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Assessment of Vulnerability to Natural Hazards

A European Perspective

Edited by

Jörn Birkmann, Stefan Kienberger and David E. Alexander

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Elsevier
525 B Street, Suite 1900, San Diego, CA 92101-4495, USA
225 Wyman Street, Waltham, MA 02451, USA

Library of Congress Cataloging-in-Publication Data
Assessment of vulnerability to natural hazards: a European perspective/[edited by] Jörn Birkmann, Stefan Kienberger, David E. Alexander.
pages cm
ISBN 978-0-12-410528-7 (hardback)
1. Natural disasters–Europe. 2. Hazard mitigation–Europe 3. Environmental risk assessment–Europe. 4. Emergency management–Planning–Europe. 5. Human security. I. Birkmann, Jörn. II. Kienberger, Stefan. III. Alexander, David (David E.)
GB5008.E87A77 2014
363.34'2064–dc23
2014006590

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN: 978-0-12-410528-7

For information on all Elsevier publications visit our web site at store.elsevier.com

Printed and bound in China

14 15 16 17 18 10 9 8 7 6 5 4 3 2 1

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Chapter 8

Vulnerability to Heat Waves, Floods, and Landslides in Mountainous Terrain: Test Cases in South Tyrol

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Chapter Outline

Assessment of Vulnerability to Natural Hazards. http://dx.doi.org/10.1016/B978-0-12-410528-7.00008-4

8.1 INTRODUCTION

South Tyrol is located in the Eastern Alps, south of the main chain. The climate is mild and dry and the average temperature is 12.3 °C. It includes mainly the upper part of the Etsch/Adige river catchment and its contributors. The landscape is characterized by high mountains (up to 3905 m a.s.l.) and densely populated and intensively used valleys. South Tyrol has a population of 500,000, which is split into three different language groups (German, Italian, and Ladin). South Tyrol is part of the autonomous region Trentino-Alto Adige and, therefore, has a wide independence in legislation. The present study focuses on the assessment of different dimensions of vulnerability to landslides, floods, and heat waves at local scale in South Tyrol (Table 8.1). In this chapter, the term "landslides" is being used to express all these processes that can be defined as the downslope movement of soil, rock, or debris due to gravitational forces that can be triggered by rainfall, rapid snow melting, slope undercutting, etc. (Crozier, 1999; Glade and Crozier, 2005). The studies were conducted in close contact with the stakeholders that were involved at the early stages in the development of the methodologies (Table 8.1).

All studies were conducted on a local scale in different locations in South Tyrol that can be seen in the map (Figure 8.1).

TABLE 8.1 Hazards That are Investigated in These Case Studies, the Scale of the Study, and the Stakeholders Involved

Hazard Type	Location	Vulnerability Dimension	Stakeholders Involved
Landslides	Martello (Martell)	Physical	Local authorities (Hydraulic engineering, Fire and Civil Protection Departments of Autonomous Province of Bolzano)
Floods	Vipiteno (Sterzing)	Social	Residents and local Business, local and provincial administration
Heat waves	Bolzano (Bozen)	Social	Provincial and local health care services, Civil Protection Department, regional and local authorities, residents (especially elderly)

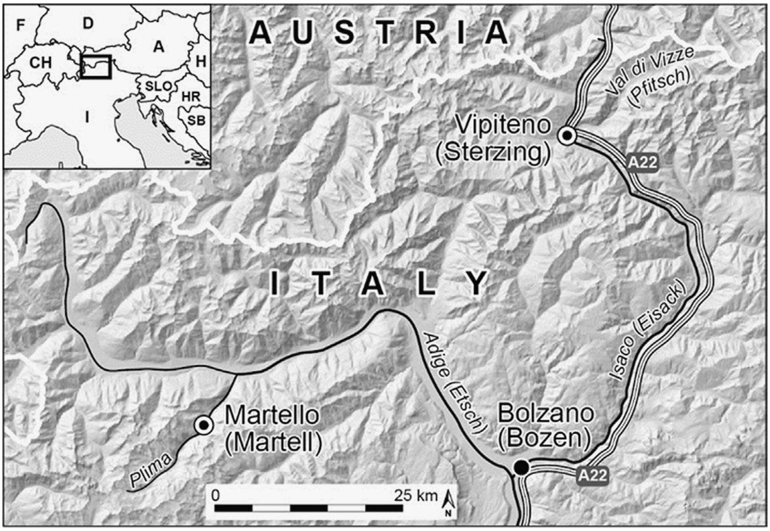

FIGURE 8.1 The location of the three case studies in South Tyrol.

8.1.1 The Effect of Climate Change on Natural Hazards

The report of IPCC (2012) suggests that "There is high confidence that changes in heat waves, glacial retreat, and/or permafrost degradation will affect high-mountain phenomena such as slope instabilities, mass movements, and glacial lake outburst floods. There is also high confidence that changes in heavy precipitation will affect landslides in some regions" (IPCC, 2012, p. 114). More specifically, in South Tyrol, Staffler et al. (2008) identified alpine torrents and river catchments in which future climate change may modify the hazard situation as far as floods and debris flow are concerned. The study of Staffler et al. (2008) revealed that an increase in the intensity and frequency of flood and debris flow events in the area is to be expected and they pointed out the importance of reducing the vulnerability of the elements at risk in order to reduce overall risk.

As far as heat waves are concerned, time–series measurements of land-surface and sea surface temperature of the last century show a clear warming trend. A shift in mean air temperature may lead to a nonlinear response in the frequency of extreme events such as heat waves (IPCC, 2001). Actually, recent regional climate models suggest an increased variability of temperature for the future in addition to an increase in mean temperature, which would likely augment the frequency of extreme events (Schär et al., 2004). In South Tyrol, the average temperature in the summer of 2003 was about 3–4° above the average of the last four decades (APB/SHA, 2003). However, predictions for the future also suggest an increase in the social susceptibility at local level, due to an increase in the number and percentage of elderly people.

8.1.2 Local Preparedness in South Tyrol

The province of South Tyrol has produced a publicly available Internet platform (Hazard Browser Südtirol[1]), showing information on catastrophic events related to mass movements and floods. At municipality level, local hazard maps are also available together with a report describing the methods, models, definitions, and software that has been used for hazard mapping. An early warning system for landslides in two case study areas in South Tyrol has been developed within the project ILEWS (Integrative Landslide Early Warning Systems) (Röhrs and Glade, 2010). In the case study area for landslides (Martell) an early warning system that is connected to the neighboring reservoir has been established and response exercises are regularly carried out. Following the catastrophic event of 1987 there was permanent removal and relocation of buildings, as well as prohibition of building in areas previously built at the bank of the river. Moreover, a protective reinforced concrete wall was built at the bank of the river in parts of the valley (Pfitscher, 1996).

