# Landslide risk reduction measures: A review of practices and challenges for the tropics

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Abstract:

The overall objective of this review is to gain insights into landslide risk reduction measures that are applied or recommended in tropical landslide-prone countries, and the challenges at play. More specifically, this review aims at (i) presenting an overview of recent studies on landslides and landslide risk reduction in these countries, (ii) exploring the factors controlling the publication output on landslides and landslide risk reduction, (iii) reviewing the various landslide risk reduction measures recommended and implemented, and (iv) identifying the bottlenecks for the implementation of these strategies.

A compilation of recommended and implemented landslide risk reduction measures in 99 landslide-prone tropical countries was made, based on an extensive review of scientific literature (382 publications). The documented measures are analysed using a scheme of risk reduction measures that combines classifications of the Hyogo Framework for Action and the SafeLand project.

Our literature review shows that the factors influencing the number of publications on landslides and landslide risk reduction per country are (in order of importance) the absolute physical exposure of people to landslides, the population and the Human Development Index of a country. The ratio of publications on landslide risk reduction versus publications on landslides for landslide-prone tropical countries does not vary much between these countries (average: 0.28). A significant fraction (0.30) of all known landslide hazard reduction measures are neither implemented nor recommended according to our review. The most recommended landslide risk reduction component is ‘risk management and vulnerability reduction’ (0.38). However, the most implemented component is ‘risk assessment’ (0.57). Overall, the ratio of implemented versus recommended landslide risk reduction measures in the tropics is low (<0.50) for most landslide risk reduction components, except for ‘risk assessment’ (3.01). The most cited bottlenecks for implementing landslide risk reduction measures are scientific (0.30) and political (0.29) in nature.

Review article

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## 1. Introduction

Landslides (LS) are defined as 'the movement of a mass of rock, debris or earth down a slope' (Cruden, 1991:27). They present a serious problem in many regions worldwide, claiming thousands of deaths per year (Petley, 2012). Especially in the tropics, many regions are strongly affected by LS due to high precipitation and weathering rates, particularly in zones with steep topography and tectonic activity (Kirschbaum et al., 2015). Moreover, LS risk in the tropics is expected to increase in the near future as a response to increasing demographic pressure, deforestation and land use changes (Kjekstad, 2007) as well to climate change (Gariano and Guzzetti, 2016). In addition, most fatalities due to LS occur in the Global South countries that are predominantly located within the tropics (Kirschbaum et al., 2015; Petley, 2012). Furthermore, the impact of LS on the population can be very high in tropical developing countries due to their high economic, social, political and cultural vulnerability (Alcántara-Ayala, 2002).

The recent Sendai Framework for Disaster Risk Reduction (DRR) has renewed the international focus on reducing risk of disasters (UNISDR, 2015). Investing in DRR was identified as one of the key priorities. Disaster 'risk' is defined as 'the potential disaster losses, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period*'* (UNISDR, 2009:9), while 'hazard' refers to the natural event itself that may affect different places singly or in combination at different times (Wisner et al., 2004). According to UNISDR (2009:10), DRR is 'the concept and practice of reducing disaster risks through systematic efforts to analyze and manage the causal factors of disasters, including through (i) reduced exposure to hazards; (ii) lessened vulnerability of people and property; (iii) wise management of land and the environment; and (iv) improved preparedness for adverse events'. Especially for low-intensity, high-frequency events like LS, DRR is considered the most cost-effective option to limit the negative impacts of disasters (Mechler, 2010).

It is relevant to first analyze what is currently being recommended and implemented globally to support research and investment in DRR (UNISDR, 2015). A hazard for which such a review of risk reduction (or mitigation) measures is still lacking is LS. As the scientific literature on LS is rapidly increasing (Gutiérrez et al., 2010; Wu et al., 2015), it is important to maintain an overview, meaning that we understand which LS-DRR is being investigated and where, what explains observed differences between recommended and implemented measures and which potential pitfalls the implementation of such DRR is facing. Although such overview is certainly relevant to a wide audience, this is especially the case for earth scientists since most of the research on LS is currently conducted by this research community. A meta-analysis of recommended and implemented measures may certainly help in identifying the next steps to contribute to long-term LS-DRR.

The overall objective of this review is therefore to gain more insights into the implementation of LS-DRR measures applied and recommended in tropical LS-prone countries, and the challenges at play. We focus on the tropics for two reasons. First, this research frames in the AfR*e*Slide project (Kervyn et al., 2015), which tries to identify LS-DRR measures for tropical countries like Uganda and Cameroon. This study thus serves as a good starting point to understand LS-DRR in these two countries. Second, LS risk is expected to increase in tropical regions due to climate change, while many of these regions in Africa, South America and Asia are currently understudied (Gariano and Guzzetti, 2016). The projected increases in the intensity and frequency of extreme precipitation events in the tropics (IPCC, 2014) and subsequently on increasing LS risk (Seneviratne et al., 2012) serve as a valid reason to target tropical LS-prone countries for our analysis. The specific objectives are: (i) to compile an overview of studies on LS and LS-DRR in tropical LS-prone countries, (ii) to explore the factors controlling the number of scientific studies conducted on LS and LS-DRR per country, (iii) to review the various LS-DRR measures recommended and implemented, and (iv) to identify the bottlenecks for implementing these measures.

## 2. Materials and methods

### 2.1 Selection of study area and country-specific data

In this study, we only considered countries for which (1) at least 50% of their land area lies between the tropical circles and (2) if at least one inhabitant per year was exposed to either rainfall- or earthquake-triggered LS per year, according to the Global Risk Data collected by the Norwegian Geotechnical Institute (NGI) for the Global Assessment Report on DRR (Giuliani and Peduzzi, 2011). This Global Risk Data is to our knowledge the most complete and consistent global dataset. It expresses the absolute physical exposure to LS as the expected average annual population exposed (# inhabitants/year) and is based on the modelling of LS susceptibility and population density (NGI, 2013). Ninety-nine out of the 138 tropical countries met this second criterion and were considered for our review on recommended and implemented DRR measures for LS (Table 1). Evidently, the Global Risk Data used to identify the LS-prone countries is subject to uncertainty. This uncertainty, combined with the relatively coarse spatial resolution of the data, may induce erroneous inclusions or exclusions in our list of tropical LS-prone countries. Especially some small island states are not LS-prone according to this database, while this is not necessarily the case (Table 1). E.g. the Bahamas (Buchan, 2000), the Seychelles (Payet, 2005), and St. Vincent and the Grenadines (Anderson et al., 2010). Therefore, this list should be interpreted with caution. To investigate the potential extension of these errors, we also checked for each not landslide-prone country whether articles on LS-DRR were published for that country (using the same methodology and criteria described in section 2.2). This was the case for 9 countries (Table 1). However, given their small area, limited population and publication count, the impact of these wrongfully assigned countries on our analyses is likely to be very limited. On the other hand, the Global Risk Data (NGI, 2013) provided an independent and objective criterion of countries to focus on. This helped avoiding that our literature review was biased towards our prior knowledge of available literature. We therefore decided not to further correct or adapt our list of LS-prone countries and to focus our review on the tropical countries that were indicated as LS-prone based on the Global Risk Data (NGI, 2013).

[Insert Table 1.]

In order to identify the factors controlling the application rate of LS-DRR measures, data on the Human Development Index (HDI) and the physical exposure to LS were collected for each tropical LS-prone country (n = 99). The HDIs of 2013 were collected from the Human Development report of 2014 (Malik et al., 2014). For 14 out of the 99 countries, data on HDI were not available. Most of these 14 countries are island states. The physical exposure of people to LS, i.e. the overlay of population density with LS susceptibility, was collected from the Global Risk Data of the Norwegian Geotechnical Institute (NGI, 2013; Fig. 1). The LS susceptibility depends on the slope gradient, lithology (or geology), soil moisture, vegetation cover, precipitation and seismicity (NGI, 2013). The population data were retrieved from the UN Population Division and cover data of 2010 which was also used for the physical exposure (NGI, 2013). In order to obtain country-specific data, the physical exposure values for both precipitation- and earthquake-triggered LS were summed up for every pixel lying within the country's boundaries.

[Insert Fig. 1.]

## 2.2 Compilation of scientific literature

Scopus® (Elsevier B.V., 2015) was chosen as the search engine to select articles for the detailed review on recommended and implemented LS-DRR measures. Initially, literature was searched using Web of Science™ (WoS; Thomson Reuters, 2015), Google Scholar (Google, 2015) as well as Scopus because these search engines cover most published scientific literature (Falagas et al., 2007). Scopus however yielded the highest number of countries with publications and includes more social sciences oriented publications besides natural sciences which is deemed crucial for this research (Table 2). Furthermore, Scopus produces more citation counts than WoS (Bergman, 2012; Falagas et al., 2007) and it has been shown to result in less inconsistencies regarding content verification compared to WoS and Google Scholar (Adriaanse and Rensleigh, 2013).

An inventory of peer-reviewed articles on LS and LS-DRR, published between January 2005 and January 2015, was thus made using Scopus. The keywords and Boolean search criteria described below were applied to the 'title', 'abstract' and 'keywords' simultaneously. In order to analyse the literature on LS-DRR, we first searched for publications on LS in general and then specifically publications on LS-DRR. For the LS literature, we used the following keywords and Boolean search criteria: *<country name> AND (landslide* OR 'mass movement' OR 'mass wasting').* For the LS-DRR literature, we used the same keywords and Boolean search criteria but added the terms 'prevention', 'management', 'mitigation', 'risk reduction' or 'remediation' in order to narrow down to DRR. Only peer-reviewed publications with English abstracts have been taken into account. An overview of the compiled literature is given in Table 2. Noteworthy is that 25% of the 536 publications concerned India. After detailed investigations, 154 out of the 536 LS-DRR publications were excluded because they were irrelevant for this research (e.g. articles on submarine LS). As a comparison, not tropical LS-prone countries like Italy and the USA respectively yield 1,529 and 208 publications on LS, and 294 and 37 publications on LS-DRR, using the same keywords and Boolean search.

