Nat. Hazards Earth Syst. Sci. Discuss., 3, 2419–2449, 2015
www.nat-hazards-earth-syst-sci-discuss.net/3/2419/2015/
doi:10.5194/nhessd-3-2419-2015

Natural Hazards and Earth System Sciences
Discussions
Open Access

The hostel or the warehouse? Spatiotemporal exposure assessment for natural hazards

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Received: 23 March 2015 – Accepted: 27 March 2015 – Published: 10 April 2015

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Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

A spatially explicit object-based temporal assessment of buildings and citizens exposed to natural hazards in Austria is presented, including elements at risk to river flooding, torrential flooding, and snow avalanches. It is shown that the repeatedly-stated assumption of increasing losses due to continued population growth and related increase in assets has to be opposed to the local development of building stock. While some regions have shown a clearly above-average increase in assets, other regions were characterised by a below-average development. This mirrors the topography of the country, but also the different economic activities. While hotels and hostels are extraordinary prone to mountain hazards, commercial buildings as well as buildings used for recreation purpose are considerably exposed to river flooding. Residential buildings have shown an average exposure, compared to the amount of buildings of this type in the overall building stock. In sum, around 5 % of all buildings are exposed to mountain hazards, and around 9 % to river flooding, with around 1 % of the buildings stock being multi-exposed. It is shown that the dynamics of elements at risk exposed have a time lag once land use regulations are enforced, and it is concluded that an object-based assessment has clear advantages compared to the assessment using aggregated land use data.

1 Introduction

World-wide data on natural disasters suggest an increasing number of reported events, of people affected and economic losses, but – in the most-developed countries – a decreasing number of reported fatalities since around 1900 (e.g. CRED, 2014; Munich Re, 2014). Regional analyses supplement these global data, but these regional data are less-well available because they are often not collected in global databases due to relatively low event magnitudes only affecting society on a regional or even local scale (United Nations, 2013). Focusing on mountain regions, an increase in hazardous events and associated losses is repeatedly claimed (a) as a result of increasing exposure of elements at risk (Mazzorana et al., 2009; Preston, 2013), (b) due to natural fluctuations in flood frequencies (Schmocker-Fackel and Naef, 2010), and (c) due to the effects of climate change (e.g. Huggel et al., 2012; Korup et al., 2012). A review of Fuchs et al. (2013) has shown that overall conclusions on the dynamics of natural hazards, including floods, landslides and snow avalanches, may be challenging due to the inherent complexity behind data. In Fig. 1, the annual number of natural hazards occurring in the Eastern European Alps (Republic of Austria) is shown. The data for the period 1900–2014 is describing snow avalanches, torrential flooding, landslides and river flooding, as well as the 10 years moving average of the total amount per year. While between 1900 and 1960 an increase in the annual number of hazard events of around a factor of four can be concluded – presumably also due to an increased event observation – between 1960 and 2000 a decrease of around 50 % is traceable. This decrease is in clear contrast to the world-wide data (e.g. Keiler, 2013) and may result from (a) increased efforts into technical mitigation (Keiler et al., 2012) and (b) an increased awareness of threats being consequently considered in land-use planning (Wöhrer-Alge, 2013; Thaler, 2014) and leading to less exposure. Since 2000, the number of reported events is again increasing. During the period of investigation, specific years with an above-average occurrence of individual hazard types can be traced as for example snow avalanches in 1951, 1954, 1999 and 2009, torrential flooding in 1965, 1966, 2005 and 2013, and river flooding in 1904, 1959, 1966 and 2002. Apart from the ongoing discussion of the effects of climate change influencing the hazard trigger (e.g. Auer et al., 2007; Keiler et al., 2010; Lung et al., 2013), the effects of dynamics in exposure have so far not been studied sufficiently as a possible reason behind the process dynamics shown in Fig. 1. Since spatially explicit data on the dynamics of exposure were missing so far, data on the temporal dynamics of natural hazards resulted in misleading conclusions, and studies on dynamics in hazardous processes may therefore have over-emphasized the effects of climate change.

Focusing on exposure, the effectiveness of natural hazard risk management depends on the availability of data and in particular an accurate assessment of elements at risk (Jongman et al., 2014), which also requires a temporal and spatial assessment of their dynamics. Until now, however, in mountain regions of Europe such data has only been available on the local scale as a result of individual case studies. Such – often conceptual – studies related to the temporal dynamics of exposure to mountain hazards include both the long-term and the short-term evolution of risk indicators. Long-term changes were found to be a result from the significant increase in numbers and values of buildings endangered by natural hazard processes, and can be observed in both rural and urban mountain areas of Europe (Keiler, 2004; Fuchs et al., 2005; Keiler et al., 2006a; Shnyparkov et al., 2012). Short-term fluctuations in values at risk supplemented the underlying long-term trend, in particular with respect to temporary variations of people being present in endangered areas and of vehicles on the road network (Fuchs and Bründl, 2005; Keiler et al., 2005; Zischg et al., 2005).

It has been repeatedly claimed with respect to flood hazards in Europe that the main driver of increases in observed losses over the past decades is increased physical and economic exposure (Bouwer, 2013; Hallegatte et al., 2013; Jongman et al., 2014). First results from mountain regions confirm such conclusions and suggest that the spatial occurrence of losses is not so much dependent on the occurrence of specifically large events with high hazard magnitudes but more a result of an increased amount of elements at risk in endangered areas (Fuchs et al., 2012). Most of the recent works, however, rely on local studies (Zischg et al., 2004; Fuchs et al., 2012) or aggregated land use data (Bouwer et al., 2010; de Moel et al., 2011; Cammerer et al., 2013), leading to substantial uncertainties in risk assessment (de Moel and Aerts, 2011; Jongman et al., 2012a) and neglecting any local-scale dynamics which may be specifically responsible for increasing exposure due to the relatively scarceness of development plots in mountain areas (Holub and Fuchs, 2009). Because of the limited data availability, comprehensive object-based and therefore spatially explicit analyses have thus not been extended beyond the regional level (Huttenlau et al., 2010; Zischg et al., 2013), and

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studies focusing on the national level in mountain regions using such data remain fragmentary (Fuchs et al., 2013).