Regarding floods, structural measures for flood protection are installed on the Eisack River and on most of the contributors upstream of the case study Sterzing/Pfitsch. Nonetheless, a flood hazard map indicates a high level of exposure to flood risk for a big part of the site (see Figure 8.2). A major river dredging was implemented to reduce the risk level. The provincial warning system is based on sirens combined with news in local broadcast stations. Early warning systems are based on weather information and a precipitation discharge model. Emergency exercises are held regularly in the autonomous province of Bolzano. In November 2005, in Sterzing and Pfitsch a big intercommunity emergency and simulated evacuation on a flooding/debris flow scenario was exercised.

Regarding heat waves, following the summer of 2003 the national civil protection department set up a national heat health warning system (HHWWS) for some Italian cities including Bolzano, which monitors the heat health danger situation. In addition, the local authorities of the autonomous province of Bolzano have set up a regional forecast system and local initiatives for elderly people in case of heat waves. The lack of consultation between the authorities at local and national level often leads to different results. Consequently, the warnings do not always coincide. The activities carried out by the local administration focus on short-term measures that help to reduce the direct impact of emerging heat. Long-term measures to mitigate impacts such as the avoidance of urban heat islands or the creation of fresh air corridors are currently foreseen (or are under discussion) within the context of urban planning.

Given the expected changes regarding the intensity and frequency of some natural processes due to climate change in combination with gaps in local preparedness and the need for reliable information to support risk reduction strategies, the assessment of different dimensions of vulnerability in the area is considered essential.

1. Available at: http://www.provinz.bz.it/wasserschutzbauten/wildbachverbauung/hazardbrowser.asp.

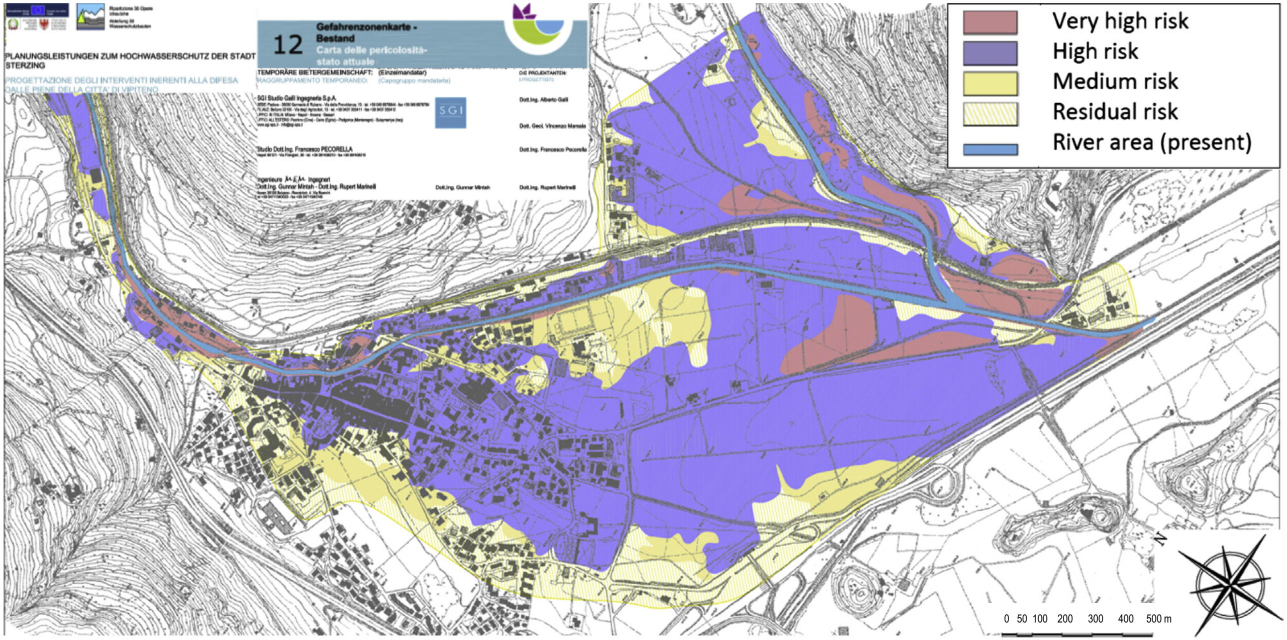

FIGURE 8.2 Great potential flood damage derives from situating big parts of the settlement in zones with high risk. In particular, the historic city center is highly exposed, which is essential for economy and tourism. Also other critical infrastructure such as transportation lines are situated in high risk zones. *Autonomous Province of Bolzano.*

In this chapter, social and physical vulnerability to three types of hazards is assessed and the results are demonstrated through the three following case studies.

8.2 LANDSLIDES

8.2.1 The Study Area: Martell

The case study area (Martell) has suffered in the past from flood and debris flow events. However, the most disastrous event that has been recorded in the area until now, and it is also the one that we are using in our case study, is the event of August 1987, which was a combination of natural and man-made disaster. The height of water and debris reached at some areas in the valley the height of 2.5–3 m and the destruction was severe. At least 12 houses were totally swept away and many more were severely damaged (Pfitscher, 1996). Roads were washed away, animals died, industry and agricultural buildings suffered damages and loss of equipment, water, sewage, and electricity lines were destroyed. Fortunately, due to early evacuation there were no casualties (Pfitscher, 1996). The cost of the specific event for the Municipality of Martell totaled 7,762,000,000 Italian Lire (Pfitscher, 1996), which corresponds to approximately 8.5 million € in indexed 2011 values.

8.2.2 Vulnerability Assessment Methodology for Landslides

This case study assesses physical and economic vulnerability to debris flow. However, the results of the case study can be used in the future for risk management decisions including risk reduction (exposure and vulnerability reduction), prevention, and mitigation. Physical vulnerability is often defined as the degree of loss. In more detail, natural scientists define physical vulnerability mainly as: "the degree of loss to a given element or set of elements within the area affected by a hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss)" (UNDRO, 1984). Although the physical vulnerability of an element at risk depends on a series of indicators and it is more complicated than a damage assessment, the degree of loss following a disastrous event bears information regarding the vulnerability of an element at risk. The indicator used in our methodology is the degree of loss. It depends on two values: the monetary loss and the object value. Our focus was to collect information regarding the monetary loss and the value of the elements at risk (the buildings in our study area).