[Insert Table 2.]

Not all the research on LS-DRR in LS-prone tropical countries was published in peer-reviewed articles. To evaluate to what extent our review might be biased by the fact that only scientific peer-reviewed literature was considered, we conducted a much broader search, including 'grey literature', for Uganda. This country was chosen as a case-study due to an in-depth expertise by the authors and easy access to internal documents from national experts. Such access could not be obtained for the other countries considered. The grey literature considered includes reports of government institutions, NGOs, dissertations of national and foreign master students, retrieved through personal secondary data collection in Uganda and targeted search in Google. In total 16 documents on LS-DRR were selected for Uganda in addition to the three peer-reviewed publications found in Scopus. This grey literature is by no means exhaustive but representative judging from expert knowledge.

### 2.3 Factors explaining the number of publications on landslides and landslide risk reduction

The initial search in Scopus resulted in 1928 LS publications and 536 LS-DRR publications (Table 2). Correlations between the number of publications and potential controlling factors, like HDI, physical exposure to LS and population numbers were searched for using the Spearman rank correlation (ρ) as this method is not sensitive to outliers (Heinisch, 1962). In addition, we calculated Partial Spearman rank correlations (partial ρ), which measures the degree of association between two considered variables, with the effect of one or more controlling variables removed (Heinisch, 1962). For these analyses, only the 85 countries having an available HDI were used.

### 2.4 Classifications

To examine the LS-DRR research output in the tropics, the compiled publications on LS-DRR were classified in terms of spatial scale of analysis, authors' country of origin, authors' organisation, and research discipline. For the spatial scale of analysis, the compiled publications were classified into six categories: local (e.g. cities, villages, roads and catchments), provincial (e.g. districts and states), national, regional and global (e.g. global scale highlighting a specific country as an example). For the authors' country of origin, the four categories are: national, foreign, mixed national and foreign, and unknown. For the authors' organisation, the six categories are: university, government, non-governmental organisation (NGO), private sector, multiple organisations and unkown. For the research discipline, the journals and proceedings in which the publications were published were divided into four categories: natural science, social science, interdisciplinary and unkown.

To classify the LS-DRR measures, we used the general DRR classification suggested by Twigg (2007). This classification consists of five components: (i) risk management and vulnerability reduction, (ii) governance, (iii) knowledge and education, (iv) preparedness and response, and (v) risk assessment. 'Risk management and vulnerability reduction' contain all measures related to reducing the occurrence of LS hazards, the vulnerability to LS and the exposure to LS. 'Governance' relates to institutional frameworks and policies on LS-DRR. 'Knowledge and education' consist of all measures related to awareness raising on LS. 'Preparedness and response' comprise all measures dealing with early warning and emergency response. 'Risk assessment' includes all aspects of understanding LS risk. These five components can then be further classified into specific risk reduction measures. The classification of LS-DRR has been the subject of much debate (Nadim and Lacasse, 2008). Here we used the classification of the SafeLand project to further divide the component of 'risk management and vulnerability reduction' in subcategories (see section 3.2), since this was the most recent classification and since it was based on a comprehensive literature review (Vaciago, 2013). For a detailed description of specific LS-DRR measures we refer to Twigg (2007) and Vaciago (2013).

Using this classification, the implemented and recommended LS-DRR measures in LS-prone tropical countries were identified by screening the abstract and conclusions of the 382 collected publications on LS-DRR in Scopus for the period Jan. 2005 to Jan. 2015. With implemented LS-DRR measures, we understand specific actions and techniques that are mentioned in the article (not necessarily with detailed explanation) as currently being developed or operational. Similarly, with recommended measures we mean specific actions and techniques that are suggested as recommendations (not necessarily with detailed explanation) but not yet developed or operational in the country.

Finally, the bottlenecks for implementing LS-DRR measures have been identified by screening the abstract and conclusions of the 382 publications. After identification, these bottlenecks were classified into six sections based on our own judgement: i.e. scientific, political, social, economic, disaster risk management related and geographic bottlenecks. All categories are however not mutually exclusive.

## 3. Results and discussion

### 3.1 Analysis of the number and nature of publications

#### 3.1.1 Factors explaining the number of publications on landslides and on landslide risk reduction

Several factors influence the number of publications on LS per country (#pubs LS/co; Table 3 and Fig. 2).

[Insert Fig. 2.]

The #pubs LS/co best correlates with the absolute physical exposure of people to LS per country ($\rho = 0.77$, $p < 0.001$; Table 3), which suggests that countries with a larger exposed population (e.g. Philippines in comparison with Guatemala) are generally more concerned about LS (Fig. 2a). This is, of course, assuming that the number of publications reflects the level of concern. High risk perception does however not necessarily result into more preparedness as indicated by Wachinger et al. (2013). The partial correlation between the absolute physical exposure and the #pubs LS/co remains significant after controlling for the effect of the other controlling variables, i.e. HDI (partial $\rho = 0.77$, $p < 0.001$) and population (partial $\rho = 0.68$, $p < 0.001$). The countries with the relatively lowest LS publication count per exposed citizen are Indonesia, Philippines, Guatemala, Costa Rica, Ethiopia, Colombia, India and Myanmar, while Malaysia and Brazil have the highest publication count – absolute physical exposure ratio (Fig 2a). Noteworthy is that the #pubs LS/co is also correlated with the relative physical exposure, i.e. the people exposed to LS per country divided by the total population per country ($\rho = 0.49$, $p < 0.001$; Table 3).

[Insert Table 3.]

The #pubs LS/co is also correlated with population ($\rho = 0.55$, $p < 0.001$, Fig. 2b; Table 3). The Spearman rank is smaller for the correlation with population than with the absolute physical exposure per country, despite the lower coefficient of determination. This correlation remains significant after removing the effect of the other controlling variables, i.e. absolute physical exposure of people to LS (partial $\rho = 0.28$, $p < 0.01$) and HDI (partial $\rho = 0.67$, $p < 0.001$).

The third most important determining factor is the HDI of a country ($\rho = 0.35$, $p < 0.001$; Fig. 2c; Table 3). This correlation remains significant after removing the other controlling variables, i.e. the absolute physical exposure of people to LS (partial $\rho = 0.34$, $p < 0.01$) and population per country (partial $\rho = 0.55$, $p < 0.001$). This correlation suggests that countries with a high HDI have more resources to support scientific research, including on LS. This is in line with the correlation made by Petley (2012) indicating that globally, countries with the highest #pubs LS/co have generally lower numbers of fatalities. However, this correlation is relatively weak and clearly less significant than the absolute physical exposure to LS.

Finally, it is noteworthy that the number of publications on LS-DRR per country (# pubs LS-DRR) are strongly correlated with the #pubs LS/co ($\rho = 0.90$, $p < 0.001$; Table 3; Fig. 2d). The ratio between the two variables is rather constant, even when the outlier (India) is excluded. Given this strong correlation, it is not surprising that none of the factors considered here (i.e. HDI, population and physical exposure) correlated significantly with the ratio between LS-DRR and LS. In fact, this strong correlation implies that this ratio is relatively constant (~0.3) over the countries considered. As a comparison, this ratio is 0.19 and 0.17 for the, not tropical LS-prone, countries Italy and the USA respectively.

### 3.1.2 Nature of publications on landslide risk reduction

On average, there are 20 publications on LS per country and five publications on LS-DRR (Table 2). Figure 3 shows the number of publications on LS and LS-DRR per tropical LS-prone country for the period Jan. 2005 - Jan. 2015. Overall, these maps indicate that especially larger countries in Asia and South America (e.g. India and Brazil) have a high number of publications on LS and LS-DRR, while most African countries clearly have less peer-reviewed literature on these subjects.

[Insert Fig. 3.]

The LS-DRR literature from Scopus is described in detail in the following paragraphs. In terms of spatial scale, the largest number of the 382 consulted publications are local (176 pubs), while articles focusing on a provincial scale form the second largest group (88 pubs; Fig. 4). The third largest group consists of studies for which the spatial scale could not be clearly identified (51 pubs).

[Insert Fig. 4.]

Overall, up to 52% of all the 382 publications involve scientists from the country of interest. This percentage is clearly smaller for Africa and Latin America than for Asia and the Pacific (Fig. 5). Interestingly, a relatively large percentage of the publications involve only foreign institutions (24%). In African and Latin American countries, publications conducted by only foreign institutions form even the largest group (42% and 36% respectively). Knowing that only 6% of the compiled articles concerns LS in Africa, this indicates that the number of African scientists publishing on LS is very small.

[Insert Fig. 5.]

Universities employ the largest percentage of authors (41%). In Africa, however, a fairly large percentage is connected to a NGO (25%), while collaborative research between different types of actors is also common (38%; Fig. 6).

[Insert Fig. 6.]

The literature on LS-DRR is dominated by natural sciences, as 65% of the articles was published in a 'natural science' journal or proceedings volume, 19% in an 'interdisciplinary', only 2% in a 'social science', and 14% in a journal or proceedings volume of unknown research discipline.