In order to close this gap, we show how detailed property level data can be used to improve the understanding of trends in hazard exposure on a national level, and how this knowledge provides valuable input for local-scale natural hazard risk management.

2 Methods

This study is based on two different datasets, (a) hazard information providing input to the exposure of elements at risk, and (b) information on the building stock combined from different spatial data available on the national level. We considered hazard information for river flooding, torrential flooding including debris flows, and snow avalanches since these hazard types are responsible for the majority of damages in the European Alps (Sinabell and Url, 2007; Hilker et al., 2009). In the following, the composition and preparation of datasets is described.

2.1 Hazard information

For mountain hazards (torrential hazards defined as constantly or temporarily flowing watercourses with strongly changing perennial or intermittent discharge, sediment load and flow conditions (ONR, 2009) and snow avalanches) existing hazard maps were used. Hazard maps usually refer to an individual community, and depict the area affected by a design event with a return period of 1 in 150 years (Republik Österreich, 1976). Red hazard zones indicate those areas where the permanent utilisation for settlement and traffic purposes due to the exposure to the design event is not possible or only possible with extraordinary efforts for mitigation measures. Yellow hazard zones indicate those areas where a permanent utilisation for settlement and traffic purposes is impaired by the design event. The red and yellow hazard zones were combined for the query in order to select exposed property. The digital dataset was provided by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management in March 2013 and included 92 % of all communities with an obligation for hazard mapping in Austria.

For river flooding data from the digital eHORA platform (http://www.hochwasserrisiko.at/) was used. This data on river flooding is unique in Europe and has been jointly implemented by the Federal Ministry of Agriculture, Forestry, Environment and Water Management and the Austrian Insurance Association on more than 25 000 river km (Stiefelmeyer and Hlatky, 2008). By using a hydrological model runoff data for a 1 in 30, 100, and 300 year event was computed and converted into water levels and flood zones based on a nation-wide DEM and a digital slope model. Following an ongoing discussion on the harmonisation of hazard mapping in Austria (Rudolf-Miklau and Sereinig, 2009), the 1 in 100 year event was provided by the Austrian Insurance Association in terms of a vector representation of flood plain boundaries and taken for our analysis.

2.2 Data on the building stock

Since the implementation of the Federal Law related to the Building Register (Republik Österreich, 2009), municipalities in Austria are responsible for the collection and digital processing of specified information related to the entire building stock. This information is centrally stored in a database and contains information on the location and size of each building, as well as on the building category and the construction period (1919–2000) and year of construction (since 2001), respectively (Statistik Austria, 2012). Additional information related to the individual floors, such as their height and net area, main purpose and configuration, is included. Moreover, this dataset has an interface to the population register and allows therefore retrieving the number of primary residents per accommodation unit for each building. Because this information contains x and y coordinates based on the address it can be processed within a GIS environment. Each building is characterized by the main use, which is assessed by the net area of used space for different purposes of every floor. If at minimum 50 % of the total net area of the building is for residential purpose, the building is characterized as a residential building. If the total sum of net areas for residential use is below 50 %, the main use is derived from the use with the largest total net area. If the net area of different types of use is the same, the main use is hierarchically classified in decreasing order by (1) hostels and hotels, (2) office buildings, (3) commercial buildings, (4) communication and transportation buildings, (5) industrial buildings, (6) buildings for cultural activities and leisure, (7) agricultural buildings, (8) sacral buildings. Since the amendment of the respective law (Republik Österreich, 2013) the data may be used by the Federal administration for research purpose, and as such the information was made available through the Federal Ministry of Agriculture, Forestry, Environment and Water Management.

2.3 Exposure analysis

In exposure analysis, the building dataset was intersected with the hazard information. The hazard information was represented as polygon, and the address location in terms of x and y coordinates by a point. A relational database composed from different modules was created.

With the exception of sacral buildings, an economic module was used to compute the monetary value of buildings exposed using (a) an auxiliary dataset on the building footprint of every building retrieved from the digital cadastral map, (b) the information of the building register such as building type, number of storeys and utilisation, and (c) regionally averaged construction costs following a method outlined in Fuchs and Zischg (2013) based on Keiler et al. (2006b) and Kranewitter (2002). The construction costs were based on replacement values instead of market values following general insurance principles (Fuchs and McAlpin, 2005), and were adjusted to inflation using the respective index of construction costs (Statistik Austria, 2013).

An exposition module was applied to connect the spatially-defined information from the building register (x and y coordinates) to the hazard information in order to achieve information whether or not a building is exposed. Using GIS and information from the digital cadastral map it was tested whether or not the spatial location of a building corresponds to the point information of the digital building register. If the location of the x and y coordinates of the building did not match exactly with the location of the building, they were snapped to the border of the nearest building footprint available within a distance of ≤ 15 m around a polygon. Address information inside a polygon or in a distance exceeding 15 m were not changed, the first was included in the analyses as point information, the latter was excluded due to missing preciseness in geographic location. Assuming that hazards may damage buildings also if just parts are affected, an intersection between the building footprint and the hazard information was made. Thereby, any building was computed as being part of the highest hazard intensity level it was intersecting with.

