilities. Villagran (2006) described such an analysis where structural characteristics of buildings (e.g. material of the roof and walls) are associated with classes of low, medium and high vulnerability. These are assigned values of one, three and five, respectively, and combined into one figure. Thirdly, quantitative analysis relies on numerical values based on metric variables on an interval/ratio scale allowing for mathematical operations. Differences between variables can be quantified as true numeric magnitudes. Metric variables can be used as indicators and aggregated into one index. Examples of an index-based methodology are given by Briguglio (1995), Davidson (1997), Davidson and Shah (1998), Cutter *et al.* (2000), Davidson and Lambert (2001), Cutter (2003), Boruff *et al.* (2005), Cardona (2005, 2006), Bollin and Hidajat (2006) and Plate (2006). Challenges encountered when developing an index-based approach of vulnerability assessment are manifold and include issues such as data availability, subjectivity and opportunities to manipulate results, and overall the lack of validation options. Consequently, uncertainty and sensitivity analysis are mandatory for maximising methodological transparency and soundness, and hence the acceptance of research findings (Gall, 2007). Despite this demand, both analyses are often missing in vulnerability assessments.

The following exemplifies the rather classical way of incorporating vulnerability in the context of landslide risk studies. Scales covered in such landslide vulnerability and risk studies range from the very detailed local scale to the regional scale and the more abstract scale of society when calculating 'societal' vulnerability and risk. Vulnerability to landslides is usually considered for individuals in relation to buildings, for buildings themselves and roads in the potential path of the landslide (Glade, 2003; Alexander,

2005). Generally, when analysing the vulnerability to landslides, the following factors are taken into account:

1. the location of the element at risk in respect to the landslide (e.g. uphill, on the landslide, or downhill);
2. the temporal component (e.g. day/night, weekend/workweek);
3. the impact of the landslide, assuming that the level of vulnerability changes with the level of impact, which depends on:
   a. the velocity of the landslide,
   b. the depth of the landslide (e.g. magnitude: volume/spatial extent);
4. the characteristics of the element at risk; for structures this is well documented, e.g. in order to design structures that can resist the impact (IUGS, 1997). See Corominas *et al.* (2005) for an example of such a conceptualisation. Leone *et al.* (1996) developed a damage matrix to classify the potential damage according to the building structure. Another approach is to assemble historical data on damages, as done by Remondo *et al.* (2005) for the built environment within a catchment in northern Spain. The problem with historical data is their availability, and even if historical damage data are available, the level of detail is often not sufficient to capture landslide type and magnitude (Glade, 2003).

The landslide risk assessment carried out for the Geoscience Australia 'Cities Project' with respect to urban communities in Cairns is a (modified) example for an approach as described above. The vulnerability of people, buildings and roads is expressed as the probability of a fatal injury or destruction, expressed on a scale of 0 to 1 (Michael-Leiba *et al.*, 2003, 2005).

The need to understand vulnerability in all its multi-dimensionality on the one hand (often done qualitatively), and the need for relatively simple tools of analysis on the other hand (often required quantitatively), can be conflicting. This dilemma was observed by Davidson (1997), who reviewed earthquake risk assessment models developed from the two camps of social sciences and engineering. For example, clear and readily available vulnerability indicators are often what hazard and disaster managers seek – before, during or after an emergency (Birkmann, 2006; Queste and Lauwe, 2006). Vulnerability indicators or indices simplify reality, and the degree of simplification depends on the target audiences (Karlsson *et al.*, 2007; Moldan and Dahl, 2007; Stanners *et al.*, 2007). Hence there is no general preference for qualitative, semi-quantitative or quantitative approaches. As a general rule the approach best suited to meet the defined goal should guide the methodology applied (AS/NZS, 2004).

Besides hazard-specific studies, multi-hazard approaches emerge. A multi-hazard perspective was initiated by the human ecologist approach of Hewitt and Burton (1971), who presented a case study that includes 'all hazards at a place'. Based on this work, Cutter developed the 'hazards-of-a-place-model of vulnerability' (Cutter, 1996; Cutter *et al.*, 2000, 2003). The progress from single-hazard dominated research is particularly important considering the combined occurrence of many hazards, such as a hurricane followed by floods and landslides, or an earthquake triggering landslides. Some concepts of addressing multi-hazard risks within natural sciences have already been suggested (e.g. van Westen *et al.*, 2002; von Elverfeldt and Glade, 2008). However, constructing a 'multi-hazard' assessment of vulnerability still appears to be extremely challenging (UNDP, 2004).

Although the importance of social aspects is recognised, the concept of 'physical vulnerability', meaning the susceptibility of physical elements such as houses or infrastructures, dominates the applied sciences (Mueller-Mahn, 2005). The common catalogue of risk reduction measures is based on the adjustment strategies identified by the human ecology school, as for example presented by Dai *et al.* (2002).