### 3.2 Overview of landslide risk reduction measures

Of all LS-DRR measures, 'LS risk assessment' is by far the most implemented DRR component (57%), while 'risk management and vulnerability reduction' is the most recommended DRR component (38%; Fig. 7). 'LS risk assessment' is the most implemented component in all regions, but receives relatively more attention in Africa (72%) which might be attributed to the fact that landslide hazard research is still emerging on this continent and that governance remains  a challenge for the implementation of other DRR actions (UNISDR, 2012). While 'LS risk management and vulnerability reduction' is the most recommended component in all tropical regions, it receives somewhat less attention in Asia-Pacific (27%) as compared to Africa (40%) and Latin America (42%). Generally, implemented and recommended measures vary relatively little between different regions.

[Insert Fig. 7.]

Overall, 575 LS-DRR measures were cited as being implemented in 304 articles, while 906 measures were recommended in 279 articles (Table 4). In the following sections, each LS-DRR component is described in detail, first, by stating the most recommended measures, second, the most implemented measures and, third, by explaining their implementation/recommendation ratio.

[Insert Table 4.]

Noteworthy is that the main focus of landslide research remains on 'hazard' assessment. This focus might be explained by the fact that disaster research is rooted in the natural sciences (Watts, 1983). Our review also indicates that implemented LS-DRR measures are dominantly focusing on the collection of 'hazard' instead of 'vulnerability' data. Of the 255 publications citing the implementation of 'collection of hazard/risk data and assessment' (Table 4), 236 publications refer to the collection of 'hazard' data, while only 19 cite the collection of 'risk' data. This focus on understanding hazards in disaster research is however gradually shifting towards understanding vulnerability and loss of resilience to disasters (Manyena et al., 2013). Our review shows that this shift is indeed increasingly being recommended but not yet reported as implemented. Similarly, most publications focusing on the combination of both hazard and vulnerability, i.e. risk, are relatively new (69% of these studies were published in 2010 or later).

### 3.2.1 Risk management and vulnerability reduction

‘Risk management and vulnerability reduction’ is the most recommended component (38%, 342 pubs) while being amongst the least implemented component (15%, 84 pubs; Table 4; Fig. 7). This component faces the least progress of all DRR components for all hazards globally (UNISDR, 2013). Our review suggests the same for LS in tropical LS-prone countries despite being highly recommended. The fact that LS risk management and vulnerability reduction is highly recommended might be because it involves LS-specific actions whereas others are valid for all hazards.

For the ‘risk management and vulnerability reduction’ component, a list of specific actions for each category of our combined classification is provided in Table 5, based on the SafeLand project that presents the most recent classification and is based on a comprehensive literature review (Vaciago, 2013). Table 5 illustrates that many measures listed by the SafeLand project are neither implemented nor recommended, e.g. expensive measures like drainage tunnels and deep mixing with lime and/or cement. This indicates that, although complete, this classification is too comprehensive for LS-prone tropical countries.

Risk zoning for land use planning is mostly recommended and implemented in the literature for the tropics (117 and 15 pubs, respectively) followed by bio-engineering techniques (32 and 6 pubs, respectively; Table 5). Noteworthy as well is the recommendation and implementation of the modification of the surface water regime (39 and 15 pubs, respectively).

‘LS risk management and vulnerability reduction’ has a relative low implementation/recommendation ratio, i.e. 0.25 (Table 4). Similarly, Anderson et al. (2014) state that the implementation of LS hazard reduction measures, also known as remedial or slope stabilisation measures, is limited in many tropical regions mainly because of the perceived high costs.

[Insert Table 5.]

### 3.2.2 Governance

Governance is cited as the second most recommended LS-DRR component (20%, 184 pubs; Table 4; Fig. 7). Likewise, it is the second most implemented component (11%, 66 pubs). This strong attention for governance might be explained by the strong emphasis of the Hyogo Framework for Action (HFA) on nations as prime actors for setting up DRR measures (Twigg, 2007). Since the ratification of the HFA in 2005, disaster governance is put forward as a key priority (UNISDR, 2015).

The most commonly recommended and implemented governance actions are the improvement of institutional mechanisms, capacities and structures and the allocation of responsibilities (63 and 24 pubs, respectively; Table 4). The latter includes improving coordination and communication in LS risk management and improving capacities at all policy levels. These capacities vary largely between different tropical countries, according to the level of decentralisation, the availability of resources and the political-administrative structure (Maskrey, 2011).

The ratio of implemented and recommended measures is, with an average value of 0.36, rather low (Table 4). The measures with a clearly higher ratio are the integration of LS-DRR with emergency response and recovery (1.00) and creating partnerships (0.75). Partnerships between countries and within countries can be between the government and other stakeholders such as NGOs, the private sector and research institutes. Especially since the HFA in 2005 and the first World Landslide Forum (WLF) in 2008 several international partnerships have been established, e.g. regional networks of the International Consortium on LS in Latin America (Alcántara-Ayala et al., 2014), Asia (Billedo et al., 2013) and to a lesser extent in Africa (e.g. Igwe, 2013). Other examples are the Multi-national Andean Project in seven Latin American countries (Jaramillo, 2008), the Disaster Research Nexus for collaborative research in Malaysia (Koh et al., 2012) and the Integrated Disaster Risk Management Plans for 12 provinces within Vietnam (Long et al., 2010). The measure with a relatively low implementation ratio is the integration of DRR with development policies and planning (0.10). This low rate is in line with the call of the Sendai Framework for a common 'sustainable development' and DRR agenda (UNISDR, 2015).

### 3.2.3 Knowledge and education

Knowledge and education is amongst the least recommended (15%, 133 pubs) and least implemented LS-DRR components (11%, 62 pubs; Table 4; Fig. 7). Nevertheless, literature suggests that it serves as a prerequisite for the implementation of any other measure (Wamsler et al., 2012).

The main recommendations for this DRR component are public awareness in combination with the improvement of knowledge and skills (62 pubs), information management and sharing (35 pubs) and education and training (24 pubs; Table 4). For example in Guatemala, awareness on how to detect early warning signs is recommended (Santi et al., 2011). Because local people are the first actors after a LS occurs, their role in DRR cannot be underestimated (Parkash, 2013). It is therefore recommended that especially local people should be targeted in awareness campaigns related to LS-DRR (e.g. in Sri Lanka: Dias et al., 2013). Remarkably, cultural and individual behaviour receive very limited attention altogether although perception and cultural representation of risk have been reported to be essential in the implementation of DRR (Cannon and IFRC, 2014).

Knowledge and education has a moderate implementation/recommendation ratio, i.e. 0.47 (Table 4). Cultures, attitudes and motivation has a high ratio (1.50). This measure includes studying motivations for adopting measures and using indigenous knowledge for DRR. Information management and sharing has a relatively higher ratio (0.89) and includes the development of web-based or GIS tools for data collection as well as the development of guidelines for implementation of LS-DRR measures. Education and training also has a relatively higher ratio (0.54). Examples are the inclusion of LS-DRR topics in the university curricula and the training of officials on LS-DRR. A national education program on LS has been introduced in Bangladesh (Ali et al., 2014), Colombia (Hermelin & Bedoya (2008), India (Parkash, 2013), Malaysia (Abdullah, 2013; Motoyama and Abdullah, 2013), Sri Lanka (Bandara and Weerasinghe, 2013) and in Vietnam (Long et al., 2010). A distinctly small number of studies discuss the implementation of public awareness schemes and improvement of knowledge and skills on LS mitigation, despite the fact that this action is highly recommended (0.18) and the positive effects of such DRR actions (e.g. Shaw et al., 2009). This could be partly attributed to the limited involvement of scientists in this type of actions (Cutter et al., 2015).

### 3.2.4 Preparedness and response

Preparedness and response to LS events is amongst the least recommended components (15%, 139 pubs) while also being the least cited implemented DRR component (7%, 38 pubs; Table 4; Fig. 7).

The main recommended and implemented measures belonging to this DRR component are recognising physical signs that LS might occur in the near future (e.g. development of tension cracks), warning and subsequent evacuation (74 and 36 pubs, respectively), and contingency planning to a limited extent (14 and 1 pubs, respectively; Table 4). Examples of measures like implementing contingency plans (Scolobig et al., 2014) and temporarily relocation (Gorokhovich et al., 2013) are fairly isolated. No scientific publications could be found on the evaluation of LS emergency response and recovery, coordination, response resource and infrastructures nor the involvement of volunteers.

Preparedness and response measures have a relative low implementation/recommendation ratio, i.e. 0.27 (Table 4). Only early warning systems (EWS) have a higher ratio (0.49). For an overview of EWS in South East Asia we refer to Billedo et al. (2013) and to Larsen (2008) for EWS in general. LS are predicted based on monitoring earthquakes and rainfall events (Bandara et al., 2013) or applying LS prediction models, e.g. in Indonesia (Liao et al., 2011), and through community-based reporting systems, e.g. in the Philippines (Marciano et al., 2011). LS monitoring is often considered as an effective and even affordable measure for DRR and has helped to reduce the number of fatalities in several countries during recent years, e.g. in Sri Lanka (Bandara et al., 2013).

Interestingly, risk insurance is not often recommended despite an internationally growing interest for its general implementation (UNISDR, 2013). This lack is most probably due to the fact that risk insurance is less profitable for low-intensity, high-frequency events like LS as losses might be covered more effectively domestically (Mechler et al., 2010) and because of a lack of formal insurance markets in many rural areas in the tropics. Nevertheless Anderson and Holcombe (2013) argue that social funds, i.e. informal insurance based on social relations, play a major role in the tropics and increasingly focus on the vulnerability component of LS-DRR (e.g. Mertens et al., 2016).