Using information of the population register, the number of exposed citizens (principal residences) was calculated on the level of individual buildings.

The spatial and temporal analyses were relying on the information in the digital building register, i.e. on the construction period and construction year, respectively. This means that the dynamics of elements at risk analysed is based on present-day values and actual numbers of citizens exposed, and can neither be used to deduce the historical composition of society, nor the historical value distribution. However, this approach can be used to show the temporal and spatial dynamics beyond the economic development in the country, and may therefore serve as a proxy for the absolute development of exposure.

3 Results

In the following sections results from the analyses are presented, focusing on the amount of exposed buildings and citizens. Both the spatial and temporal analyses resulted in considerable heterogeneities among the communities and among different building categories. In Sect. 3.1 the results of the spatial analysis are shown, and in Sect. 3.2 the results of the temporal analysis are presented.

3.1 Results spatial analysis

In Austria, 2 399 500 million buildings are located, 319 026 of which (13.3 %) are exposed to natural hazards (Table 1). Of these almost 2.4 million buildings, 9 % (219 359) are exposed to river flooding, and 5 % to mountain hazards (torrential flooding 111 673 and snow avalanches 9009). Altogether, 298 248 buildings (93.5 % of exposed buildings and 12.4 % of the entire building stock in Austria) are exposed to one hazard type, and 20 778 buildings (6.5 % of exposed buildings and 0.9 % of the entire building stock in Austria) are exposed to more than one hazard type: 18 089 buildings are exposed to river and torrential flooding, 2595 to torrential flooding and snow avalanches, 568 to snow avalanches and river flooding, and 237 to river and torrential flooding as well as snow avalanches.

Citizens exposed were defined as primary residents according to the compulsory residency registration. When comparing the building stock with the number of primary residents, a slightly higher percentage (9.7 vs. 9.1 %) of citizens is exposed to river flooding, while to mountain hazards, a lower percentage (5.0 vs. 4.3 %) is affected. In total, 1 125 601 citizens are exposed to natural hazards, 1 058 594 (94.0 % of the exposed residents and 13.3 % of the entire population) to one type of hazard and 67 007 (5.95 % of the exposed residents and 0.8 % of the entire population) to more than one hazard type (Table 2).

Analysing the data set according to the type of building, a considerable part of the building stock is composed from residential buildings (category 1–3), but also a high amount of hotels (category 4) and commercial buildings (category 5–8) is exposed (Table 3):

- A total of 2 056 322 residential buildings represent 85.7 % of the entire buildings stock in the country, but only 12.62 % of them (259 687) are exposed.

- A total of 140 470 commercial buildings represent 5.86 % of the entire buildings stock in the country, and 21.06 % of them (29 593) are exposed.

- A total of 37 272 hotels and hostels represent 1.55 % of the entire buildings stock in the country, and 23.04 % of them (8589) are exposed.

Analysing Fig. 2 it becomes evident that – with the exception of hostels and hotels – the percentage of buildings exposed to torrential flooding is below the percentage of buildings exposed to river flooding. A relatively high share of buildings from the category of residential buildings and commercial buildings is exposed to river flooding, whereas apart from hostels and hotels a considerable percentage of sacral buildings and agricultural buildings is exposed within the hazard type of torrential flooding. The percentage of hotels exposed to torrential flooding is even higher than the percentage of hotels exposed to flooding, which is exceptional: the other building categories exposed to torrential hazards fall relatively below the river flooding exposure. Only a minority of buildings is exposed to snow avalanches. Moreover, it can be deduced from Fig. 2 that the exposed values are higher for buildings exposed to river flooding in almost all building categories, and lower for buildings exposed to torrential flooding. The exception is again within the group of hostels and hotels, as well as agricultural buildings, garages, pseudo buildings and detached houses. Sacral buildings were not considered during economic analysis.

If queried spatially on a municipal level, considerable differences were manifest throughout the country, as shown in Fig. 3 by using a bipolar representation. The reference for the figures in the right column was the entire amount of municipalities in Austria. The reference for the figures in the left column was those communities which are affected by the respective hazard, which in turn means that communities with no data available (grey colours) were not considered during the set of computations.

- Regarding snow avalanches, the mean number of exposed buildings is 30.4 per municipality focusing on avalanche-prone municipalities, and 3.8 if all municipalities are considered during computation. The highest exposure is found in those municipalities next to the main chain of the Alps in western Austria (Federal States of Vorarlberg and Tyrol).

- The mean number of buildings exposed to torrential processes is 87.7 per municipality focusing on torrent-prone municipalities, and 47.7 if all municipalities are considered during computation. Apart from some outliers the highest exposure can be found in the Federal State of Salzburg as well as in municipalities of adjacent Federal States.
- River flooding is a threat to the entire country, and a mean number of 97.1 buildings is exposed per municipality, and 93.2 if also the few non-exposed municipalities are considered during computation. Due to the considerable amount of buildings exposed to river flooding in the larger Vienna agglomeration, the highest exposure can be found in this area. Moreover, communities along the larger rivers show an above-average exposure.