The aim of our study is to design a vulnerability curve as a function of the intensity of the process and the degree of loss. The degree of loss equals the monetary damage of an element expressed as the percentage of its overall value. The curve was based on data concerning the event of 1987 in the Martell valley. A stepwise description of our methodology follows:

1. *Data collection*: photos of the buildings, damage information, and information on previous events and existing compensation data for specific buildings.
2. *Intensity assessment*: from photos of damaged buildings following an event the height of the debris deposits can be assessed.

3. *Monetary damage assessment*: the damages could be evaluated from photos and with the help of price lists indicating the costs of repair/reconstruction the monetary damage can be calculated. Information regarding the costs of repair of buildings following a debris flow was taken from Kaswalder (2009) and it was used throughout the study with some necessary modifications. The monetary loss includes only the costs of direct losses (cleaning, new paint on the walls, new doors and windows, testing and reinstalling electricity, heating and sewage systems, etc.).
4. *Calculation of the degree of loss*: The degree of loss of each building was calculated as the monetary damage expressed as percentage of the overall value of the building. The object value was calculated using the real compensation price for rebuilding (Italian Lire of 1989 was converted to Euros 2011).
5. *Development of the curve*: Based on the intensity and degree of loss for each building the vulnerability curve could be developed.
6. *Validation of results*: the results can be compared to real compensation data.

The resulting curve can be improved in the future by adding more data of more buildings and it can be used for loss estimation of future events. In order to ensure high quality of damage information, the post-event damage assessment methods have to be improved. The vulnerability curve can be integrated in a tool. The tool allows rapid damage assessment and loss estimation while at the same time the new information that will be included will improve the existing vulnerability curve.

8.2.3 Results, Validation, and Discussion on the Landslide Case Study

Following the methodological steps mentioned above, a vulnerability curve was developed (Figure 8.3). The degree of loss was calculated for 51 buildings that were damaged in the event of 1987. The focus of the study was strictly on residential 1, 2, or 3 storey buildings with similar architecture, material, and condition. Photographic documentation provided information not only on the extent of the damage on buildings following specific events but also information on buildings characteristics such as use, material, condition, floors, surroundings, etc. Additional background information included information of historic events and compensation data, existing protection measures, and a GIS database showing the land use, the location of the protection, and the distribution and size of the buildings. The vulnerability curve shows clearly that the higher the intensity of the process, the higher the degree of loss. In order to validate our results, a second curve was plotted using data from the municipality of Martell regarding the compensation that the house owners received following the event of 1987. In this way, the real degree of loss of a number of buildings could be calculated and compared with our own results.

The final product of our study is the vulnerability and the validation curve (Figure 8.3) based on the assessment of the intensity of the process and the monetary damage for individual buildings that were affected.

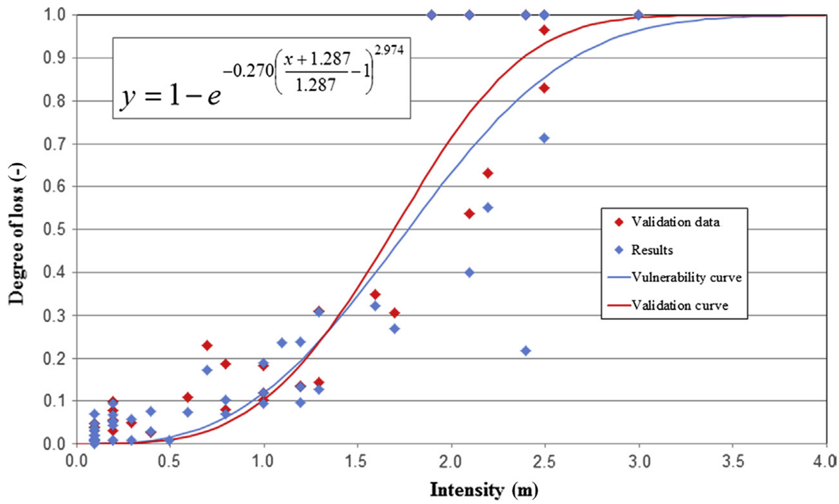

FIGURE 8.3 The vulnerability and the validation curve for buildings affected by the August 1987 event in Martell valley, South Tyrol. *Data source: Municipality of Martell, South Tyrol (Papathoma-Köhle et al., 2012).*

In this study, post-damage photographic documentation was used for the first time in order to calculate the monetary damage and the degree of loss of individual buildings. The vulnerability curve produced showed that total destruction of buildings can occur with intensities less than 2 m. For intensities higher than 1.4 m the degree of loss raises rapidly. This can be explained by the fact that after 1–1.5 m the deposit height reaches the window and it is possible that it enters the interior, which means more damages and costs. However, damages may appear already with intensities of a few centimeters due to damages in the basement. The validation curve that was developed based on compensation data appears very similar to the vulnerability curve based on photographic documentation.

The vulnerability curve that was produced gives the opportunity to decision makers to calculate the costs of future events not only for individual buildings but for the entire municipality. However, in order to improve the existing vulnerability curve or produce more curves for different types of landslides, improvements in the way damage assessment is carried out are necessary. The methodology can be transferred to areas with similar architecture and building material as it is and with modifications it can be transferred in any other places in the world facing the impact of similar hazards. The methodology itself can be slightly modified to be used for other types of landslides (e.g., shallow landslides, rock falls, etc.) but also for snow avalanches. However, the assessment of the intensity of the process on individual buildings may be exceptionally difficult, partly due to lack of data and partly due to difficulties in adequately expressing intensity.

8.2.4 Uncertainty Analysis for the Landslide Case Study

A very important part of the vulnerability assessment is the analysis of the uncertainties involved. Each step of the above described methodology for the development of the vulnerability curve bears a certain amount of uncertainty. In more detail, the sources of uncertainty for the empirical data points are listed below:

- Uncertainties in intensity:
  - The use of deposit height as the single intensity parameter. The effect of velocity and of duration of the water and debris staying inside the building was not considered.
  - Assessment of intensity from debris- and water-marks on the buildings and extent of the damage, interpreted from photographs. The quality, the aspect, and the number of photos per building influence the credibility and preciseness of the intensity assessment.
- Uncertainties in the degree of loss:
  - Assessment of damage pattern from photos which show mainly the external damage and not the interior damage.
  - Assessment of costs of reconstruction which was based on and modified from a list of repair costs that was developed for floods rather than debris flows.
  - Estimation of value of buildings with unknown use and size of basement and attic.
- Credibility of the existing data: For some buildings there is a mismatch between the damage shown on the photo and the received compensation.

