

Regional prioritisation of flood risk in mountainous areas

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The authors present an approach to rank different watersheds according to the height of flood risk for a more effective mitigation planning. As such, this is a topic of considerable relevance to the readers of Natural Hazards and Earth System Sciences. Therefore, the work should be considered for publication. However, some of the content needs additional efforts before this manuscript may become acceptable for publication, and the structure of the paper has to be improved in order to better allow the readers to follow the string of argumentation.

In general there seems to be a particular lack in the method description as well as in the target of this manuscript. It is not entirely clear which hazard the authors are assessing, if it is flash floods, debris flows or static/dynamic inundation. Moreover, the PCA is not sufficiently explained and how the results were achieved. The results section needs a better structure, and the discussion section is missing reference to limits and uncertainties as well as the results of comparable studies in order to show how the method can be used to improve still existing gaps in risk assessment. Furthermore, I am missing a sound definition of vulnerability, susceptibility, risk and so that the specific niche of this work seems a bit unfocused.

More specific concerns are listed below.

1 Introduction:

P. 4266/4277:

Effective disaster risk reduction requires a comprehensive assessment of hazard and vulnerability. Flood risk represents the probability of negative consequences due to floods and emerges from the convolution of flood hazard and flood vulnerability (Schanze et al., 2006). Assessing flood risk can be carried out at national, regional or local level (IWR, 2011), with the regional scale aiming at contributing to regional flood risk management policy and planning. Regional approaches vary widely, including hydrodynamic model-based hazard analyses with damage estimations (Liu et al., 2014; Su and Kang, 2005) as well as indicator-based analyses (Chen et al., 2014; Safaripour et al., 2012; Greiving, 2006), with the latter being less data-demanding.

A common approach is to obtain grades (e.g. high, medium and low) for the risk categories that allow prioritisation or ranking of areas for implementation of flood risk management measures such as flood warning systems and guiding preparations for disaster prevention and response (Chen et al., 2014).

From my point of view this introduction is not leading to the hypotheses of this manuscript. Moreover, I have the feeling that the authors just mixed some of the terms without connecting them one by one. To give an example, while the first sentence addresses DRR and calls for the assessment

of hazard and vulnerability in general, the second sentence suddenly introduces flood risk. How are they connected? -> needs revision.

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This kind of damage or loss modelling typically provides an estimate of the expected monetary losses (Seifert et al., 2009). However, more holistic approaches go further than including just physical vulnerability and incorporate social, economic, cultural and educational aspects, which are in most cases the cause of the potential physical damage (Cardona, 2003).

Depending on the school and scientific background, there are many conceptualisations of vulnerability. As such the authors should not judge that “just” physical vulnerability is not enough, and it remains debatable whether or not social vulnerability leads to physical vulnerability. If the authors think so they should precisely argue why, and provide citations. Moreover, I kindly would like to suggest that the authors have a closer look to the more recent literature, being either in the IPCC or in the UN/ISDR (Sendai) context; and with the focus on the hazards introduced later on maybe also some reference to the scholars from mountain hazard risk assessment, not just from those working on the larger rivers of the lowlands. For physical vulnerability maybe not only an article solely addressing industrial assets.

As important as the understanding of the hazard, the knowledge of the social system and its vulnerabilities is a key element of risk, and determines the social response to floods (Barroca et al., 2006). Birkmann (2006) suggests that indicators and indices can be used to measure vulnerability from a comprehensive and multidisciplinary perspective, capturing both direct physical impacts (exposure and susceptibility), and indirect impacts (socio-economic fragility and lack of resilience).

Here the authors could indicate why they are jumping back to social vulnerability (and the social response to floods). The authors could also consult other comprehensive works from scholars such as Papatoma-Köhle et al. (2011), Fuchs (2009) or even the editorials to the recently published special issues on vulnerability in the journal Natural Hazards. Moreover, the distinction between indicator-based approaches and other approaches seems not be sufficient in the current version of the manuscript.

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Furthermore, the complex interrelations between hazard and vulnerability, which are mutually conditioning (Cardona, 2003), constitute a key aspect in the comprehension of risk.

-> this statement is absolutely not clear, the authors should specify how hazard and vulnerability are “mutually conditioning”.