### 3.2.5 Risk assessment

Risk assessment is the least recommended (12%, 86 pubs) but most implemented LS-DRR component (57%, 262 pubs; Table 4; Fig. 7). This might be attributed to the fact that risk assessment is considered the first step towards LS risk management (Crozier and Glade, 2005; DeGraff, 2012), which can also be seen in our literature review from the fact that 53% of recommended measures are made in case risk assessment was already implemented. The large focus on scientific knowledge about LS cannot only be attributed to the fact that we restrict this review to peer-reviewed scientific literature, as a comparison with literature including grey literature for Uganda shows that the preference for implementing LS risk assessment is visible in both reviews (Fig. 8).

[Insert Fig. 8.]

Within this DRR component, the most frequently reported LS risk assessment techniques are the collection and analysis of LS susceptibility, hazard and risk data (59 pubs for recommendation, 255 pubs for implementation) including LS susceptibility and hazard mapping (124 pubs for implementation) and the compilation of LS inventories (61 pubs for implementation; Table 4). LS susceptibility mapping involves the classification and spatial distribution of current and potential LS in a certain area, while LS hazard mapping adds an estimated frequency to the potential LS (Fell et al., 2008). LS risk mapping goes further by taking the outcomes of the hazard mapping and assessing the potential damage to persons, private property, and infrastructure (Fell et al., 2008). The fact that the latter is more complicated explains why LS risk mapping is less implemented than susceptibility and hazard mapping (16 versus 97 pubs). A systematic procedure for assessing LS risk at national scale is in most cases lacking (but not necessarily desirable), except for countries like Brazil (Soler et al., 2013), Cuba (Abella and Van Westen, 2007), India (van Westen et al., 2012), Malaysia (Abdullah, 2013) and Vietnam (Long et al., 2010). Important to note here is that an exclusive promotion of LS susceptibility maps for landslide risk zoning, without site-specific hazard assessments for diagnosis and design of landslide hazard reduction measures, might potentially lead to a lack of effective LS mitigation on the ground (Anderson et al., 2014). For an extensive review on current landslide susceptibility mapping methodologies we refer to the LAMPRE project (Malamud et al., 2014).

LS risk assessment has a high implementation/recommendation ratio, i.e. 3.01 (Table 4). Especially scientific and technical capacities and innovation have a very high ratio (4.32). Noteworthy is that the only scientific and technical innovation cited in literature is the identification of rainfall thresholds that might trigger LS. Countries where rainfall thresholds have been identified are: Ecuador (Ibadango et al., 2007), India (Bhusan et al., 2014), Jamaica (Miller et al., 2009), Malaysia (Althuwaynee et al., 2014), Mexico (Antinao and Farfan, 2013) and Puerto Rico (Wieczorek and Leahy, 2008).

### 3.3 Bottlenecks for implementation of LS-DRR measures

Despite the increased literature on LS-DRR measures (Gutiérrez et al., 2010; Wu et al., 2015), we show that the implementation of measures and their scientific documentation remains rather scarce in the tropics. Furthermore, the low implementation/recommended ratio of most LS-DRR components and difference between recommended and implemented measures suggest that implementing LS-DRR measures remains challenging in the tropics. As their implementation involves different actors and consequently depends on socio-economic and political relations (Kjekstad, 2007), most challenges for implementing LS-DRR measures are to be sought within a political economy perspective. Nonetheless, the view that science is neutral and only decision-makers are responsible for implementation remains dominant (Cannon, 2008). This is illustrated by the fact that many publications still use outpaced concepts like 'natural' disasters, although it is internationally acknowledged that disasters are socially constructed, i.e. their causes are both bio-physical as well as social, economic and political (Wisner et al., 2004).

The different challenges for implementing LS-DRR measures that were identified in this literature review are classified in political, scientific, social, economic, related to disaster risk management and geographic bottlenecks (Table 6). The main bottlenecks are scientific (30%) and political (29%) in nature, corresponding to the first two priorities of the Sendai Framework, i.e. (1) understanding disaster risk and (2) strengthening disaster risk governance to manage disaster risk (UNISDR, 2015). In the following sections, these two main categories of bottlenecks are described in detail with examples from our literature review. The other categories can be found in Table 6.

[Insert Table 6.]

### 3.3.1 Understanding landslide risk

Much progress is made in understanding LS risk in tropical LS-prone countries, i.e. through LS risk assessment, however gaps remain in scientific knowledge. The fact that scientific bottlenecks are cited as the most important in the literature (Table 6) can partly be attributed to the dominance of natural sciences in the literature on LS-DRR.

The most important scientific impediment is the lack of LS inventories and reliable data on hydro-meteorology (19 pubs). LS are often underreported (Wamsler, 2007) or even missing in many LS-prone tropical countries (Nadim and Lacasse, 2008; Petley, 2012) because they are low-intensity, high-frequency hazards and also often considered inseparable from other natural hazards, such as extreme precipitation, earthquakes and floods (e.g. Jacobs et al., 2016). For instance in Malaysia, LS are only reported when casualties occur or infrastructural damage is severe (Althuwaynee et al., 2014). Consequently, most risk assessments tend to focus on susceptibility mapping instead of the more detailed hazard and risk mapping, while it is especially the risk aspect that is crucial for providing improved mitigation (Nadim and Lacasse, 2008). The translation of susceptibility or hazard assessment into risk, requires not only the identification of element at risks, but also the estimation of loss functions for expected impacts (Vranken et al., 2015). Realistic LS risk assessments remain a challenge that is not only restricted to the Global South which indicates a need for the development of adequate methods (Corominas and Mavrouli, 2011). The Sendai Framework however points out the need for a persistent knowledge transfer of current disaster risk understandings from North to South (UNISDR, 2015).

The challenge for LS-DRR is thus not only a lack of available appropriate mitigation measures (Corominas et al., 2013) but also the poor translation of LS risk assessment into actual slope management (e.g. DeGraff, 2012; Majid et al., 2007; UNISDR, 2014). This is also illustrated by the fact that there has been a minimal uptake of LS hazard maps and vulnerability assessments into policy actions by governments, as argued by Anderson et al. (2014) based on evidence from Caribbean countries. There is a lack of communicating LS risk from the academic world to decision-makers as well as from decision-makers to groups at risk due to difficulties in translating the scientific content of the models and their associated uncertainties into more generalised, simplified and practically applicable formats (e.g. Jaiswal and van Westen, 2013; Leroi, 2005). Risk communication can be seen as a two-way interactive tool for sharing risk information amongst government officials, researchers and communities-at-risk (Shaw et al., 2009). It seems that, currently, sharing this risk information is not interactive nor done in a systematic manner. In many cases risk reduction measures are not delivered on the ground but rather delivered as secondary output like maps, policies and (building) codes (e.g. in St. Lucia: Mycoo, 2011). This lack of delivery is partly attributed to the fact that cost-benefit analyses and inclusive multi-criteria analyses are largely absent in scientific literature.

### 3.3.2 Strengthening landslide risk governance

The most restricting political condition is the lack of a stable environment for scientific development, land use planning and ensuring the continuity of risk reduction activities (11 pubs; Table 6). This might be attributed to several reasons such as the high rates of staff turnover, changes to institutional mandates, the short lives of some geosciences institutions and the fluctuating levels of foreign-exchange rates in many LS-prone tropical countries (e.g. Devoli et al., 2007; Jaramillo, 2008; Künzler et al., 2012). Due to a lack of long-term commitment by the government, low-budget but relatively long-term and time-consuming activities are neglected (DFID, 2004; Gue et al., 2009). Especially the lack of secure land tenure rights is considered as a major driver for the misuse of lands (Hofer, 2013).

Another challenge is the lack of institutionalisation of LS-DRR, i.e. the integration of LS-DRR into the national institutional framework (8 pubs). Although this institutionalisation was one of the main priorities that the HFA strived for, the actual implementation remains superficial. Countries with a national slope stability plan as part of their disaster risk management plan are still scarce. We found evidence of available plans only in Costa Rica (Andreas and Allan, 2007), Malaysia (Motoyama and Abdullah, 2013) and Sri Lanka (Bandara and Weerasinghe, 2013). While recently countries are starting to incorporate LS-DRR into their institutional frameworks (Gue et al., 2009), actual implementation remains low due to limited law enforcement (e.g. Ahammad, 2011), poor inclusion of local stakeholders (El-Masri and Tipple, 2002; Santi et al., 2011) and few policy actions that are based on site-specific scientific knowledge as will be discussed further.

Setting political priorities on LS-DRR remains challenging in many tropical LS-prone countries. Nationally a focus remains on post-LS emergency actions (6 pubs). In practice DRR is only considered after LS events happen and enough media attention is given (e.g. Hori and Shaw, 2014). A global review on the status of institutional and legislative systems for LS mitigation in 2009 confirms this focus on response and recovery (Gue et al., 2009). This is explained by the fact that decision-makers hesitate to invest in projects with unobservable benefits combined with the absence of cost-effectiveness studies (Anderson et al., 2014) as will be discussed further. Moreover, LS are very localised and often affecting marginalised population thus attracting considerably less political attention compared to large-scale events such as floods or drought.

### 3.4 Methodological limitations

This literature review is affected by some limitations. A bias in the dataset exists because only peer-reviewed publications with English abstracts have been consulted. Many LS-DRR efforts are published in the national language of the country affected or not published in scientific journals but only as reports by governments, NGOs, private sector or not published at all like indigenous knowledge or 'silent evidence' (e.g. Taleb, 2007). Other LS studies (Gokceoglu and Sezer, 2009; Gutiérrez et al., 2010; Sepúlveda and Petley, 2015) have however used similar methods as this literature review. Furthermore, several observations and trends are based on small numbers of publications, so the reported statistics should be considered indicative.