To quantify the uncertainty in the proposed model, uncertainty in the empirical data points was assessed. The intensity and the degree of loss were specified as ranges rather than as single values, by using expert judgment and estimations. The ranges were defined by specifying six data points for each observed building.

The empirical data points, with uncertainty, were used to quantify the uncertainty in the vulnerability model for buildings affected by debris flow. The model uncertainty is represented by uncertainty bands (Figure 8.4). The uncertainty bands are presented in terms of percentiles: the 64 percentile means that 64% of the empirical data is below the curve, the 13 percentile means that 13% of the empirical data is below the curve.

Figure 8.4 illustrates the uncertainty in the model and is comprehensive for the stakeholders. The vulnerability curve represents the averaged degree of loss of the observed buildings, while the uncertainty bands represent the spread in the data represented by observations of single buildings. However, the exact probability distribution of damage is not shown and the information could not be applied directly into a detailed probabilistic loss assessment. In order to provide a probability distribution of damage for intensity, the empirical data could also be used to define a fragility function for buildings hit by debris flow.

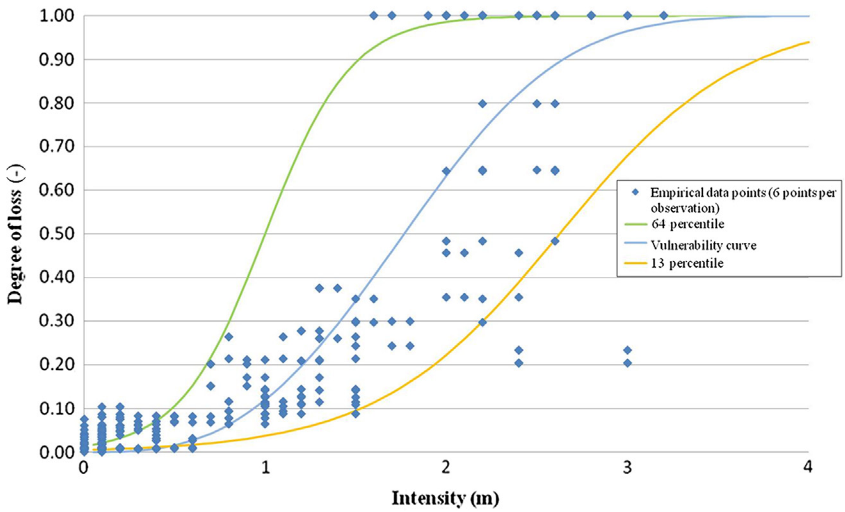

FIGURE 8.4 The model uncertainty represented by uncertainty bands. A high (64% of the empirical data below the curve) and a low (13% of the empirical data below the curve) estimate of the degree of loss were developed.

8.3 FLOODS

8.3.1 The Study Area: Sterzing/Pfitsch

Sterzing and the adjacent settlement of Pfitsch are among the municipalities most prone to be affected by extreme floods. In this area, three mountain torrents—Pfitscher Bach, Mareiter Bach, and Faller Bach—open out into Eisack River within or near built-up areas. Sterzing on the east bank and Pfitsch on the west bank of the Eisack River are located in their flood plain at 950 m a.s.l. The valley is important for transalpine traffic since the Brenner highway (A22) and railway pass through (Figure 8.1). A (preliminary) risk zone map (Figure 8.2) illustrates that a major part of both settlements, including the historic center of Sterzing and critical transport infrastructure is highly exposed.

To protect the settlement, river regulation started in the 1870s, largely reducing the frequency of floods and debris flows. Additional river regulations on the contributors of Eisack in the 1970s further reduced flood frequency. To improve the level of protection the provincial administration dredged the Eisack River in 2011.

8.3.2 Vulnerability Assessment Methodology for Floods

Detecting the susceptibility of social and cultural systems is an essential part of vulnerability assessment. Attitudes and motivations that encourage people to take flood precaution or not may be explored by qualitative methods. In the flood case study, we utilize focus group discussions (FGD) to identify attitudes and beliefs that determine motives and, therefore, influence flood risk behavior and vulnerability.

The first step of applying the methodology is to gain support of the provincial Department for Hydraulic Engineering and the mayors of Sterzing and Pfitsch.

In step two, we collected background information, such as data on historic floods and debris flows, flood protection measures, flood hazard maps (see Figure 8.2), and a report on social vulnerability of Sterzing and Pfitsch (De Marchi et al., 2007).

The third step was to invite local residents and businesses for an FGD through the local monthly magazine "Der Erker" (Der Erker 06.2010). Institutional stakeholders and larger enterprises located in the hazard zone were invited personally.

The fourth step was to build up a set of research questions to identify criteria affecting vulnerability of residents and businesses. We formulated open topics for participants to discuss. A schedule with a brief agenda and discussion topics was provided for participants.

Step five was composing the discussion groups. We assembled the groups with stakeholders from administration and relief organizations mixed with private stakeholders. We planned to conduct three focus group sessions: one with local businesses and two with residents split by different levels of exposure. Owing to low participation we could only hold one mixed session.

In step six the group discussions were conducted. The group included six residents of Sterzing/Pfitsch and one representative of the administration of each Sterzing and Pfitsch, the local fire brigade, and the provincial Hydraulic Engineering Department. Small businesses were also represented.

The discussion was structured into four parts:

- A brief introduction of the context, the research method, and setting up discussion rules.
- A round of introductions focusing on how participants are connected to flooding.
- Open discussion: The questions aimed at triggering discussions on flood awareness, responsibilities for flood protection, private flood precaution, and reaction to a flood warning. The moderators intervened only to steer the flow of the discussion, to dig deeper when participants raised thrilling issues, and to clarify when arguments remained unclear, avoiding inducing bias.
- A short summary by the researchers and a feedback from participants.

With participants consent the session was taped.

Step seven was to hand out a survey composed of 20 questions following the discussion. The survey supports the discussion results by describing the setting in more detail and characterizing the participants' background. We gathered data on: flood awareness, flood experience, private flood control measures, anticipated reaction to flood warning, living conditions, and demographics. Combining qualitative data gathered in the FGD and quantitative data generated in the survey helped reveal, to best effect, which attitudes, beliefs, and motivations lay behind arguments.

Finally, step eight was the analysis of the accumulated data. To conduct the analysis we prepared a transcript of the FGD and searched for arguments related to the following indicators:

- Flood risk awareness: Only if the residents and businesses at risk are aware of the possibility and consequences of a flood are they likely to take action to protect their lives and prevent or mitigate material and other losses.
- Attitudes on responsibilities: Only if residents and businesses understand and know their own responsibility for flood protection measures they might take action.
- Attitudes on self-precaution. Only if residents and businesses know possible measures of self-protection and have a positive attitude toward them, appraising them as reasonable and feasible, they may take action.
- Reaction to warning: When residents and businessmen receive a warning they need to react fast and efficiently to protect their lives and property against flash flooding. Therefore, it is important for them to know in advance how to respond.