Vulnerability is closely tied to natural and man made environmental degradation at urban and rural levels (Cardona, 2003), while at the same time the intensity or recurrence of flood hazard events can be partly determined by environmental degradation and human intervention in natural ecosystems (Cardona et al., 2012). This implies that human actions on the environment determine the construction of risk, influencing the exposure and vulnerability as well as enhancing or reducing hazard, or even creating new hazards.

-> this statement is also not entirely clear, the authors should specify and maybe in general also use other sources than Cardona (which is not bad, but maybe there are also other viewpoints worth being discussed).

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The complex interaction between hazard and vulnerability is explored in this paper in the context of small watersheds where human-environment interactions that determine risk levels take place in a limited area. The mountainous environment and the particular sensitivity to anthropic intervention of flash flood prone watersheds provide an ideal scenario to study the dynamics of risk conditions in the urban environment. Unplanned urbanisation characterised by a lack of adequate infrastructure and socioeconomic issues (both contributors to vulnerability), may result in severe environmental degradation, which increases the intensity of natural hazards (UNISDR, 2004). The consequence of the interaction between hazard and vulnerability in the context of small watersheds is that those at risk of flooding themselves play a crucial role in the processes that enhance hazard.

I have several concerns here. Firstly, again the authors used the wording “complex” without explaining why the relation between hazard and vulnerability may be complex (see my remarks above). Secondly, I do not understand why small watersheds are particularly prone to anthropogenic intervention – and if this manuscript is centered on small mountain watersheds (and not flooding, which is not clear until here), the authors definitely should include the results of recent works from scholars working on mountain hazards, and discuss their approaches in comparison to the specific needs identified within this manuscript. Just relying on Cardona or UN/ISDR and Schanze/Merz etc. is definitely not enough simply because they were not working in small mountain watersheds. Moreover, the link between the UN/ISDR approaches and the current challenges remains unclear, as does the last sentence (“*The consequence of the interaction between hazard and vulnerability in the context of small watersheds is that those at risk of flooding themselves play a crucial role in the processes that enhance hazard.*”) -> needs clarification.

This paper aims at the prioritisation of watersheds, which can be interpreted as a proxy for flood risk assessment, thus providing guidelines for the managing of those risks. A key factor is the determining of flood exposure at the regional level, which provides the areas where vulnerability is studied. Flood-prone areas are generally obtained through hydrologic and hydraulic modelling. These can be expensive and time consuming, particularly when large areas have to be modelled. Moreover, these require information that may not readily be available for all areas (Degiorgis et al., 2012). Flood hazard maps are therefore usually only available for limited areas. This creates difficulties when a regional assessment is needed. To overcome this challenge a combination of simplified existing methods is proposed in order to obtain the outline of the areas potentially exposed to floods. Vulnerability is then assessed through application of an indicator system that considers social, economic and physical aspects that are derived from the available data in the study area. This is subsequently combined with a flash flood susceptibility indicator based on morphometry and land cover (Rogelis and Werner, 2013). The resulting priority index reflects the watersheds with the highest damage potential that require detailed risk studies to establish appropriate flood risk management strategies.

The first sentence in this paragraph is unclear, needs specification. Prioritisation for what? Why this is then a proxy for flood risk, and not the height of flood risk. Moreover, vulnerability and exposure are

totally different concepts -> needs thorough clarification here. Then, the authors focus on flood hazard, but this is not the only challenge when working on the regional level (also exposure and vulnerability are scale-dependent in their assessment). It is not clear to me why (if the authors already assessed the flood risk on the regional level) they need additional assessment of flash flood risk. Is the manuscript on flash floods or floods, and how are these defined? How is the last sentence connected to the previous ones? Which is the “*resulting priority index*” and how this index is computed/estimated/quantified?