With respect to landslides, their prediction and control, especially for first-time failures, is limited. Consequently, the assessment of vulnerability and the identification of loss reduction strategies are especially important. As Liu *et al.* (2002) and Liu and Lei (2003) demonstrated, this is highly relevant for debris flows, in which case the modification of the human system (removing people and assets from hazardous areas) is the most feasible strategy to reduce landslide loss. Alexander (2005) underlined that vulnerability can determine the extent of losses to a greater extent than the landslide process itself. Overall, the importance of the vulnerability concept in landslide risk studies has been and is increasingly acknowledged. However, more cooperation between the 'physical' and 'social' vulnerability approaches, and more synergies with perspectives and solutions offered by the 'structuralist paradigm', are needed in order to maximise the effectiveness of loss reduction strategies.

19.6 Vulnerability and the structuralist paradigm

In the 1970s, criticism of the increasingly dominant research approach to natural hazards and disasters, the combination of science, technology and human ecology, mounted ('dominant paradigm'). This criticism came to be known as the 'structuralist paradigm' (Smith, 2004). The structuralist alternative focuses not so much on people's perception and their subsequent choice of adjustment, as on people's individual socio-economic and demographic characteristics within a specific social, cultural, economic, political and environmental fabric. It is not the choice as such, but the ability to choose between adjustment options that is the nucleus of this vulnerability research.

Similarly to White and colleagues, one can argue against labelling disasters as 'natural' (O'Keefe *et al.*, 1976). Richards (1975) stressed the interaction of natural and social processes. He highlighted that factors 'such as economic development can affect natural systems "causing" famine and soil erosion for example. This should make us think again about the term "natural" disaster' (cited in Timmerman, 1981, p. 11).

It is criticised that within the dominant view, 'The sense of causality or the direction of explanation still runs from the physical environment to its social impacts' (Hewitt, 1983, p. 5). The usefulness of better process understanding and improved forecasting is not doubted per se. However, the emerging paradigm questions the view that mainly improved predictions will reduce damage and loss, while social aspects are ignored (Hewitt, 1983). In addition to predictions, the trust in security provided by the existence of structural measures is seen as most dominant in society.

Especially in less developed countries the unsuccessful strategies of loss reduction conceptualised by the dominant view featured as an impetus for the structuralist paradigm (Smith, 2004). Increasingly, social scientists active mainly in the less developed countries of Latin America and Asia could not sufficiently decipher the rising number of disasters using the characteristics of the natural process alone (van Westen *et al.*, 2005). Focusing on hazard as a specialised problem, which can only be cured by scientific expertise and technology transfer, is identified as part of the problem, not the solution. The usual approach is seen as more of a technical monologue rather than a dialogue with 'grass roots' knowledge (Copans, 1983; Hewitt, 1983). It is increasingly recognised that under the pressure of daily threat, local people have developed their own successful strategies to cope with hazards and disasters (Bankoff, 2004; Heijmans, 2004).

The understanding of vulnerability from a structuralist perspective incorporates a wider appreciation of the social, economic, cultural and political context people live in, as well as their day-to-day personal socio-economic situation (Blaikie *et al.*, 1994; Wisner *et al.*, 2004). Wisner *et al.* (2004, p. 11) identified a range of variables determining vulnerability as 'class (including differences in wealth), occupation, caste, ethnicity, gender, disability and health status, age and immigration status ("legal" or "illegal") and the nature and extent of social networks'. Sometimes poverty is identified as the main cause of vulnerability, since very often the poor are those who suffer the most (Cuny, 1983). However, equalling vulnerability with poverty is an approach that is too simplistic (Wisner *et al.*, 2004). Wisner (1993) rated the model of marginalisation as one of the most useful of disaster occurrence anchored in social theory. Examples of marginalisation are informal settlements in dangerous areas prone to landslides as underlined by Smyth and Royle (2000) or by Anderson and Holcombe (2006).

Pronounced economic, social, environmental and political marginalisation can generally render people vulnerable – no matter if they are threatened by a flood, a landslide or an earthquake. In this context, Briguglio (2003) and Cardona (2005, p. 12) used the term 'inherent' vulnerability. Allen (2003, p. 170) referred to this phenomenon as 'underlying vulnerability', which she interpreted as a 'contextual weakness or susceptibility underpinning daily life'. Wisner (1993) and Wisner *et al.* (2004) preferred the term 'generalised' vulnerability. In the context of community response to disasters, Quarantelli (1997) differentiated between 'agent-specific' (hazard-specific) and 'generic' factors.

A comprehensive model summarising the structuralist perspective on multi-causal vulnerability combining far-reaching political, economic and cultural processes is the 'pressure and release' model (PAR). The complementary 'access model' focuses on the household scale and identifies access to resources, such as capital, land, or relief, as the drivers of vulnerability (Blaikie *et al.*, 1994; Wisner *et al.*, 2004). Research outcomes, such as the PAR-model, can deliver insight and increase the understanding of how risk is created in the developed world, as demonstrated recently by the events during and following Hurricane Katrina.

