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Identifying spatial clusters of flood exposure to support decision making in risk management

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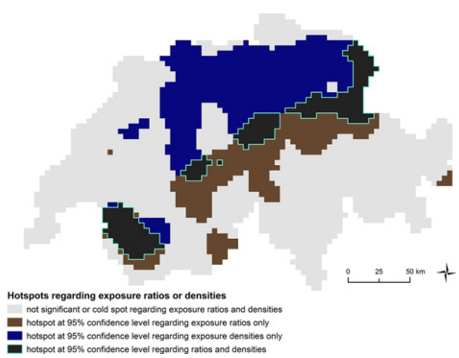
HIGHLIGHTS

- Evaluation of methods and parameters pertinent to flood exposure analyses
- Spatial exposure analyses support prioritization in flood risk management.
- Feasible detection of hotspots at national scale based on spatially explicit data
- Complementary spatial distribution of exposure *densities* and *ratios* in Switzerland
- Data aggregation scheme (i.e. by municipalities or grids) influences the results.

GRAPHICAL ABSTRACT



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ABSTRACT

A sound understanding of flood risk drivers (hazard, exposure and vulnerability) is essential for the effective and efficient implementation of risk-reduction strategies. In this paper, we focus on 'exposure' and study the influence of different methods and parameters of flood exposure analyses in Switzerland. We consider two types of exposure indicators and two different spatial aggregation schemes: the density of exposed assets (exposed numbers per km^2) and the ratios of exposed assets (share of exposed assets compared to total amount of assets in a specific region) per municipality and per grid cells of similar size as the municipalities. While identifying high densities of exposed assets highlights priority areas for cost-efficient strategies, high exposure ratios can suggest areas of interest for strategies focused on the most vulnerable regions, i.e. regions with a low capacity to cope with a disaster. In Switzerland, the spatial distribution of high exposure densities and exposure ratios tend to be complementary. With regards to the methods, we find that the spatial cluster analysis provides more information for the prioritization of flood protection measures than 'simple' maps of spatially aggregated data represented in quantiles. In addition, our study shows that the data aggregation scheme influences the results. It suggests that the aggregation based on grid cells supports the comparability of different regions better than aggregation based on municipalities and is, thus, more appropriate for nationwide analyses.

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1. Introduction

Flood risk has been increasing during the last decades on a global scale (IPCC, 2012); this is exemplified by the occurrence of flood events associated with high losses in Europe (e.g. 2002 Danube, Elbe and Vltava catchments, 2007 United Kingdom, 2014 Southeast Europe, 2016 Northwest Europe). The flood events prompted political actions with a focus on the generation of flood risk maps and enhanced national risk management strategies, e.g. the European Parliament's Floods Directive (2007) or the respective frameworks in Switzerland (Bründl et al., 2009; PLANAT, 2005). Flood risk analysis combines information about the hazard (i.e. the frequency and magnitude of floods), exposure (i.e. the population and assets located in flood-prone areas) and vulnerability (i.e. the susceptibility of the exposed elements to the hazard) (Klijn et al., 2015; Merz and Thieken, 2004; Papathoma-Köhle et al., 2011; UNISDR, 2015a). These three main factors of the risk analysis show spatiotemporal patterns (Aubrecht et al., 2013; Black and Burns, 2002; Fuchs et al., 2013; Mazzorana et al., 2012; Winsemius et al., 2016. In particular, several studies and reports identify increasing in exposure as the main driver of increasing risk (Hallegatte et al., 2013; IPCC, 2012; de Moel et al., 2011). In the future, flood risk will continue to increase because of socio-economic development and climate change (Visser et al., 2014; Winsemius et al., 2015). Consequently, effective and efficient strategies for risk reduction are essential for the future (Jongman et al., 2014; Rojas et al., 2013) and a sound understanding of relevant risk drivers is a prerequisite for the implementation of risk-reduction strategies (IPCC, 2012; UNISDR, 2015b).