3.2 Results temporal analysis

In Fig. 4 the temporal analysis of the building stock in Austria is presented. There is evidence that the absolute number of buildings exposed to individual hazard types follows a steady increase in the country, which means that over the study period there were no exceptionally construction activities traceable in either flood-prone areas or areas prone to torrential hazards (Fig. 4a). In contrast, a considerable increase of non-exposed buildings is evident for the period since the 1950s. Additionally, it can clearly be shown that snow avalanche hazard is not a major threat in the country, even if individual events occurred leading to considerable economic loss in recent decades (Fuchs et al., 2013). Since 1919, the total number of properties in Austria has increased by 643 % from 373 067 to 2 399 500 buildings. For 4.25 % of buildings, however, a year of construction was missing in the data and they were therefore excluded from further analysis. The total number of properties exposed to river flooding has increased by 650 % from 33 697 to 219 359 buildings (4.16 % excluded due to missing information on the year of construction). The total number of properties exposed to torrential flooding has risen by 594 % from 18 797 to 111 673 buildings (3.35 % excluded due to missing information on the year of construction). The total number of properties exposed to snow avalanches has risen by 433 % from 2081 to 9009 buildings (2.9 % excluded due to missing information on the year of construction). Based on absolute figures it has to be concluded that the growth rate is almost the same for buildings exposed to river flooding and non-exposed buildings, whereas for torrential flooding the growth rate is slightly lower and for snow avalanches the rate is considerably lower.

In Fig. 4b, the growth rate is shown for the building stock exposed to torrential and river flooding as well as snow avalanches, based on the respective construction period 1919–2012. Additionally, the growth rate of the overall building stock is provided. While the growth rate of the buildings exposed to river flooding is above the overall growth rate over the entire time period, the growth rate of buildings exposed to torrential flooding is below this rate for the period prior to 1960 and after 1980. For the period 1960–1980, both rates are almost the same. The growth rate of buildings exposed to snow avalanches is clearly below over the entire time span.

In Fig. 4c, the average annual amount of newly constructed buildings is shown for the different hazard categories. Until the 1970s, this amount has risen remarkably and since then, the number of new constructions is decreasing. Since 2000, however, there is again a slight increase detectable. What is evident, however, that both curves follow the same pattern over the study period. The annual growth was lowest in the period 1919–1944 (snow avalanches: 19, torrential flooding: 286, river flooding: 731 new buildings per year, for comparison annual growth for the entire building stock: 6894 buildings per year) and highest in the period 1971–1980 (snow avalanches: 132, torrential flooding: 1614, river flooding: 2931 new buildings per year, for comparison annual growth for the entire building stock: 33 515 buildings per year). Currently, 78 buildings are constructed each year in avalanche-prone areas, 1028 in areas prone to torrential flooding, and 2172 in areas prone to river flooding, while 26 814 buildings are constructed annually throughout the country.

The results of a cumulative analysis including the entire building stock and focusing on inter-annual changes in the construction activity between exposed buildings and the total building stock are shown in Fig. 4d by the relation between annual dynamics in new constructions per year against the respective entire building stock. Because of the relatively low amount of exposed buildings in the country (cf. Table 1), the resulting percentage is low. For river flooding, a slight increase in the amount of elements at risk from 9 to 9.8 % is detectable until the 1960s and since then a slight decrease to 9.2 % can be proven. In contrast, with respect to torrential flooding, the percentage of annual new constructions is slightly decreasing from 5 to 4.8 % for the period 1919–1944, subsequently increasing to 5.1 % until 1970, and decreasing again to 4.7 %. For snow avalanches, the values are slightly decreasing over the entire period under investigation from 0.6 to 0.4 %. The overall dynamics, however, are within percent range. The buildings exposed to river flooding and torrential flooding are increasing in value compared to the non-exposed buildings, in particular during the period 1944–1990.

If this data is related to the annual construction activities only, neglecting the high amount of already existing buildings, a reverse trend becomes obvious (Fig. 4e): the annual amount of newly-constructed exposed buildings vs. newly-constructed buildings regardless of the exposure is decreasing since the 1940s, but with different rates. The only exception is a decade of 1981–1990, where the percentage of buildings exposed to river flooding is slightly increasing, and the period between 1919–1944 and 1945–1960 with an increase from 4.2 to 5.5 %. For river flooding, the percentage of new development decreased from 10.6 to 8.1 % for the period under investigation, while for torrential flooding the decrease is from 4.2 to 3.8 %. For snow avalanches, the percentage is within a range of 0.3–0.4 % only.

4 Discussion

The results presented confirmed that a spatially inclusive and comprehensive assessment of exposure provides more insights compared to previous studies centred on a local-scale. Whereas so far a general increase in the building stock could only be proven for selected case studies if data is analysed object-based (Keiler, 2004) or aggregated in terms of land-use classes (Cammerer and Thieken, 2013), the presented results suggest a more diversified conclusion.

Around 13 % of the entire building stock is exposed to natural hazards in Austria, and considerable regional differences are manifest: while in the Federal States of Salzburg and Tyrol, 28.5 and 26.3 of the entire building stock is exposed, in Vienna it is only 1.9 %. While only around 5 % of all buildings in Austria are exposed to mountain hazards (torrential flooding and snow avalanches), around 9 % are exposed to river flooding. Above-average exposure to mountain hazards can be found in the Federal States of Salzburg, Tyrol and Vorarlberg, and buildings in Salzburg, Tyrol and Lower Austria are exceptionally prone to river flooding (Tables 1 and 2). Almost 1 % of the entire properties have to be classified as being multi-exposed, which is, according to the topography of the country, a very low value.