We also investigated participants' risk perceptions, flood beliefs, integration in local social networks, and knowledge of the warning system. These data were contrasted with each other, the background information collected on the study site and the survey. The results were published in the local press (Der Erker 08.2010) and a protocol was sent to the participants. The results of the analysis are summarized in the following section. The method can be adapted in the future to investigate also other aspects of risk governance.

8.3.3 Results and Discussion on the Flood Case Study

The FGD was analyzed with regard to vulnerability, focusing on the indicators—"flood risk awareness", "attitude on responsibilities", and "self-precaution" and "reaction to warning", as well as related topics that arose during the discussion. Participants brought up topics on exposure, responsibility of the authorities for flood precaution, emergency response, and evacuation. Another intensively discussed topic was the authorities' plans for flood control measures and the communication thereof, as well as the transparency and scope for participation that was integrated into that planning process.

Participants agreed that "everybody living here next to the river is aware of what will happen, when the river bursts its banks" stating high-risk awareness regarding floods. Contradicting this low participation of the FGD alludes lacking of flood awareness. This lack might be a consequence of having been spared of flooding for a long period.

It seems that existing flood controls support local risk awareness. Nevertheless, several residents doubt the high rating of risk levels. They reason this appraisal from the absence of severe floods after constructing defenses in the 1970s. Based on experiences from past events, residents rely on sufficient warning lead times. In contrast to this, the provincial Hydraulic Engineering Department warns that lead times are maximum 6h and flash floods can surprise at night.

It was remarkable that participants disagreed as well on the scope of self-precaution measures as on attributing responsibility for flood control. Some participants take flood precautions. Those accept private responsibility and say: "residents also have to do something themselves" to protect their own property. This group recognizes that there is no 100% flood security. In contrast, others expect very little effect from private measures and claim: "responsibility clearly lies with the authorities". The fire brigade chief and local mayors advocate this view. They consider it more efficient and fair.

This research revealed twofold effects on vulnerability and lead us to define local factors that are increasing as well as reducing vulnerability. The factors that are increasing or decreasing vulnerability are shown in Table 8.2.

The study involved local stakeholders in risk governance. It improved communication and understanding among stakeholders. Surprisingly, we found that all residents participating in the discussion agree to appreciate public flood control measures, even though they have to give up private land. Nevertheless, they demand to be informed about plans earlier and to be granted more scope for participation.

TABLE 8.2 **Factors That Increase or Decrease Social Vulnerability According to the Results of the Focus Group discussions**

Factors Increasing Social Vulnerability	Factors Decreasing Social Vulnerability
• High exposure in most areas of the town • Susceptibility of economy and critical infrastructure • Underestimation of risks • Overreliance in existing protection measures • Objectively incorrect assumptions from past experiences • Too much trust in the warning system • Often lack of feeling for own responsibility • Often little knowledge of private precaution measures	• Participants are aware of flood risks, (nevertheless overall participation was low) • Well-understood siren-based warning system • Short routes for evacuation • Some residents take private precaution measures • No oil heating being installed in endangered households (district heating instead) • Functioning local social network • Residents agree on flood defense as a target of spatial planning

Applying FGD enabled us to generate data with relevant stakeholders in a time frame that was easy to schedule and independent from external data providers. Furthermore, the application was fast and cheap and produced relevant findings, which might not have been discovered by quantitative research alone.

Understanding attitudes and beliefs that lead to or prevent taking flood defense actions is a premise for successfully encouraging vulnerable populations to take individual measures for vulnerability reduction and to understand social/cultural vulnerability. FGDs are an adequate and easy way to uncover attitudes and beliefs. Social interaction and group dynamics generate high validity, but they are sensitive to low participation and depend on good group dynamics in discussions. Results are validated by the discussion among stakeholders.

A major drawback of our case study was that a great number of affected local residents and businessmen were not integrated. Based on only 10 participants our findings have limited explanatory power. Yet, in other case studies with more recent floods the method succeeded to attract far more stakeholders.

A motivation of this case study lay in exploring the application of the method for assessing vulnerability. Testing the method has succeeded, since it provided substantial knowledge on aspects raising and reducing vulnerability in our study area. Our findings are backed up by research on social vulnerability conducted by FLOODSITE (De Marchi et al., 2007). However, constructions for an extensive river dredging for flood protection started in 2011. Therefore, the level of exposure has changed.

Additionally, this case study contributed to easing conflicts, finding a compromise between local stakeholders, and in creating mutual understanding and trust. FGD therefore proved to support vulnerability assessment and to be an efficient way to allow public participation and to reduce potential conflicts in local planning.

8.4 HEAT WAVES

8.4.1 The Study Area: The City of Bolzano

Bolzano lies in the center of the south-eastern Alps, at an altitude of about 250 m a.s.l. Due to its location in the basin of a deep valley, the city is affected by high temperatures and heat waves during the summer months. During the last 30 years, the annual average temperature in Bolzano increased by +1.5 °C (see Figure 8.5). However, not only the maximum temperature during the days but also the minimal temperature during the night is relevant to the impacts of heat stress on human health. In Bolzano, the number of tropical nights ($T_{min} > 20$ °C) has increased significantly over the last 20 years. Until 1995, Bolzano had less than five tropical nights per year, whereas 20 tropical nights were recorded in 2010.

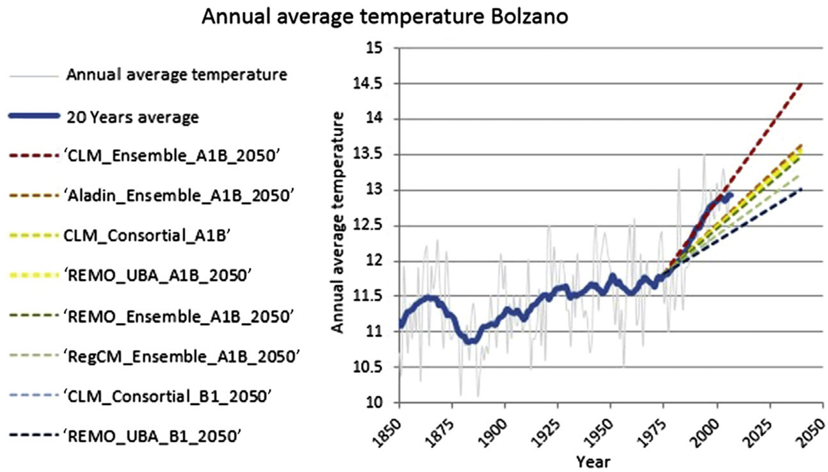

FIGURE 8.5 Warming in Bolzano. The graph shows the increase of the annual average temperature as yearly values (gray line) and smoothed as 20 year average (blue line) in the last 150 years since 1850. *EURAC based on data provided by the autonomous province of Bolzano.*

The colored dashed graphs in Figure 8.5 represent the results of various climate scenarios for South Tyrol. The measured warming from 1975 to present mainly follows the red dashed line of that scenario with the highest values of temperature increase.