In this paper, we focus on exposure and how the associated data analysis can influence decisions in different risk-based strategies. Exposure analysis is strongly dependent on availability, resolution and quality of data, namely data on assets (i.e. including affected people, buildings and infrastructure) and on the nature of the hazards (i.e. flood extent and magnitude). Asset data characteristics, in particular the spatial resolution and the aggregation level, also influence the choice of methods for exposure analysis. Examples of exposure analysis approaches include intersecting flood areas with average asset values based on aggregated land-use classification (e.g. Cammerer et al., 2013; Jonkman et al., 2008; Muis et al., 2015) and spatially explicit intersections of building polygons (Figueiredo and Martina, 2016; Fuchs et al., 2015). The latter approach generates high quality and spatially explicit information on exposure, thereby reducing uncertainties if upscaled to a larger spatial entity. Merz (2006) compares different exposure analysis approaches and de Moel et al. (2015) provide an overview concerning spatial scales. Additionally, the levels at which exposed assets are aggregated are dependent on data privacy restrictions, data availability and study objectives. Aggregation levels can range from municipality level (Fuchs et al., 2015; Hallegatte et al., 2013; Huttenlau et al., 2010; Staffler et al., 2008) to NUTS levels for European studies (Lugeri et al., 2010; Lung et al., 2013) and aggregation based on countries (and 'food producing units') for global studies (Jongman et al., 2012; UNISDR, 2015a). However, due to limited data availability, comprehensive object-based and therefore spatially explicit analyses are generally restricted to local and regional levels (Huttenlau et al., 2010; Zischg et al., 2013). Since additional information has become increasingly available (e.g. on building stock, i.e. existing buildings within a defined environment) throughout Europe based on new European regulations, more accurate information on exposed elements can be obtained (e.g. Figueiredo and Martina, 2016; Fuchs et al., 2015) and will be used as a basis for decision-making in risk management.

In Switzerland, object-specific information about the building stock and flood hazards map are available nationwide. In this study, we investigate and test the application of different aggregation and normalization methods on these datasets and highlight their impact on resultant differences to build awareness among relevant decision makers. The legislative framework and the limited funds for protection measures oblige authorities to prioritize the most efficient and effective risk reduction schemes. Thus, decision makers need to know "which region should risk reduction focus on?" or alternatively, "where are the flood exposure hotspots located?". To answer these questions, we propose an approach of spatial cluster analysis based on the aggregation of point data with respect to different spatial units. Spatial cluster analyses are well established in many disciplines (crime, health, archeology, with Snow's (1855) publication on the 1854 cholera outbreak in Soho district of London being to our knowledge the first work on spatial clusters), but with limited applications in natural risk analysis and management to date. The few studies on natural hazards that apply spatial cluster analyses (e.g. Borden and Cutter, 2008; Fuchs et al., 2012; Kazakis et al., 2015; Su et al., 2011; van der Veen and Logtmeijer, 2005) often use aggregated data and rarely consider the influence of the shape and size of the data aggregation units. In our study, we investigate if and to what extent the aggregation scheme influences the results. In other words, we examine the relevance of the still unresolved and thus often ignored Modifiable Areal Unit Problem (MAUP) (Openshaw, 1984; cf. also Section 2.4 in this paper).

We further consider two types of exposure indicators: the density of exposed assets (exposed number of assets per km^2) and the share of exposed assets (share of exposed assets compared to the total number of assets in a specific region). The first indicator, the exposure density, supports risk management strategies that follow the concept of utilitarianism (Mill, 2007). Utilitarianism in natural hazard and risk management means to choose the most cost-efficient measures. Numerous factors influence a measure's efficiency, i.e. the ratio of resource input to the risk reduction output. The density of exposed assets is an example of the aforementioned factors. Provided that all factors are the same except the exposure density, the efficiency of a measure is higher in areas with high densities of exposed assets than in areas with low exposure densities. That is, the density of exposed assets is a meaningful criterion for the selection of measures with respect to cost efficiency. The second exposure indicator, the share of exposed assets, informs strategies which comply with Rawls' concept of justice (Rawls, 1971). The application of this concept in risk management implies the prioritization of the most vulnerable areas and people (Johnson et al., 2007). The term 'vulnerable' in this context does not refer to the individual physical susceptibility of assets in a region, but to the missing capacity of a region to cope with a disaster. We assume an inverse relationship between the share of affected assets and a region's coping capacity. Consequently, we propose that the share of exposed assets in a given spatial unit is used as an indicator of the unit's vulnerability.

The proposed approach of spatial cluster analysis is generally applicable, i.e. for different regional and national flood exposure surveys. In this paper it is applied and illustrated with the case study of Switzerland.

2. Material and methods

For the analysis of flood exposure, we overlay spatially explicit information about buildings and inhabitants with data describing flood prone areas. Based on different aggregations of the exposed assets we search for statistically significant hotspots of flood exposure. The following sections outline the methods applied and describe the datasets used in the Switzerland case study.

2.1. Data on buildings and inhabitants

Two datasets are extracted from (1) a topographic landscape model and (2) from point data on residential buildings and combined to obtain a comprehensive and homogenous, country-wide database of buildings polygons and of residents in Switzerland.

The feature group 'buildings' from the 'Topographic Landscape Model' (TLM) (swisstopo, 2016a, 2016b) contains footprints of all buildings currently in Switzerland. The TLM building data is highly accurate (10^{-1} m), however, the spatial subsets of the data are not updated