To investigate this bias, an additional survey of the grey literature for Uganda was made to check for inconsistencies. Including grey literature shows that looking at peer-reviewed scientific literature tends to neglect the implemented governance and awareness components of LS-DRR in the case of Uganda (Fig. 8). This Ugandan case-study thus illustrates that recommendations made by authors of peer-reviewed publications do not necessarily align with those made by governments or civil society actors. The clear preference for implementing LS risk assessment is however visible in both reviews.

## 4. Conclusions and recommendations

The literature on landslides (LS) and landslide disaster risk reduction (LS-DRR) is rapidly increasing worldwide (Gutiérrez et al., 2010; Wu et al., 2015). Our review shows that:

- The factors that influence the number of publications on LS and LS-DRR per country are the absolute physical exposure of people to LS ($\rho = 0.77; 0.73$), the population ($\rho = 0.55; 0.61$) and –to a lesser extent- the HDI of a country ($\rho = 0.35; 0.32$).
- The ratio of publications on LS-DRR versus publications on LS for LS-prone tropical countries for the period 2005-2015 does not differ much between these countries (0.28).

- The vast majority (0.64) of all publications on landslide risk reduction in the tropics was published in journals or proceedings relating to ‘natural sciences’.

Our review further clarifies the main recommended and implemented LS-DRR measures to date based on the compiled classifications of Twigg (2007) and Vaciago (2013; Table 4). More specifically, it shows that:

- A significant fraction (0.30) of all potential LS hazard reduction measures (as classified by the SafeLand project) are neither recommended nor implemented for the tropics.
- The most recommended LS-DRR component (expressed as a fraction of all measures cited) for the tropics is ‘risk management and vulnerability reduction’ (0.38), while the most implemented component is ‘risk assessment’ (0.57).
- The ratio of implemented versus recommended LS-DRR measures in the tropics is rather low for most LS-DRR components (‘risk management and vulnerability reduction’: 0.25; ‘preparedness and response’: 0.27; ‘governance’: 0.36; ‘knowledge and education’: 0.47), except for ‘risk assessment’ (3.01).
- The most cited bottlenecks for implementing LS-DRR measures (expressed as a fraction of all bottlenecks cited) are scientific (0.30) and political (0.29).

Based on this study, several research needs for LS-DRR can be distilled. Overall, this review shows that a lot of research has focussed on understanding landslide susceptibility and hazards in relation to the bio-physical factors that control them. However, quantitative assessments of the impacts of landslides are much rarer. Also scientific assessments of the effectiveness of implemented DRR measures is largely lacking in the current scientific literature. Nonetheless, such information is crucial to support cost-benefit analyses and research on how to effectively translate risk assessment into risk reduction measures. This will require multi-criteria analyses identifying the most effective LS-DRR measures as a function of the spatial scale, the type of LS, the (potential) impact, the underlying root causes and bottlenecks which are currently lacking at national and lower levels.

Moreover, it appears that the responsibility of scientists cannot end at the identification and characterisation of LS hazard and risk, or the recommendation of generic DRR measures. Effectively reducing LS risks will not only require better scientific insights, but also efforts to communicate and transfer scientific research results to policy makers and the population at risk. Involving stakeholders at all stages of the scientific research, i.e. from problem identification to delivery of the most practical results, is crucial to promote ownership and to ensure more site-specific and effective efforts. As landslide research currently remains mainly driven by earth scientists, this will require initiatives in developing trans-disciplinary approaches that are able to go beyond the analysis of the physical drivers of landslides, but integrate the social, political, cultural and economic dimensions of disaster risk reduction in order to identify and characterise the effectiveness of specific DRR measures (Cutter et al., 2015). Hence, earth scientists should actively seek interactions with experts in social sciences and grass-root organisations in order to bridge the gap between the improved understanding of landslide hazard and the effective reduction of landslide risk.

## References

Abdullah CH (2013) Landslide risk management in Malaysia. *WIT Transactions on the Built Environment* 133: 255–265.

Abella EAC and Van Westen CJ (2007) Generation of a landslide risk index map for Cuba using spatial multi-criteria evaluation. *Landslides* 4(4): 311–325.

Adriaanse L and Rensleigh C (2013) Web of Science, Scopus and Google Scholar: A content comprehensiveness comparison. *The Electronic Library* 31(6): 727–744.

Ahammad R (2011) Constraints of pro-poor climate change adaptation in Chittagong city. *Environment and Urbanization* 23(2): 503–515.

Alcántara-Ayala I (2002) Geomorphology, natural hazards, vulnerability and prevention of natural disasters in developing countries. *Geomorphology* 47: 107–124.

Alcántara-Ayala I, Carreño R, Ávila G, et al. (2014) The ICL Latin American Network: Past Activities and Challenges Ahead. In: Sassa K, Canuti P, and Yin Y (eds), *Landslide Science for a Safer Geoenvironment*, Cham: Springer International Publishing, pp. 181–185. Available from: http://link.springer.com/10.1007/978-3-319-04999-1_22 (accessed 29 April 2015).

Ali I, Hatta ZA and Azman A (2014) Transforming the Local Capacity on Natural Disaster Risk Reduction in Bangladeshi Communities: A Social Work Perspective. *Asian Social Work and Policy Review* 8: 34–42.

Althuwaynee OF, Pradhan B and Ahmad N (2014) Estimation of rainfall threshold and its use in landslide hazard mapping of Kuala Lumpur metropolitan and surrounding areas. *Landslides*. Available from: http://link.springer.com/10.1007/s10346-014-0512-y (accessed 22 April 2015).

Anderson MG, Holcombe E, Esquivel M, et al. (2010) The Efficacy of a Programme of landslide risk reduction in Areas of Unplanned Housing in the Eastern Caribbean. *Environmental Management* 45(4): 807–821.

Anderson MG and Holcombe E (2013) *Community-Based Landslide Risk Reduction: Managing Disasters in Small Steps*. The World Bank. Available from: http://elibrary.worldbank.org/doi/book/10.1596/978-0-8213-9456-4 (accessed 16 March 2015).

Anderson MG, Holcombe E, Holm-Nielsen N, et al. (2014) What Are the Emerging Challenges for Community-Based Landslide Risk Reduction in Developing Countries? *Natural Hazards Review* 15(2): 128–139.

Andreas M and Allan A (2007) Incorporating geology and geomorphology in land management decisions in developing countries: A case study in Southern Costa Rica. *Geomorphology* 87(1-2): 68–89.

Antinao JL and Farfan LM (2013) Occurrence of landslides during the approach of tropical cyclone Juliette (2001) to Baja California Sur, Mexico. *Atmósfera* 26(2): 183–208.

Bandara RMS and Weerasinghe KM (2013) Overview of Landslide Risk Reduction Studies in Sri Lanka. In: Margottini C, Canuti P, and Sassa K (eds), *Landslide Science and Practice*, Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 345–352. Available from: http://link.springer.com/10.1007/978-3-642-31325-7_45 (accessed 22 April 2015).

Bandara RMS, Bhasin RK, Kjekstad O, et al. (2013) Examples of Cost Effective Practices for Landslide Monitoring for Early Warning in Developing Countries of Asia. In: Margottini C, Canuti P, and Sassa K (eds), *Landslide Science and Practice*, Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 581–588. Available from: http://link.springer.com/10.1007/978-3-642-31445-2_76 (accessed 22 April 2015).

Bergman EM (2012) Finding Citations to Social Work Literature: The Relative Benefits of Using Web of Science, Scopus, or Google Scholar. *The Journal of Academic Librarianship* 38(6): 370–379.

Bhusan K, Kundu SS, Goswami K, et al. (2014) Susceptibility mapping and estimation of rainfall threshold using space based input for assessment of landslide hazard in Guwahati city in North East India. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XL-8: 15–19.

Billedo EB, Bhasin RK, Kjekstad O, et al. (2013) An Appraisal on Ongoing Practices for Landslide Early Warning Systems in Selected South and East Asian Countries. In: Margottini C, Canuti P, and Sassa K (eds), *Landslide Science and Practice*, Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 573–580. Available from: http://link.springer.com/10.1007/978-3-642-31445-2_75 (accessed 22 April 2015).

Buchan KC (2000) The Bahamas. *Marine Pollution Bulletin* 41(1-6): 94–111.

Cannon T (2008) Vulnerability, ‘innocent’ disasters and the imperative of cultural understanding. *Disaster Prevention and Management* 17(3): 350–357.

Cannon T and International Federation of Red Cross and Red Crescent Societies (eds) (2014) *World disasters report: focus on culture and risk*. World disasters report, Genf: International Federation of Red Cross and Red Crescent Societies.

Corominas J and Mavrouli O-C (2011) *D2.4 Guidelines for landslide susceptibility, hazard and risk assessment and zoning*. Work Package 2.1 - Harmonisation and development of procedures for quantifying landslide hazard, SafeLand project.

Corominas J, van Westen C, Frattini P, et al. (2013) Recommendations for the quantitative analysis of landslide risk. *Bulletin of Engineering Geology and the Environment*. Available from: http://link.springer.com/10.1007/s10064-013-0538-8 (accessed 2 March 2015).

Crozier MJ and Glade T (2005) Landslide Hazard and risk: Issues, Concepts, and approach. In: Thomas G, Anderson M, and Crozier MJ (eds), *Landslide hazard and risk*, UK: John Wiley & Sons Ltd, pp. 1–34.

Cruden DM (1991) A simple definition of a landslide. *Bulletin of the International Association of Engineering Geology* 43(1): 27–29.