8.4.2 Vulnerability Assessment Methodology for Heat Waves

The case study focuses on the social dimension of vulnerability. To establish the impact of heat waves on the citizens of Bolzano, it seemed most reasonable to focus on subgroups that are most susceptible to heat waves. As already identified by previous studies (Drinkwater and Horvath, 1979; Basu and Samet, 2002), these are the elderly.

Spatial exposure and social vulnerability were assessed by using the following methods:

1. Remote sensing (Spatial exposure):

Land-surface temperature was derived from the thermal band of various Landsat Images after atmospheric correction in order to receive rough information about temperature distribution within Bolzano. Overall 12 Landsat 5 scenes of summer months (June, July, August, and September) were used for the period 2003–2009 and in each scene the temperature deviation from each pixel to the maximum temperature value of the same scene was calculated.

2. Statistical analysis (Social susceptibility):

Correlation analysis was carried out by comparing time series of demographic and health-related data with respect to time series of meteorological data. The demographic dataset was split into various subgroups according to age and gender. Hospital emergency/admission data were divided by gender and age in order to focus on different subgroups. Two different age limits were chosen in order to establish a relationship between the climate data and the hospital data for men and women (A) aged 65 and older; and (B) aged 75 and older.

The aim of the statistical analysis was to investigate the correlation between the hospital admissions of the different subgroups and the temperature data in order to find out the most vulnerable population group. A correlation between the two datasets would show the impact of heat stress on the different subgroups and sustain the hypothesis that heat problems are an issue in Bolzano. Therefore, we compared the means of the various subgroups by performing *T*-tests.

3. Potential heat wave index (Social vulnerability):

A composite indicator was applied which combines different factors, using the semiquantitative fuzzy logic technique (Kropp et al., 2009). This approach allowed for an assessment and comparison of the social vulnerability of the five districts of Bolzano, considering spatial exposure and social susceptibility. Quantitative data provided by the province and the regional hospital of Bolzano were analyzed and visualized with the statistical programming tool R and ArcGIS within the scope of identifying the parts of the city which are more vulnerable than other ones, a comparative vulnerability assessment was then made within Bolzano. This technique has the advantage that variable values are allocated gradually rather than in binary fashion. Thus, a ranking of the districts referring to possible heat wave impacts was created.

4. Stakeholder involvement (Lack of resilience, Risk Governance):

Stakeholders such as responsible for heat waves in civil protection and municipality, experts, health care managers, representatives from volunteer organizations, and spatial planning experts were interviewed. The aim of these interviews was to collect information on awareness issues, experience with heat waves in the recent past, existing monitoring and forecast systems, and information flow issues between different institutions but also media and the population. The interviews may enable the identification of gaps and the possibilities for improvement.

The indicators used for each of the above mentioned approaches are shown in Table 8.3.

8.4.3 Results, Validation, and Discussion on the Heat Wave Case Study

Land-surface temperature maps that were produced based on Landsat satellite imagery indicated the city center, as well as the city-adjacent industrial

TABLE 8.3 **Methods and Indicators Used for the Assessment of Vulnerability to Heat Waves**

Method	Indicators
Statistical analysis	• Maximum air temperature (exposure) • Number of heat days; i.e., days with $T_{max} \geq 30\,°C$ (exposure) • Number of heat waves, i.e., number of events with three consecutive days of $T_{max} \geq 30\,°C$ (exposure) • Number of tropical nights • Number of combined heat days and tropical nights (exposure) • Relative air humidity (exposure) • Combined indicators: the dew point temperature and the heat-index. Both combine temperature and relative air humidity (exposure) (Steadman, 1979) • Elderly population divided by gender, considering different age classes (≥65 years and ≥75 years) (sensitivity indicator)
Potential heat wave index	• Percentage of impervious area (exposure) • Percentage of area with land-surface temperature >28 °C, derived from Landsat images of July 2003 (exposure) • Population density (people/km^2) (sensitivity) • Population older than 65 years (sensitivity) • Population older than 65 years living alone (sensitivity)
Stakeholder involvement	• Risk monitoring and forecasting: analysis of existing monitoring system • Information flow: analysis of the information flow in case of heat waves (responsible authority for the forecast, involvement of mass media, and dissemination through health care institutions) • Response measures for most vulnerable population groups: through interviews with managers of care homes and volunteer associations • Risk governance: assessment of the procedures of risk governance in the case study areas

zone, as the hottest areas of Bolzano. These areas are coinciding with the areas of the highest values of soil sealing. Therefore, the results require a validation check in order to be used in heat wave studies that are mainly dealing with air temperature values. Nevertheless, the land-surface temperature may indicate areas representing an urban heat island effect.

In order to identify the impact of heat waves on the elderly population of Bolzano, time series of climate data and hospital emergency/admission data for the years 2003, 2006, and 2009 were analyzed in parallel and in comparison to each other. By means of simple correlation analysis, the daily numbers of hospital emergencies/admissions were plotted against various exposure factors (maximum daily temperature, relative air humidity, etc.)

and considering a potential time-lag of a heat impact but no relationship could be established.

Boxplots that visualize the distribution of the daily number of hospital emergencies/admissions according to these exposure factors confirmed that there is no extraordinary difference between hotter and less hot days. Nevertheless, with a time-lag of 3 days, for the heat summer of 2003 a slight visible difference in the boxplots could be detected for the hospital data of both women ≥65 years and women ≥75 years between the subgroups of days without heat wave issues and the subgroup which considered only the hospital data for days with a combination of heat day conditions and tropical night conditions (see Figure 8.6(a) and (b)). For the latter, the mean value was visibly greater. However, the result of a Welch's *T*-Test which compares the mean values of the two entities shows that on a significance level of 95% there is no significant difference between the two.

The fact that no Welch's *T*-tests reached the claimed significance level is probably due to the high fluctuation rate in the number of samples per day compared to the low number of samples per day. Therefore, for small cities with such small number of samples it seems to be difficult to show correlations of weather condition and health issues by means of statistical analysis.