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The paper is structured as follows. Section 2 reviews the conceptual definition of vulnerability as the foundation of the paper. Subsequently, Sect. 3 describes the study area, and the data and methodology used; to delineate areas susceptible to flooding; to chose indicators and carry out the principal component analysis; to carry out the sensitivity analysis of the vulnerability indicator; to create categories of recorded damage in the study area; and to prioritise the watersheds. Section 4 presents the exposure areas obtained through the simplified methods; the results of the principal component analysis in terms of a socio-economic fragility indicator, a lack of resilience indicator and a physical exposure indicator; the overall vulnerability indicator obtained from the combination of the socio-economic fragility, lack of resilience and physical exposure indicators; the sensitivity analysis of the vulnerability indicator; and the prioritization of watersheds according to the qualitative risk indicator and comparison with damage records. Section 5 section interprets the results of the exposure area delineation, the representativeness and relative importance of the indicators obtained from the principal component analysis; the sensitivity of the vulnerability indicator; and the interrelations between susceptibility and vulnerability in the prioritisation indicator. The conclusions are summarised in Sect. 6.

I have different problems with this paragraph being quite central for the conclusion of an introduction. Firstly, the structure is not entirely clear; “*to chose (sic!) indicators and carry out the principal component analysis [indicators for what?, principal component analysis?]; to carry out the sensitivity analysis of the vulnerability indicator [which vulnerability indicator?, sensitivity is mentioned here for the first time, but is quite central once such methods are used to represent a proxy for vulnerability on a regional scale]*”. Secondly, terms are used that have not been introduced before, such as fragility indicators or resilience – the concept of resilience and vulnerability is maybe coupled, but there are scholars who argue differently. Thirdly, why the focus is now on exposure (Section 5) when the authors were only addressing vulnerability as the central component? -> needs a thorough definition and separation...

2 Concept of vulnerability:

From my point of view the authors mix up some concepts here, above all different approaches to vulnerability. Vulnerability to flash flooding and to flooding follows completely different patterns because of the different underlying process dynamics. This should be more carefully addressed here.

It is common sense that “*vulnerability to environmental hazards means the potential for loss*” but what does this mean for the present study? Also the statement that “*the definition of vulnerability depends on the type of study, on the results required, on the kind of hazard (flashflood or slow*

evolving-flood) on the spatial and temporal scale of study, on the characteristics of the study area, and on the temporality (prevention, crisis, post crisis)" is not very targeted in this context. If vulnerability is so important for this study the authors need a broader review on the published material (at least from social sciences and natural sciences), also with respect to hydrological hazards in mountain watersheds. The publications of The Worldbank are maybe not suitable for application at regional scale in mountain environments: "Jha et al. (2012) see vulnerability as the degree to which a system (in this case, people or assets) is susceptible to, or unable to cope with the adverse effects of natural disasters. It is a function of the character, magnitude and rate of hazard to which a system is exposed, the sensitivity or degree to which a system is affected adversely or beneficially, and its adaptive capacity (the ability of a system to adjust to changes, moderate potential damages, take advantage of opportunities or cope with the consequences)" -> vulnerability is depending on the magnitude and frequency of a hazard (in its broadest sense), the exposure and the coping capacity. The idea of adaptive capacity is tricky, and should be more precisely explained.

The following paragraphs need more research efforts. While e.g. the approaches from UN/ISDR and UNDP address certain aspects of vulnerability, remote sensing scholars (Taubenböck et al.) may address other issues. What are the differences of these approaches presented, and how can these be used within the presented study. At the moment it seems more like a quick and non-targeted literature review where the authors did not manage to use the right key words in the search engine (very sorry for my harsh words)... Why did the authors not focus on available reviews on the vulnerability concept? Moreover, the internal and external side of vulnerability, here ascribed to Birkmann, were originally from Bohle (2001) which again highlights the weakness of Section 2 – nevertheless, Bohle is cited in Section 5.4 with respect to susceptibility versus vulnerability. Since the authors use "*the approach to vulnerability assessment (...) corresponding to the holistic approach proposed by Cardona (2001)*", they simultaneously state that there was not progress in vulnerability science since then, which is simply not true. Moreover, one could even ask the question more nuanced: When the authors just use an approach originally published by 2001, the scientific novelty of the manuscript content can be questioned.

3 Methods and data:

3.1 Study area

Please provide more information on the hazard source, could be a table with the number of torrents (?) and the damages occurring in recent years to provide more information on the selection of the study site.

3.2 Methods

3.2.1...