Cutter SL, Ismail-Zadeh A, Alcántara-Ayala I, et al. (2015) Global risks: Pool knowledge to stem losses from disasters. *Nature* 522(7556): 277–279.

DeGraff JV (2012) Solving the dilemma of transforming landslide hazard maps into effective policy and regulations. *Natural Hazards and Earth System Science* 12(1): 53–60.

Devoli G, Strauch W, Chávez G, et al. (2007) A landslide database for Nicaragua: a tool for landslide-hazard management. *Landslides* 4(2): 163–176.

DFID (2004) *Disaster Risk Reduction: A Development Concern*. DFID. Available from: www.engineersagainstpoverty.org (accessed 3 January 2015).

Dias AAV, Rupasinghe N and Gunathilaka J (2013) Joint Technical Emergency Operation Experiences on Landslide Disaster Mitigation Event 2003, Sri Lanka. In: Margottini C, Canuti P, and Sassa K (eds), *Landslide Science and Practice*, Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 785–789. Available from: http://link.springer.com/10.1007/978-3-642-31319-6_101 (accessed 22 April 2015).

El-Masri S and Tipple G (2002) Natural Disaster, Mitigation and Sustainability: The Case of Developing Countries. *International Planning Studies* 7(2): 157–175.

Elsevier B.V. (2015) Scopus Content Overview. *Scopus info*. Available from: http://www.elsevier.com/solutions/scopus/content (accessed 16 June 2015).

Falagas ME, Pitsouni EI, Malietzis GA, et al. (2007) Comparison of PubMed, Scopus, Web of Science, and Google Scholar: strengths and weaknesses. *The FASEB Journal* 22(2): 338–342.

Fell R, Corominas J, Bonnard C, et al. (2008) Guidelines for landslide susceptibility, hazard and risk zoning for land use planning. *Engineering Geology* 102(3-4): 85–98.

Gariano SL and Guzzetti F (2016) Landslides in a changing climate. *Earth-Science Reviews* 162: 227–252.

Giuliani G and Peduzzi P (2011) The PREVIEW Global Risk Data Platform: a geoportal to serve and share global data on risk to natural hazards. *Natural Hazards Earth System Sciences* 11(1): 53–66.

Gokceoglu C and Sezer E (2009) A statistical assessment on international landslide literature (1945–2008). *Landslides* 6(4): 345–351.

Google (2015) Google Scholar. *Google*. Available from: https://scholar.google.com/intl/en/scholar/about.html (accessed 16 June 2015).

Gorokhovich Y, Doocy S, Walyawula F, et al. (2013) Landslides in Bududa, Eastern Uganda: Preliminary Assessment and Proposed Solutions. In: Margottini C, Canuti P, and Sassa K (eds), *Landslide Science and Practice*, Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 145–149. Available from: http://link.springer.com/10.1007/978-3-642-31337-0_19 (accessed 22 April 2015).

Gue S-S, Karnawati D and Wong S-Y (2009) Policy and Institutional Framework for Landslide Mitigation and Risk Reduction. In: Sassa K and Canuti P (eds), *Landslides – Disaster Risk Reduction*, Berlin, Heidelberg: Springer-Verlag.

Gutiérrez F, Soldati M, Audemard F, et al. (2010) Recent advances in landslide investigation: Issues and perspectives. *Geomorphology* 124(3-4): 95–101.

Heinisch O (1962) Steel, R. G. D., and J. H. Torrie: Principles and Procedures of Statistics. (With special Reference to the Biological Sciences.) McGraw-Hill Book Company, New York, Toronto, London 1960, 481 S., 15 Abb.; 81 s 6 d. Biometrische Zeitschrift 4(3): 207–208.

Hofer T (2013) Landslides, Land-Use Systems and Food Security. In: *Landslide Science and Practice: Volume 4, Global Environmental Change*, Berlin: Springer, pp. 141–144.

Hori T and Shaw R (2014) Local disaster risk management in a changing climate: Perspective from central America. *Community, Environment and Disaster Risk Management* 17: 1–216.

Ibadango CE, Escarate S, Jackson L, et al. (2007) Application of landslide studies for risk reduction in the Andean community of Reinaldo Espinoza, southern Ecuador. In: Ventnor, UK, pp. 481–488.

Igwe O (2013) ICL/IPL activities in West Africa: landslide risk assessment and hazard mapping approach. *Landslides* 10(4): 515–521.

IPCC (Intergovernmental Panel on Climate Change) and Edenhofer O (2014) Climate change 2014: mitigation of climate change: Working Group III contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. New York, NY: Cambridge University Press.

Jacobs, L., Maes, J., Mertens, K. et al. (2016). Reconstruction of a flash flood event through a multi-hazard approach: focus on the Rwenzori Mountains, Uganda. *Natural Hazards*. doi:10.1007/s11069-016-2458-y.

Jaiswal P and van Westen C (2013) Use of quantitative landslide hazard and risk information for local disaster risk reduction along a transportation corridor: a case study from Nilgiri district, India. *Natural Hazards* 65: 887–913.

Jaramillo MM (2008) Guidelines for landslide hazard mapping in the Andes: Speaking one language. *Geological Society Special Publication* 305: 53–61.

Kervyn M, Poesen J, Vranken L, et al. (2015) AfReSlide. *AfReSlide*. Available from: afreslide.africamuseum.be (accessed 25 June 2015).

Kirschbaum D, Stanley T, and Zhou Y (2015) Spatial and temporal analysis of a global landslide catalog. *Geomorphology* 249: 4–15.

Kjekstad O and Nadim F (2005) Capacity Enhancement for Landslide Impact Mitigation in Central America. In: Washington DC, pp. 321–326.

Kjekstad O (2007) The Challenges of Landslide Hazard Mitigation in Developing Countries. In: Vail, Colorado, pp. 1-25.

Koh HL, Teh SY, Majid TA, et al. (2012) Earthquake and tsunami research in USM: The role of Disaster Research Nexus. *Pertanika Journal of Science and Technology* 20(1): 151–163.

Künzler M, Huggel C and Ramírez JM (2012) A risk analysis for floods and lahars: case study in the Cordillera Central of Colombia. *Natural Hazards* 64(1): 767–796.

Larsen MC (2008) Rainfall-triggered landslides, anthropogenic hazards, and mitigation Strategies. *Advanced Geosciences* 14: 147–153.

Leroi E (2005) Global rockfalls risk management process in ‘La Désirade‘ Island (French West Indies). *Landslides* 2(4): 358–365.

Liao Z, Hong Y, Adler RF, et al. (2011) A physically based SLIDE model for landslide hazard assessments using remotely sensed data sets. In: Shangai, China, pp. 807–813.

Long NT, Yen TH, Carroll D, et al. (2010) Application of GIS based mapping for integrated disaster risk management planning at the provincial level.

Majid R, Shaharom S, Mohamad A, et al. (2007) GPS and GIS based technique for a full-system of registration, management and publishing information of slopes along highways in JKR (PWD) Malaysia. In: Ventnor, UK, pp. 171–174.

Malamud BD, Reichenbach P, Rossi M, et al. (2014) *D6.3 Report on standards for landslide susceptibility modelling and terrain zonations*. LAMPRE, Seventh Framework Programme.

Malik K, United Nations Development Programme and Human Development Report Office (2014) *Sustaining Human Progress: Reducing Vulnerabilities and Building Resilience*. Available from: http://hdr.undp.org/sites/default/files/hdr14-report-en-1.pdf (accessed 16 March 2015).

Manyena SB, Mavhura E, Muzenda C, et al. (2013) Disaster risk reduction legislations: Is there a move from events to processes? *Global Environmental Change* 23(6): 1786–1794.

Marciano Jr. JS, Zarco MAH, Talampas MCR, et al. (2011) Real-World Deployment of a Locally-Developed Tilt and Moisture Sensor for Landslide Monitoring in the Philippines. In: IEEE, pp. 344–349. Available from: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6103662 (accessed 22 April 2015).

Maskrey A (2011) Revisiting community-based disaster risk management. *Environmental Hazards* 10(1): 42–52.

Mechler R, Hochrainer S, Pflug G, Lotsch A and Williges K (2010) Assessing the Financial Vulnerability to Climate-Related Natural Hazards: Background Paper for the World

Development Report 2010 ‘Development and Climate Change’. Policy Research Working Paper 5232, World Bank, Washington, DC.

Mertens K, Jacobs L, Maes J, et al. (2016) The direct impact of landslides on household income in tropical regions: a case study on the Rwenzori Mountains in Uganda. *Science of the Total Environment*, doi:10.1016/j.scitotenv.2016.01.171

Miller S, Brewer T and Harris N (2009) Rainfall thresholding and susceptibility assessment of rainfall-induced landslides: application to landslide management in St Thomas, Jamaica. *Bulletin of Engineering Geology and the Environment* 68(4): 539–550.

Motoyama E and Abdullah CH (2013) Landslide Public Awareness and Education Programs in Malaysia. In: Margottini C, Canuti P, and Sassa K (eds), *Landslide Science and Practice*, Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 291–296. Available from: http://link.springer.com/10.1007/978-3-642-31313-4_38 (accessed 22 April 2015).

Mycoo M (2011) Natural Hazard Risk Reduction: Making St. Lucia Safe in an Era of Increased Hurricanes and Associated Events. *Natural Hazards Review* 12(1): 37–45.

Nadim F and Lacasse S (2008) Strategies for mitigation of risk associated with landslides. In: Sassa K, Canuti P (eds), *Landslides – Disaster Risk Reduction*, Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 31–61.

NGI (2013) Global Risk Data Platform. PreventionWeb. Available from: http://preview.grid.unep.ch (accessed 11 March 2015).