Additionally, a potential heat wave impact index was developed for the different districts of Bolzano in order to identify the districts that are most susceptible to heat spells (Figure 8.7). The indicators used are those proposed by Kropp et al. (2009). Problems rose through the large areas of the administrative districts incorporating parts of the cities with a large variety of urban structure and population densities and hence hindering the identification of most endangered areas.

It must be acknowledged that the index values refer to the local reality and, therefore, they have to be interpreted in a comparative way, e.g., as a ranking rather than as absolute values. An index value of 0.98 signifies that the susceptibility in the district Europa/Novacella is relatively higher than in S. Giovanni/Don Bosco or any other district. In the districts Oltrisarco/Aslag and Gries/S. Quirinio the susceptibility is about the same; and the district Centro/Piani di Bolzano is the least susceptible district. This is mostly due to the low fraction of impervious area when looking at the whole district and does not really reflect the situation in the most densely populated part of it.

Heat wave impacts are commonly measured by means of mortality rate which may increase above the expected rate during extreme heat events. Bolzano is a relatively small city with only about 100,000 inhabitants. So, it was much more difficult to clearly identify heat health related issues, since it is not possible to assess the issue by means of mortality rate as in bigger cities.

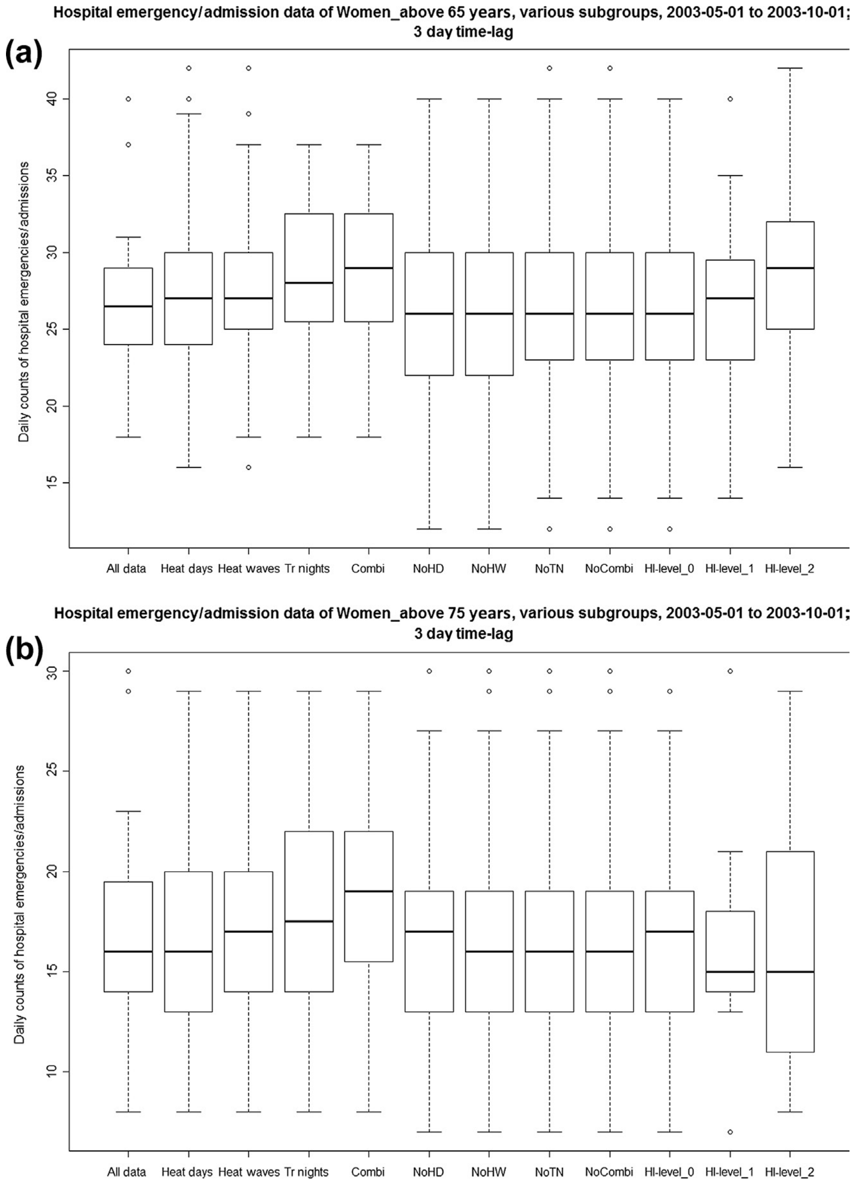

FIGURE 8.6 (a, b) The boxplots visualize the distribution of daily hospital emergency/admission counts for women (a) aged 65 years and older (the one above) and (b) aged 75 years and older (the one below) of the summer 2003 (May–September) according to various exposition factors with a time-lag of 3 days. The subgroup "Combi" (combination of days with heat wave and tropical night condition) has on average the most counts of emergencies/admissions in both plots. NoHD - Number of heat days (Number of heat days; i.e. days with maximum temperature ≥ 30 °C), NoHW - Number of heatwaves, i.e. number of events with three consecutive days of maximum temperature ≥ 30° C, NoTN - Number of tropical nights, i.e. days with minimum temperature not falling below 20 °C, NoCOMBI - Number of combined heat days and tropical nights.