The share of residential buildings in the entire building stock is 85.7 %, and with an exposure of 13.4 % this building category represents the average exposure in Austria. The category of hotels and hostels makes only around 1.6 % of the entire building stock, but almost 26 % of all of these buildings are prone to natural hazards. Almost 6 % of all buildings are commercial buildings, but almost one fourth (23 %) of all of these buildings is exposed to mountain hazards and river flooding. Similarly, a high share of exposed buildings is within the category of buildings for cultural activities (20.6 %) and agricultural buildings (11.5 %). Given the economic structural change from the primary to the tertiary sector within the country, a high number of hotels is located in mountain tourist-spots, which explains the high exposure to mountain hazards. In turn, in regions with an emphasis on the secondary sector, a considerable share of commercial buildings, which are usually space-requiring, is located in flood plains of larger rivers or – historically grown – along mountain torrents because of the demand for hydropower. The category of buildings for cultural activities also requires space, and is therefore also often located in the flood plains. These areas were traditionally also used for agricultural purpose, which explains the above-average presence of agricultural buildings in these areas.

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The spatial distribution of exposure, aggregated on the community level, confirms these results and clearly shows the demand for future investments into risk management in particular in those communities with an above-average exposure to individual hazard types (Fig. 3). While most communities with an extraordinary share of buildings prone to mountain hazards are located in the mountain part of Austria, communities with an above-average exposure to river flooding are cities or centred on agglomerations in the alpine foreland.

Focusing on the temporal development, a heavy increase in the entire building stock but also in exposed buildings is evident for the last decades (Fig. 4a). This growth of around a factor of six and a factor of four (snow avalanches) supports the suggestion that increased physical and economic exposure may be responsible for occurring losses (Bouwer, 2013; Hallegatte et al., 2013; Jongman et al., 2014), even if loss data from the European Alps cannot directly support this conclusion: an analysis of destructive torrent events between 1950 and 2008, derived from a reanalysis of written reports which were compiled during the implementation of hazard maps by the Austrian Torrent and Avalanche Control Service had shown a decreasing trend related to the overall number [$N = 9852$, annual mean = 167] (Oberndorfer et al., 2007). However, considerable events were observed in individual years, in particular in the western part of Austria (Fuchs, 2009). As such the number of documented hazards as shown in Fig. 1 should not directly be used to draw conclusions on the development of losses and exposure: while the overall stock of exposed buildings as well as the non-exposed buildings increased by a factor of 2.3 between 1960 and 2000, the number of damaging hazard events was almost divided in half. With respect to the annual growth rate of non-exposed and exposed buildings, the total building stock as well as the buildings exposed to river flooding and torrential flooding show similar characteristics and a rate of around a factor of six (Fig. 4b). The buildings exposed to snow avalanches again have a below-average rate (around 4.2). The total amount of new constructions, in contrast, increased since 1944 and culminated in the period 1971–1980 followed by a sharp decrease and an additional increase since 2000 (Fig. 4c).

Comparing the ratio between new constructions and the existing building stock (Fig. 4d) and the annual ratio of new constructions inside hazard-prone areas and the total new construction (Fig. 4e), a time lack between actual planning decisions and their effects on risk becomes evident. While the ratio of buildings exposed to river flooding compared to the cumulative development of buildings stock is increasing until the 1960s, the ratio of annual constructions inside endangered areas is already decreasing starting with 1945 by reason of the relatively high amount of non-exposed buildings in Austria (almost 87 % of the entire stock). With the exception of the decade 1981–1990, were a slight increase in this annual ratio is detectable, both the annual ratio of exposed to non-exposed buildings and the ratio between exposed buildings and the entire stock is decreasing. This may be interpreted as success of land-use planning activities (namely hazard mapping and the related ban of new constructions inside red hazard zones), even if a clear relation between new constructions and the implementation of hazard maps cannot be deduced. Because fewer buildings are exposed to torrential flooding, this pattern cannot be followed in this category of exposure: for torrential flooding both the annually constructed amount of buildings exposed compared to the entire building stock (Fig. 4d) and the annual amount of constructions inside endangered areas (Fig. 4e) is decreasing until 1944, followed by an increase until 1970 and 1960, respectively. Since then, both ratios are continuously decreasing. This clearly shows the dependency of success in land-use planning on the initial situation, and in turn reveals the challenge in exposure in a different light: even if the ratio of annual new development inside and outside endangered areas is decreasing, the effects will be unveiled decades later. More precisely, the fewer buildings are exposed in comparison to the entire buildings stock, the longer land-use regulations enacted today will take to show success.

Taking these results and assuming a further development of construction activity in Austria following the numbers of the period 1919–2012, a continued increase of buildings exposed to river flooding of 2 % yr^{-1} – compared to the entire building stock – would result in plus 530 000 buildings until 2100. If new constructions would be banned immediately in areas exposed to flooding and the annual growth rate of the new constructions is assumed as 2 %, in the year 2100 still 3.4 % of the entire building stock would be exposed to river flooding, and 1.7 % to torrential flooding. This clearly highlights the importance of risk management actions, and shows the considerable time lag as a result of previous land-use decisions.

5 Conclusions

A detailed and spatially explicit object-based assessment of buildings exposed to natural hazards in Austria was undertaken, including elements at risk to river flooding, torrential flooding, and snow avalanches. It has been shown that the repeatedly-stated assumption of increasing losses due to continued population growth and related increase in assets has to be opposed to the local development of building stock. While some regions have shown a clearly above-average increase in assets, other regions were characterised by a below-average development. This mirrors the topography of the country, but also the different economic activities: as such, hotels and hostels were found to be extraordinary prone to mountain hazards, and commercial buildings as well as buildings used for recreation purpose to river flooding. Residential buildings have shown an average exposure, compared to the amount of buildings of this type in the overall building stock. In sum, around 5 % of all buildings are exposed to mountain hazards, and around 9 % to river flooding, with around 1 % of the buildings stock being multi-exposed.