Parkash S (2013) Education, Training and Capacity Development for Mainstreaming Landslides Risk Management. In: Margottini C, Canuti P, and Sassa K (eds), *Landslide Science and Practice*, Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 257–264. Available from: http://link.springer.com/10.1007/978-3-642-31313-4_33 (accessed 22 April 2015).

Payet RA (2005) Climate policy implications of the recent ENSO events in a small island context. In: Low PS (ed.), *Climate Change and Africa*, Cambridge: Cambridge University Press, pp. 231–239. Available from: http://ebooks.cambridge.org/ref/id/CBO9780511535864A043 (accessed 24 February 2016).

Petley D (2012) Global patterns of loss of life from landslides. *Geology* 40(10): 927–930.

Santi PM, Hewitt K, VanDine DF, et al. (2011) Debris-flow impact, vulnerability, and response. *Natural Hazards* 56(1): 371–402.

Scolobig A, Komendantova N, Patt A, et al. (2014) Multi-risk governance for natural hazards in Naples and Guadeloupe. *Natural Hazards*. Available from: http://link.springer.com/10.1007/s11069-014-1152-1 (accessed 22 April 2015).

Sepúlveda SA and Petley DN (2015) Regional trends and controlling factors of fatal landslides in Latin America and the Caribbean. *Natural Hazards and Earth System Sciences Discussions* 3(4): 2777–2809.

Seneviratne SI, Nicholls N, Easterling D et al. (2012) Changes in climate extremes and their impacts on the natural physical environment. In: Field CB, Barros V, Stocker TF (eds), *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation,* Cambridge, UK: Cambridge University Press, pp. 109-230.

Shaw R, Takeuchi Y and Roubhan B (2009) Education, Capacity Building and Public Awareness for Disaster Reduction. In: Sassa K and Canuti P (eds), *Landslides Disaster Risk Reduction*, Berlin: Springer, pp. 499–516.

Soler LS, Gregorio LT, Gonçalves D, et al. (2013) Challenges and perspectives of innovative digital ecosystems designed to monitor and warn natural disasters in Brazil. 13.

Taleb NN (2007) *The black swan: the impact of the highly improbable*. 1st ed. New York: Random House.

Thomson Reuters (2015) Scholarly & Scientific Research. *Thomson Reuters*. Available from: http://thomsonreuters.com/en/products-services/scholarly-scientific-research/scholarly-search-and-discovery/web-of-science.html (accessed 16 June 2015).

Twigg J (2007) *Characteristics of a Disaster-resilient Community - A Guidance Note*. DFID Disaster Risk Reduction Interagency Coordination Group.

UNISDR (2009) Terminology on DRR. United Nations. Available from: http://www.unisdr.org/we/inform/terminology.

UNISDR (2012) *Status report on implementation of Africa Regional Strategy and Hyogo Framework for Action*. Available from: www.unisdr.org/africa (accessed 2 January 2015).

UNISDR (2013) *From Shared Risk to Shared Value –The Business Case for Disaster Risk Reduction*. United Nations Office for Disaster Risk Reduction (UNISDR). Geneva, Switzerland.

UNISDR (2014) *Progress and Challenges in Disaster Risk Reduction: A contribution towards the development of policy indicators for the Post-2015 Framework on Disaster Risk Reduction. Summary and Main Findings.* Geneva, Switzerland: The United Nations Office for Disaster Risk Reduction (UNISDR).

UNISDR (2015) Sendai Framework for Disaster Risk Reduction 2015-2030. In: *A/CONF.224/CRP.1*, Sendai, Miyagi, Japan, pp. 1–25.

Vaciago G (2013) The SafeLand Compendium of Landslide Risk Mitigation Measures. In: Margottini C, Canuti P, and Sassa K (eds), *Landslide Science and Practice*, Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 683–689. Available from: http://link.springer.com/10.1007/978-3-642-31319-6_87 (accessed 2 March 2015).

van Westen CJ, Jaiswal P, Ghosh S, et al. (2012) Landslide Inventory, Hazard and Risk Assessment in India. In: Pradhan B and Buchroithner M (eds), *Terrigenous Mass Movements*, Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 239–282. Available from: http://link.springer.com/10.1007/978-3-642-25495-6_9 (accessed 5 April 2016).

Vranken L, Vantilt G, Van Den Eeckhaut M, et al. (2015) Landslide risk assessment in a densely populated hilly area. *Landslides* 12(4): 787–798.

Wamsler C (2007) Bridging the gaps: Stakeholder-based Strategies for risk reduction and financing for the urban poor. *Environment and Urbanization* 19(1): 115–142.

Wamsler C, Brink E and Rantala O (2012) Climate Change, Adaptation, and Formal Education: the Role of Schooling for Increasing Societies' Adaptive Capacities in El Salvador and Brazil. *Ecology and Society* 17(2). Available from: http://www.ecologyandsociety.org/vol17/iss2/art2/ (accessed 22 April 2015).

Wachinger G, Renn O, Begg C, et al. (2013) The Risk Perception Paradox - Implications for Governance and Communication of Natural Hazards. *Risk Analysis* 33(6): 1049–1065.

Watts M (1983) On the poverty of theory: natural hazards research in context. In: Hewitt K (eds), *Interpretations of calamities from the viewpoint of human ecology*, Ontario: Wilfrid Laurier University, pp. 231-262.

Wieczorek GF and Leahy PP (2008) Landslide Hazard Mitigation in North America. *Environmental & Engineering Geoscience* 14(2): 133–144.

Wisner B, Blaikie P, Cannon T, et al. (2004) *At Risk: Natural hazards, people's vulnerability and disasters (Second edition)*.

Wu X, Chen X, Zhan FB, et al. (2015) Global research trends in landslides during 1991–2014: a bibliometric analysis. *Landslides*. Available from: http://link.springer.com/10.1007/s10346-015-0624-z (accessed 23 September 2015).

Fig. 1. World map with the absolute physical exposure of people to landslides, expressed as the expected annual average number of persons exposed in 2010, per pixel (5x5km) (adapted from NGI, 2013).

Fig. 2. Scatter plots of the factors determining the number of publications on landslides per country (#pubs LS/co) in Scopus for the period Jan. 2005 – Jan. 2015 ($p < 0.001$; $n = 85$) indicating the linear trend line and the coefficient of determination, (a) the absolute physical exposure of people to landslides (# inhabitants/year) of the tropical landslide-prone countries, (b) the population (# inhabitants) of the tropical landslide-prone countries, (c) the HDI of the tropical landslide-prone countries, and (d) the number of publications on landslide risk reduction (# pubs LS-DRR) of the tropical landslide-prone countries. The figures on the left present the entire dataset, while the figures on the right correspond to the zoom (indicated with a box in the figures on the left) (Note: Visual outliers are labelled).

Fig. 3. (a) World map with the number of publications on landslides (# pubs LS) reported in Scopus of the tropical landslide-prone countries for the period Jan. 2005 – Jan. 2015, and (b) World map with the number of publications on landslide risk reduction (# pubs LS-DRR) reported in Scopus of the tropical landslide-prone countries for the period Jan. 2005 – Jan. 2015. Numbers indicate the # pubs for countries with more than 15 publications (for pubs LS) and more than 4 publications (for pubs LS-DRR).

Fig. 4. Number of publications on landslide risk reduction (# pubs LS-DRR) of tropical landslide-prone countries in Scopus for the period Jan. 2005 – Jan. 2015 grouped according to the spatial scale of analysis ($n = 382$; NA is Not Available).

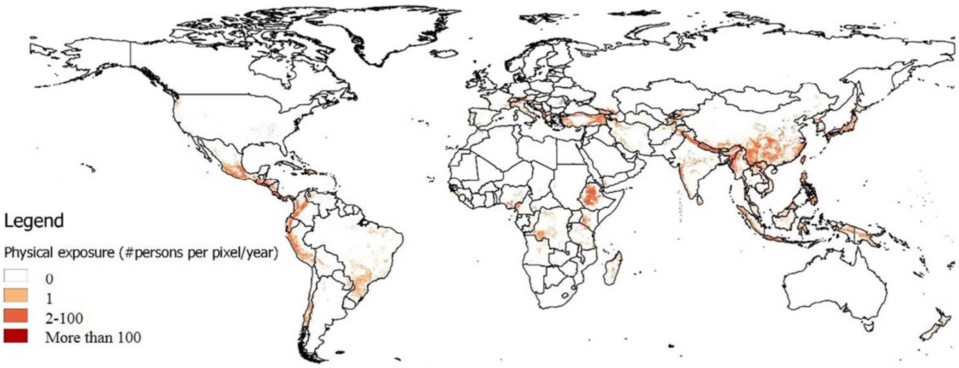
Fig. 5. Distribution of the number of publications on landslide risk reduction (# pubs LS-DRR) in Scopus for the period Jan. 2005 – Jan. 2015 according to the authors' country of origin, (a) Tropics (n = 382), (b) Africa (n = 24), (c) Asia-Pacific (n = 222) and (d) Latin America (n = 136) (NA = Not Available).

Fig. 6. Distribution of the publications on landslide risk reduction (# pubs LS-DRR) in Scopus for the period Jan. 2005 – Jan. 2015 according to the authors' organisation, (a) Tropics (n = 382), (b) Africa (n = 24), (c) Asia-Pacific (n = 222) and (d) Latin America (n = 136) (U = University, G = Government, NGO = Non-governmental organisation, P = Private sector, NA = Not Available, M = Multiple organisations).