Here for the first time the authors address debris flows, so is the study on flash floods, debris flows, floods,...??? Moreover, I would like to see a proper explanation why "*debris flow dominated areas can also be subjected to clear water floods*" because these process groups are usually quite well separated from each other. Does clear water flow mean without transport of coarse sediment? Moreover, the different methods to delineate floodplains need explanation; if for flood plain

delineation a sensitivity analysis is carried out why this was not done for the assessment of areas prone to debris flows?

3.2.2...

“The complexity of vulnerability requires a reduction of available data to a set of important indicators that facilitate an estimation of vulnerability (Birkmann, 2006)” -> this is a general statement (apart from my concern why vulnerability is complex). Moreover, in the introduction the authors were also writing that they reduced the indicators used as a proxy for vulnerability due to the availability of data, which is a contrast to the above sentence.

I doubt that only using PCA for variables where the results look nice is a scientific procedure. So the setting of the methods is highly debatable and needs more clarification. From my point of view the indicators selected should be either treated all with the same method (so all with PCA, and then the results discussed accordingly), or somehow combined in a different manner. Personally I believe that sentences such as *“(...) PCA was applied only to the variables education, illiteracy, access to information, infrastructure/accessibility, hospital beds and human resources in health. The other variables were treated independently due to their particular meaning (...) and lack of interpretation in the PCA”* show a clear lack of scientific method development.

3.2.3...

So did I get it right that the sensitivity of vulnerability indicators was just tested for those variables where PCA was performed? What about the other indicators? In combination with Section 3.2.2 I am increasingly convinced that the method applied is sound and robust.

3.2.4

A database of historical flood events was used to classify the watersheds in categories, depending on the recorded damages. However, the temporal resolution of these data was only 12 years. Moreover it is not clear why the authors assessed these data (apart from my remarks for the Section 3.1) – for classification of watersheds? This should have been done already in the respective Section 3.2.1. Moreover, the selected scoring method itself seems to be highly subjective for an evaluation of loss height (or damage intensity).

3.2.5

I would like to know more details on how the ranking into high, medium, low was performed. According to the Figures it seems that the authors used equal intervals, but why did they not make use of natural breaks since the data distribution could be better mirrored?

4 Results:

Figs 4-6 would be much more accessible if reproduced in colour. In the present form they do not support the written results because of missing readability.

5 Discussion:

General remarks: I kindly would like to suggest the authors to make use of the discussion in the discussion section. So what did other studies figure out by using comparable indicators? What are the limits of the approach used, and where are the benefits compared to e.g. more detailed/less detailed regional approaches, etc.

5.3 Sensitivity of the vulnerability indicator

I do not see any significance in Fig. 9 – simply because I do not know which indicators are presented there.

5.4 Interrelations...

I do not understand the content of this Section. If susceptibility is mainly defined by land cover (as a proxy for hazard susceptibility), and vulnerability is (also) determined by land cover indirectly, both factors are related. On the other hand, vulnerability is driven by the hazard type, which should be also discussed here. The hazard type is not so much a result of land use but more of topography (at least the distinction between flash floods (or debris flows) and more or less static inundation (named “clear-water flood” by the authors, or did they mean dynamic flooding?).

My apologies but I will stop the detailed review here. Too many new things come up in the results section that should have been presented in the method section, and the manuscript increasingly gets blurred in the presentation. Moreover, the authors were mixing up terms again in the conclusion section (Section 6, see concluding two sentences) so that I doubt that they put much effort in a proper definition of terms. This maybe an explanation also for the chaotic presentation used in Figure 2.

I strongly suggest that the authors perform a major revision of the content, including the indicated extended literature review and the streamlining of the methods and results section, otherwise the manuscript should be rejected.

Literature mentioned:

Bohle H-G (2001) Vulnerability and criticality: Perspectives from social geography. IHDP Update 02/2001:3-5

Fuchs S (2009) Susceptibility versus resilience to mountain hazards in Austria – Paradigms of vulnerability revisited. *Natural Hazards and Earth System Sciences* 9 (2):337-352

Papathoma-Köhle M, Kappes M, Keiler M, Glade T (2011) Physical vulnerability assessment for alpine hazards: state of the art and future needs. *Natural Hazards* 58 (2):645-680