The temporal assessment revealed differences in the absolute number and annual growth rate of different categories of elements at risk exposed to different hazard types. In general, twice as much buildings were found to be exposed to river flooding than to mountain hazards. River flooding regularly causes economic loss of relatively low size per building, but affects larger regions than mountain hazards and may therefore produce a higher cumulative loss. In contrast, mountain hazards occur more locally but affect also human life. To give an example, between 1972 and 2004 49 fatalities due to torrential flooding and were reported in Austria (1.53 per year, Fuchs et al., 2007) and between 1998 and 2003, 29 fatalities inside buildings affected by snow avalanches occurred (5.8 per year, Luzian and Eller, 2007). Moreover, the analysis of average new constructions in hazard-prone areas has shown a decreasing trend since the 1990s only, leading with a time lag of decades to an overall relative decrease of the building stock exposed. This leads to the conclusion that despite respective legal regulations (Holub and Fuchs, 2009), hazard mapping seems to have only an influence on land-use planning in Austria in the long-term due to the high amount of already existing older buildings. In contrast, the number of citizens exposed has been increasing during the last century.

It can be concluded that an object-based assessment has clear advantages compared to the traditional aggregated computation: exposure to natural hazards is heterogeneous, and follows small-scale patterns which cannot necessarily be satisfyingly modelled with the common approaches of aggregation. The accuracy of such information can be used – together with downscaled climate projections and combined with appropriate hazard models – to provide valuable risk estimates on a local scale. Taking the findings of this study, major benefits of an object-based assessment can be summarised as follows:

- Since information on the building stock become increasingly available throughout Europe (e.g. Jongman et al., 2012b), more accurate information on values exposed and on the temporal development of exposure can be obtained contributing to strategic hazard and risk management.
- Small-scale differences in exposure can be precisely shown, which allows for more differentiated management strategies such as local structural protection (Holub et al., 2012) or tailored insurance solutions (Paudel et al., 2013; Carina et al., 2014). Moreover, the results allow for adjusting adaptation strategies (Rojas et al., 2013).

- As a result, public investments in mitigation measures can be targeted at regions with higher values at risk, which follows the axiom of spending public funding with the highest return of investments (Meyer et al., 2013).

- Taking the results of this study it will be possible to enhance risk communication. By compiling target-oriented risk information stakeholders including affected citizens will be better informed (Fuchs et al., 2009) which is also a clear statement by the administrations and political bodies (e.g. EU Floods Directive).

The presented method together with the results may be used for similar assessments in other European countries, such as already available for the Netherlands (Jongman et al., 2014), and beyond, in order to get a more precise over view on exposure and possible losses. This may link the development of losses to socio-economic development indicators, and improve available risk management options facing the challenge of global environmental change.

Acknowledgements. This study was supported by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management. The authors kindly acknowledge data provision by Thomas Hlatky, Austrian Insurance Association.

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Table 1. Buildings exposed to river flooding, torrential flooding, and snow avalanches according to the Federal States. Data source: Fuchs and Zischg (2013).

					Single exposure			Multi-exposure			
Federal state	Buildings [N]	Non-exposed buildings [N]	Exposed buildings [N]	Exposed buildings [%]	River flooding [N]	Torrential flooding [N]	Snow avalanches [N]	River flooding and torrential flooding [N]	Torrential flooding and snow avalanches [N]	River flooding and snow avalanches [N]	Torrential flooding, river flooding and snow avalanches [N]
Burgenland	133 482	123 905	9577	7.2	9439	140	0	2	0	0	0
Carinthia	185 693	161 782	23 911	12.9	17 012	8466	188	1660	95	10	10
Lower Austria	648 693	569 085	79 608	12.3	73 239	8381	6	2018	0	0	0
Upper Austria	425 718	378 307	47 411	11.1	37 836	12 471	137	2950	22	71	10
Salzburg	139 377	99 662	39 715	28.5	20 360	23 800	594	4684	319	128	92
Styria	381 484	331 065	50 419	13.2	27 953	25 695	460	3530	130	52	23
Tyrol	192 381	141 735	50 646	26.3	25 635	24 631	4465	2975	924	276	90
Vorarlberg	106 098	91 910	14 188	13.4	4334	8089	3159	270	1105	31	12
Vienna	186 574	183 023	3551	1.9	3551	0	0	0	0	0	0
Sum	2 399 500	2 080 474	319 026	13.3	219 359	111 673	9009	18 089	2595	568	237

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Table 2. Principal residents exposed to river flooding, torrential flooding, and snow avalanches according to the Federal States. Data source: Fuchs and Zischg (2013).

					Single exposure			Multi-exposure			
Federal state	Principal residents [N]	Non-exposed residents [N]	Exposed residents [N]	Exposed residents [%]	River flooding [N]	Torrential flooding [N]	Snow avalanches [N]	River flooding and torrential flooding [N]	Torrential flooding and snow avalanches [N]	River flooding and snow avalanches [N]	Torrential flooding, river flooding and snow avalanches [N]
Burgenland	284 735	267 378	17 357	6.1	17 092	266	0	1	0	0	0
Carinthia	556 248	478 721	77 527	13.9	58 784	23 057	367	4478	203	20	20
Lower Austria	1 621 951	1 393 880	228 071	14.1	212 713	21 155	9	5806	0	0	0
Upper Austria	1 422 853	1 257 724	165 129	11.6	137 850	38 117	307	10 917	57	199	28
Salzburg	535 671	356 248	179 423	33.5	111 614	85 265	1621	18 008	969	424	324
Styria	1 212 345	1 044 934	167 411	13.8	105 888	70 219	913	9296	249	115	51
Tyrol	719 304	495 781	223 523	31.1	144 072	80 218	13 376	10 901	2542	918	218
Vorarlberg	373 566	328 682	44 884	12.0	16 363	24 749	6976	848	2318	56	18
Vienna	1 759 940	1 737 664	22 276	1.3	22 276	0	0	0	0	0	0
Sum	8 486 613	7 361 012	1 125 601	13.3	826 652	343 046	23 569	60 255	6338	1732	659

Table 3. Buildings exposed to natural hazards according to different building categories.