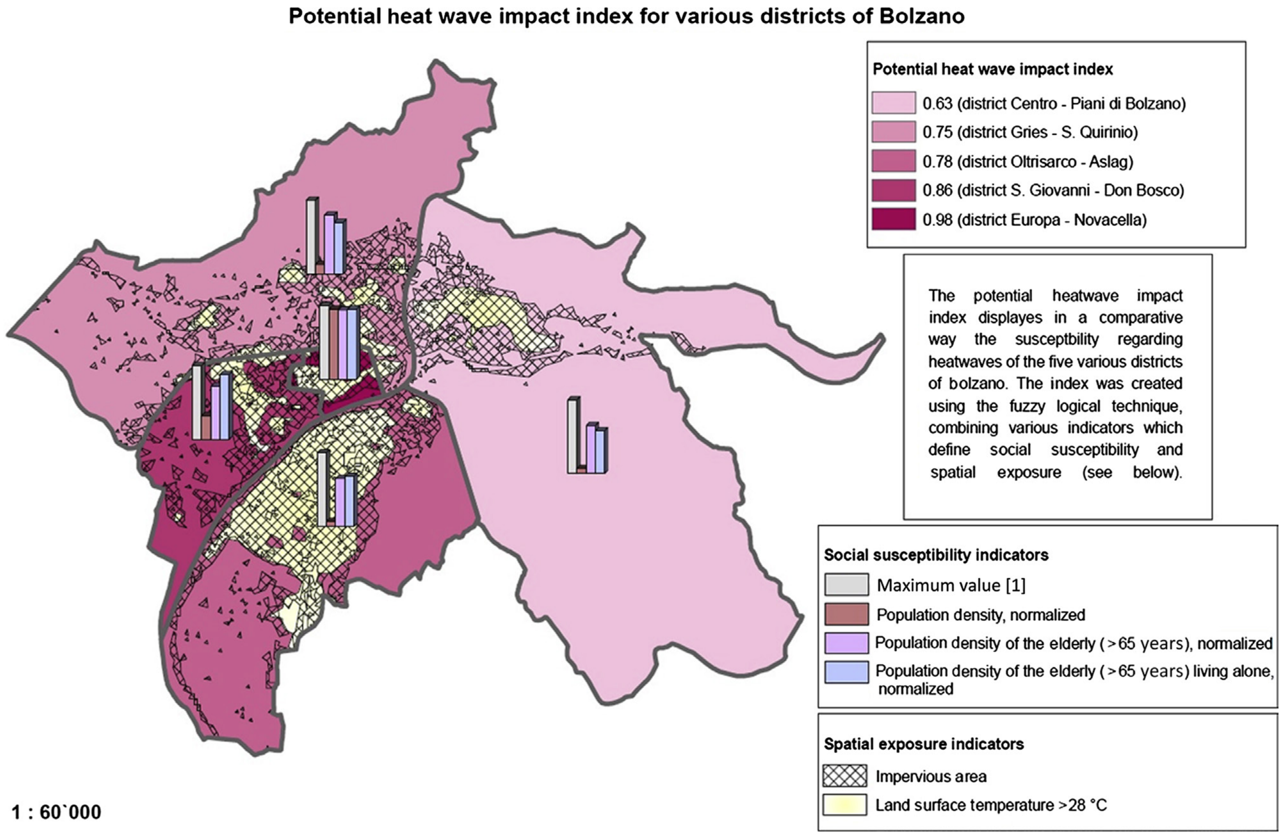

FIGURE 8.7 Potential heat wave impact index for the districts of Bolzano. The highest value was assigned to Europa/Novacella (0.98), the lowest to Centro/Piani di Bolzano (0.63). In between there are the districts S. Giovanni/Don Bosco (0.86), Oltrisarco/Aslag (0.78), and Gries/S. Quirinio (0.75).

8.5 CONCLUSIONS AND RECOMMENDATIONS

8.5.1 Landslides

A methodology for the development of a vulnerability curve for debris flow events based on information derived from past events is presented. The vulnerability curve can be used in order to assess future monetary loss in the area considering changes in the number of buildings involved. The inclusion of damages of future events in the development of the curve will increase its reliability and reduce uncertainties. Therefore, the quality of the damage information will play a major role in the reliability for the resulting curve. The results of the case study show clearly that there is a need for detailed documentation of the damages following a disastrous event. The vulnerability curve produced during the case study, together with a thorough damage documentation, can provide the stakeholders and decision makers with a tool for rapid damage assessment and loss estimation for future events. The documentation of damages and the vulnerability curve can provide information that can be used for vulnerability reduction of the elements at risk and reduction of loss due to landslides in the future.

8.5.2 Floods

Flood hazard zone maps show, in the current situation, a very high exposure for a large proportion of built-up areas of Sterzing and Pfitsch. The group discussion shows that participating residents are aware of flood risks, but assess the risk lower than flood management experts. Residents' capacity to anticipate is hampered by the long absence of floods. Residents assess risk especially for loss of life as low. Reliance on public protection measures and the warning system as well as positive experience of low damage in recent floods contribute to underestimating risks. Nevertheless, acceptance of the importance of new and better public flood protection measures is generally high among participants of the FGD. They support the reactivation of the "commission of civil protection" and putting flood defense higher on the political agenda.

Very low acceptance of self-precaution, low knowledge on private flood protection measures, and attitudes toward the split of responsibility—with participants often disclaiming their own responsibility—led to very few citizens performing private flood protection measures and therefore a low coping capacity at household scale.

8.5.3 Heat Waves

By means of a semiquantitative potential heat wave impact index, a spatial social vulnerability was shown for the five different districts of Bolzano. Hospital emergency/admission data and climate data were analyzed, but no stringent heat health issues could be shown for the elderly population of Bolzano. Nevertheless, some tendencies could be revealed which at least cannot negate a possible heat health issue due to the combination of heat days and tropical nights on elderly women. Considering future climate simulation, the frequency of heat waves will increase. In addition, the fraction of the very old people (>80 years)—hence the potentially most vulnerable—will increase due to increasing life expectancy. Therefore, it is most probable that the vulnerability related to heat wave issues in the city of Bolzano will increase and heat health impacts should be monitored more intensively in the near future.

At the moment, there are two differing heat wave warning systems at local and national level, which need to be better coordinated in order to avoid the confusion of the population. The detailed information required in order to analyze the situation in Bolzano needs extensive stakeholder involvement. Therefore, awareness of stakeholders and their interest in the investigations are key aspects for a successful study.

However, not only Bolzano but all areas of the province along the Adige River with altitudes below c. 600 m are affected by summer heat waves. Early warning systems and measures to protect those most vulnerable should be extended to those areas affected by heat waves beyond the city of Bolzano.

Furthermore, it is required to carry out long-term adaptation activities addressing urban planning issues such as the avoidance of urban heat islands and the extension of green areas.

A general recommendation is to increase awareness of the heat wave problematic, and the probable future aggravation of it, among policy makers, institutions, and citizens. This would build a stronger base and would raise acceptance for measures to mitigate and adapt to heat waves in Bolzano and the other affected areas of the Province.

8.5.4 Conclusions

South Tyrol is susceptible to a number of hazard types. Climate change is expected to influence in the future the magnitude and frequency of some events; however, the vulnerability of the population is also expected to change (more elderly people in the future) and should also be considered in future plans. Reducing vulnerability to natural hazards is the key to risk reduction. In this chapter, different dimensions of vulnerability were assessed by using a number of methods. The case study results in a number of recommendations, including better damage documentation for landslide events, development of long-term adaptation activities for more areas in south Tyrol regarding heat waves, and the enhancement of the coping capacity of citizens for flood events. The methods used in this chapter can be modified to be used for different types of hazards, but they can also be transferred to other places with similar hazard types.

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