The new and challenging interpretation of disasters leads to an ideological battle that rejects technology-based approaches and the 'behavioural' paradigm of the human ecologist school radically. The dominant view is flagged as 'naïve determinism' and 'technocratic optimism'. Political responsibility, capitalism and the resulting marginal situation of many are viewed within a Marxist context: 'Acts of God become Acts of Capital' (Waddell, 1983, p. 38). Hence the structuralist paradigm carries neo-Marxist implications (Pelling, 2003).

Predominantly, people are perceived as victims without the ability to choose where they live or how they earn a livelihood, restricted by political and economical power structures. The 'bounded rationality' of the human ecologist school is replaced by a reality where potentially rational behaviour is suppressed by political, economic and cultural forces. It should be noted that White (1961),

too, identified social, political and economic constraints influencing and potentially limiting people's perception and hence choice of adjustments. From White's perspective, however, the responsibility to undertake adjustments lies within the individual realm.

A field of research influencing the structuralist perspective on social vulnerability during the 1980s and later is the 'sustainable livelihood' approach (Carney, 1998). Also Sen's (1981) 'entitlement' approach showed that major hunger crises in India in the mid twentieth century were rooted within the societal structures with different entitlements (access) to resources. A vulnerability model containing human ecological (for example effects of land use, desertification) and political-economic elements (household income, access to markets, price development) influenced by Sen was developed by Watts and Bohle (1993) and Bohle *et al.* (1994). The economy-based entitlement approach developed by Sen can be seen as a third field besides the human ecology school and the structuralist paradigm (Pelling, 2003).

19.7 Summary and perspectives

The path of vulnerability as a key concept within hazard and risk studies was paved by the human ecology school, and increasingly explored by several other disciplines including geomorphology. Its interpretation and application is advanced by the applied sciences. Importantly, the vulnerability concept within applied natural hazard and risk research, e.g. to describe the susceptibility of built structures and areas under agricultural production, has been broadened to encompass the demographic and socio-economic characteristics of people and topics such as risk preparedness. From a structuralist perspective, globalisation and increasing socio-economic and ecologic marginalisation are identified as root causes for people's vulnerability, especially in the less developed countries. The structuralist paradigm opened up the field of hazard and disaster research for socio-economic, cultural and political aspects within risk reduction strategies. In comparison with the classical human ecology school, the recognition that some social groups are simply not able to adjust to hazards, or cannot choose between different adjustment options – offered by traditional geomorphic hazard and risk studies, which are also described in this book – is a major contribution towards reducing loss in developing and developed countries alike.

The key synergy between the applied sciences, the (traditionally opposing) classical human ecology school and the structuralist paradigm is the underpinning that natural hazards and disaster are not just 'natural' but also social phenomena. Having this in mind, the consequence should be that any hazard and risk study including vulnerability assessment has to address both the natural science approach and the related social dimension. Hewitt (1997) developed an explanation of risk out of the human ecologist school and key elements of the structuralist approach to vulnerability. Hence human agency (behaviour/adjustment) and societal structures potentially restricting human agency are combined.

It is this kind of synergy that is necessary to reduce loss induced by natural processes in a sustainable way, recognising the 'inherent' as well as the 'context-specific' nature of vulnerability, in the less developed and the developed world alike. Vulnerability analysis with respect to geomorphic hazards is traditionally associated with the science and technology domain, and only slowly responds to the developments within the field of vulnerability research. Therefore, targeting a sustainable development of a given region or area demands not only the treatment of hazard and risk with modelling and simulation techniques, it also requires social research. The key element herein is not to carry out both analyses independently. Rather a coupling of both approaches is necessary to allow and ensure sustainable development.

Furthermore, it should be increasingly recognised that vulnerability is not static, whether in social, in technological or in natural science approaches. Refer to Hufschmidt *et al.* (2005) for a summary and discussion of temporal variability in the context of risk analysis (including hazard and vulnerability), with a focus on geomorphic processes such as landslides. A key point is that ongoing global change has major implications for designs of any technical structures, and also for modelling, simulation and predictions because the boundary variables change continuously, and at different rates. Thus, any planning procedure is strongly influenced by high uncertainties as a result of the unknown future. Frequently, this is not addressed in respective research or applications.

But the challenge is even greater. Engineering structures protecting environment and society are most important in highly endangered areas and locations. However, it is often not realised that by building the structure, the problem is not solved. Any structure has a given lifetime – and if no or not enough resources are allocated to maintain these structures, they might fail in the future and might cause even greater damage. For example, if snow avalanche fences are not maintained, they artificially collect more snow than would accumulate under natural conditions. If they fail due to neglected maintenance, the consequences are much worse than ever experienced before – and we read in the literature 'Nature fights back'. This problem is also evident for other processes (e.g. landslides, river dams etc.).

There is indeed a high demand for further research on hazard and risk in the specific traditional natural, engineering and social sciences. However, there is an even greater demand to couple these approaches. Herein, vulnerability analysis can play a predominant role. The respective innovation potential is incredibly high and has to be explored.

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