						Single exposure			Multi-exposure			
Building categories	Buildings [N]	Buildings [%]	Non-exposed buildings [N]	Exposed buildings [N]	Exposed buildings [%]	River flooding (HORA100) [N]	Torrential flooding [N]	Snow avalanches [N]	River flooding and torrential floading [N]	Torrential flooding and snow avalanches [N]	River flooding and snow avalanches [N]	Torrential flooding, river flooding and snow avalanches [N]
Detached houses (1)	1 510 151	62.94	1 335 938	174 213	11.54	119 189	60 424	4607	8600	1280	221	94
Duplex houses (2)	542 118	22.59	457 359	84 759	15.63	56 195	32 477	2308	5421	681	177	58
Apartment buildings (3)	4053	0.17	3338	715	17.64	528	204	38	37	18	3	3
Hotels and hostels (4)	37 272	1.55	28 683	8589	23.04	4217	4622	994	895	302	82	35
Office buildings (5)	31 420	1.31	25 551	5869	18.68	4815	1325	63	315	17	5	3
Wholesale and retail buildings (6)	32 583	1.36	25 646	6937	21.29	5612	1761	73	481	25	5	2
Communication and transportation buildings (7)	4319	0.18	3525	794	18.38	544	295	53	73	24	9	8
Industrial buildings (8)	72 148	3.01	56 155	15 993	22.17	12 874	4113	248	1139	86	30	13
Buildings for cultural activities and leisure (9)	21 082	0.88	17 041	4041	19.17	3142	1113	90	264	35	11	6
Agricultural buildings (10)	18 496	0.77	17 341	1155	6.24	624	501	121	66	24	4	3
Garages (11)	48 819	2.03	43 412	5407	11.08	3686	1811	136	193	31	5	3
Sacral buildings (12)	4384	0.18	3896	488	11.13	289	200	47	33	15	2	2
Pseudo buildings (13)	4536	0.19	3683	853	18.81	797	71	3	18	0	0	0
Other buildings (14)	68 119	2.84	58 906	9213	13.52	6847	2756	228	554	57	14	7
Sum	2 399 500	100	2 080 474	319 026	13.30	219 359	111 673	9009	18 089	2595	568	237

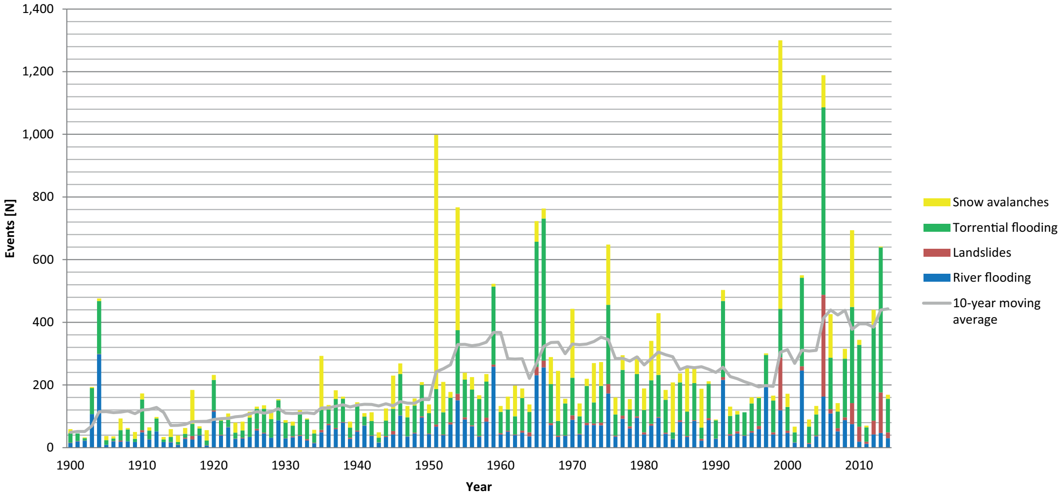

Figure 1. Annual number of natural hazards in Austria. Data source: Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management, December 2014.

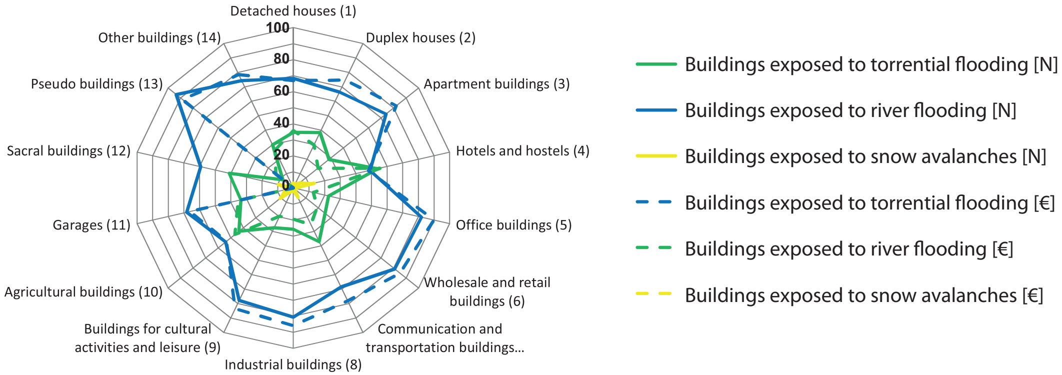

Figure 2. Radar chart of exposure (percentage of numbers and reconstruction values) to river flooding, torrential flooding and snow avalanches for different building categories.

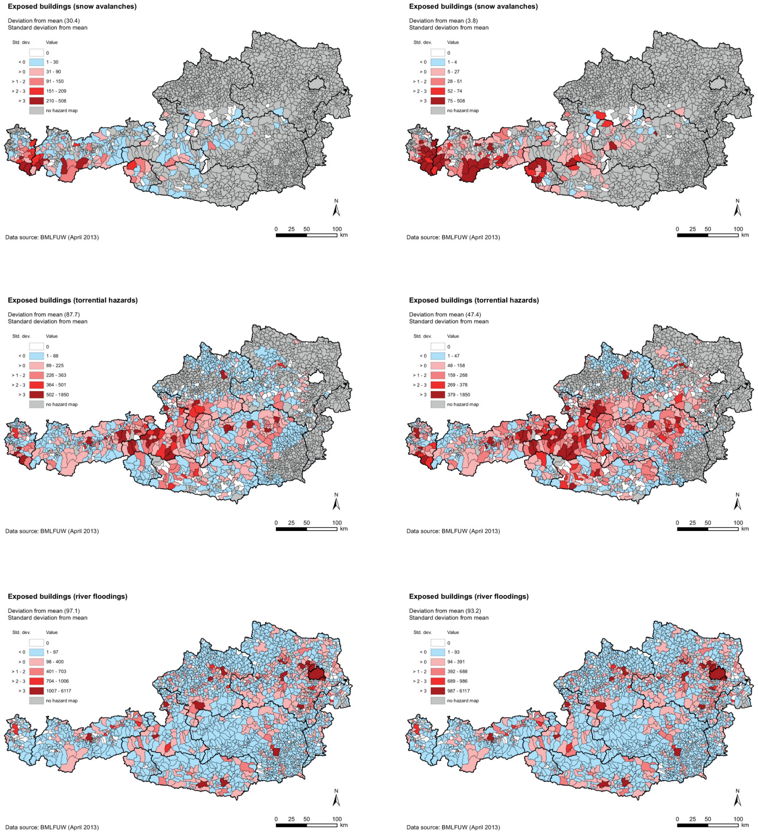

Figure 3. Number of buildings exposed to snow avalanches, torrential flooding and river flooding in Austria, shown as deviation from mean. The reference for the figures in the left column was the number of communities affected by the respective hazard. The reference for the figures in the right column was the entire amount of municipalities in Austria.

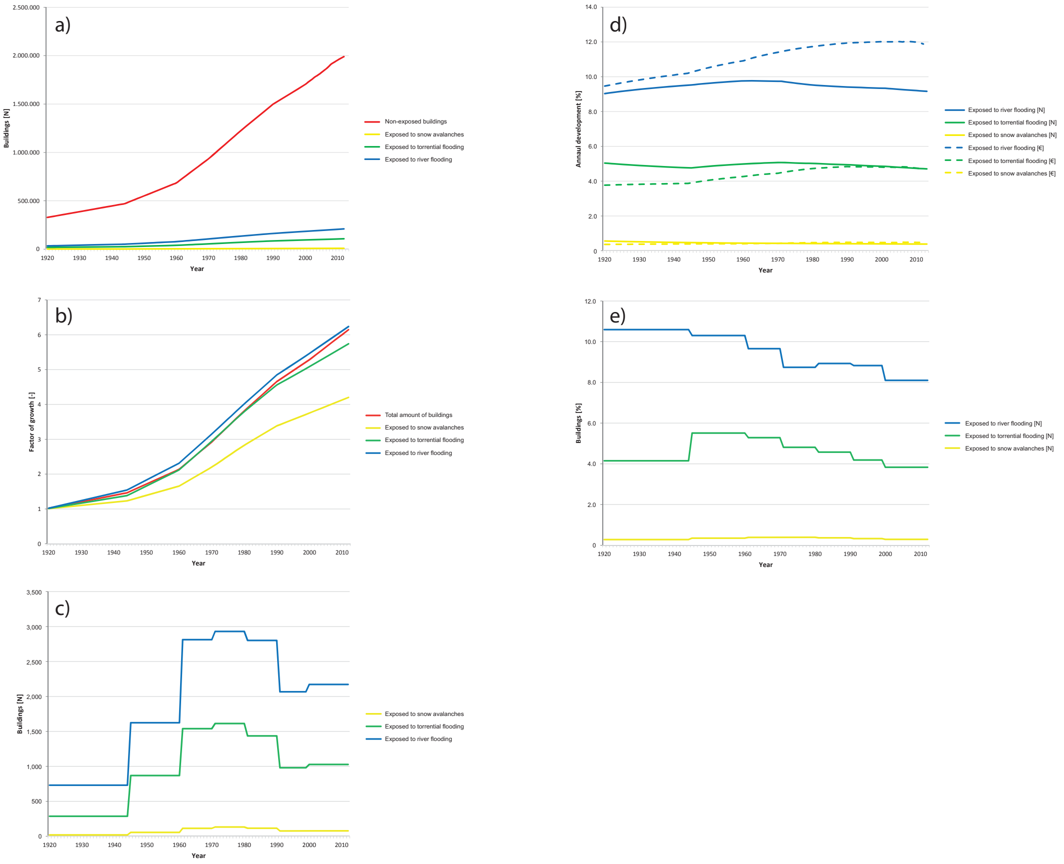

Figure 4. Temporal development of building stock in Austria.