Fig. 7. Percentage of the number of publications on landslide risk reduction (# pubs LS-DRR) in Scopus for the period Jan. 2005 - Jan. 2015 that cite the recommended landslide risk reduction components (left column) and the implemented landslide risk reduction components (right column) (see Table 4). (a) Total percentages of the number of publications reporting recommended (total number of citations is 709, reported in 225 individual papers) and implemented landslide risk reduction components (total number of citations is 461, reported in 245 individual papers). Subfigures (b-d) show these results for the specific sub-regions.

Fig. 8. Number of publications on landslide risk reduction (# pubs LS-DRR) reporting (a) recommended and (b) implemented landslide risk reduction (LS-DRR) components (see Table 4) for Uganda based on grey literature and peer-reviewed literature on landslide risk reduction in Scopus (black bars) or based on peer-reviewed literature only (white bars), (G = Governance; RA = Risk Assessment; K&E = Knowledge and Education;

R&V = Risk management and Vulnerability reduction; P&R = Preparedness and response).



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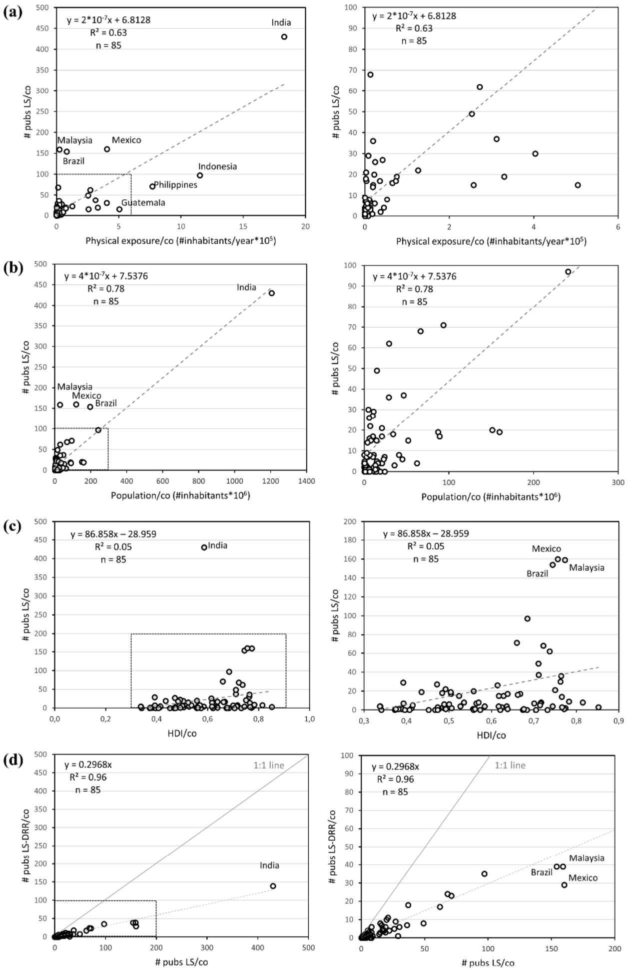

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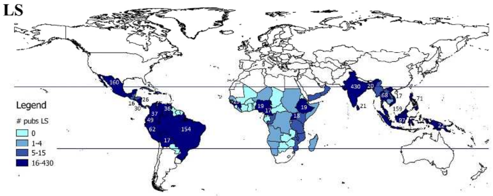
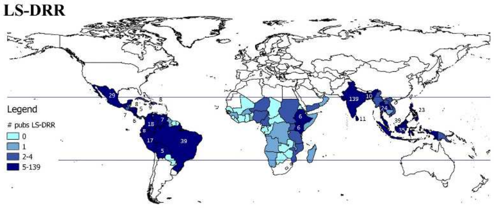
(a) LS



(b) LS-DRR



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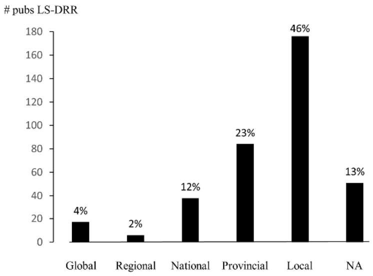

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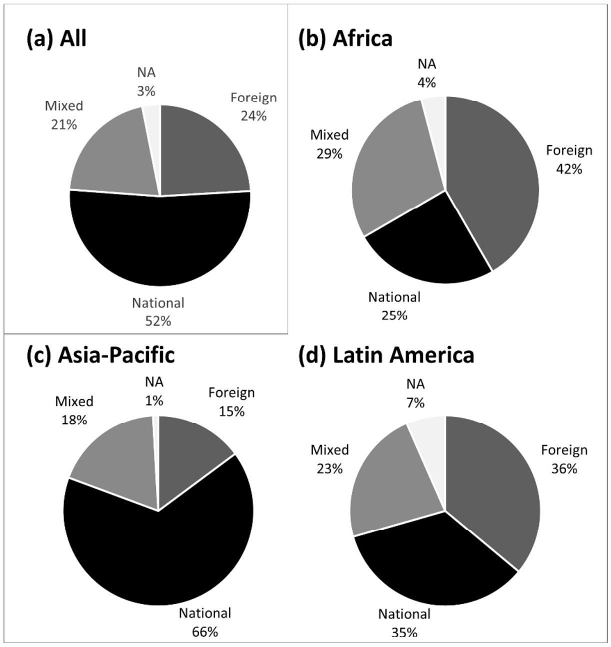

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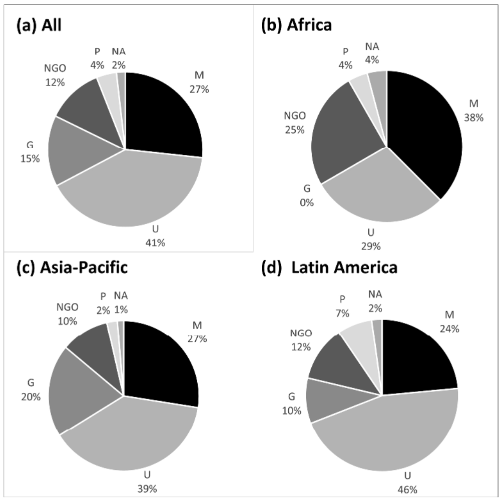

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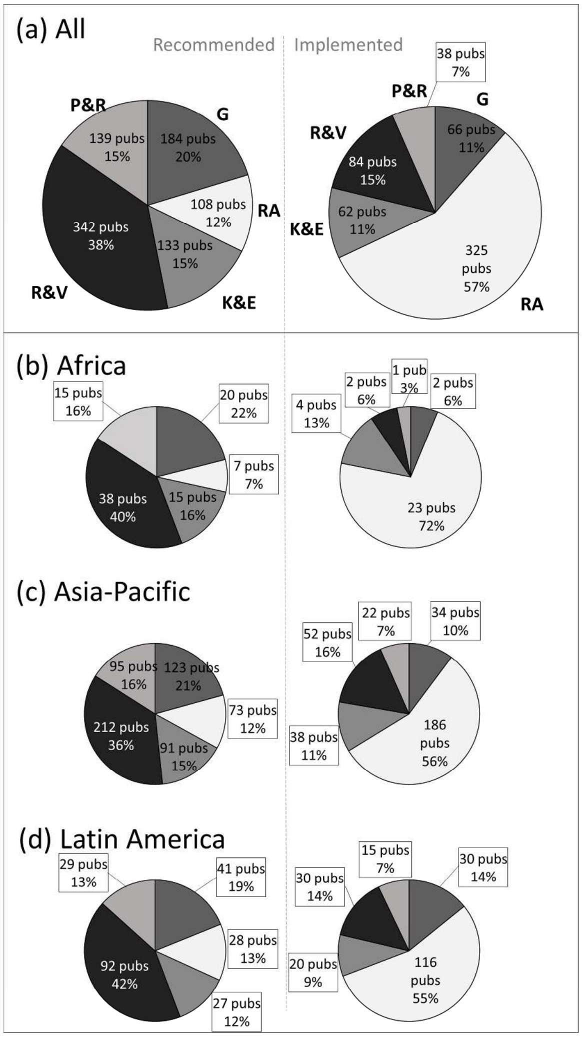

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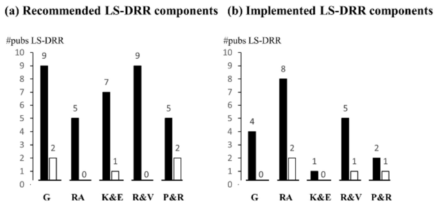

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Table 1. Overview of landslide-prone and not landslide-prone tropical countries based on global and region-specific datasets with, between brackets, the number of publications on landslides and on landslide risk reduction respectively in Scopus for the period between Jan. 2005 and Jan. 2015. An asterix '*' means that the countries do yield landslide publications in Scopus for the period between Jan. 2005 and Jan. 2015 (Note: Since the search period for articles was between Jan. 2005 and Jan. 2015, South Sudan was not considered).

| ***Landslide-prone tropical countries*** *(n = 99)* |
|---|
| Angola (4;1), Antigua & Barbuda (1;0), Bangladesh (20;10), Belize (0;0), Benin (1;0), Bolivia (17;5), Botswana (0;0), Brazil (154;39), Brunei (3;0), Burkina Faso (1;1), Burundi (1;0), Cambodia (4;1), Cameroon (17;4), Cape Verde (4;0), Cayman Islands (2;0), Central African Republic (0;0), Chad (0;0), Colombia (37;18), Comoros (2;1), Congo (7;0), Democratic Republic of Congo (4;1), Costa Rica (30;6), Cuba (8;3), Djibouti (0;0), Dominica (8;0), Dominican Republic (7;2), Ecuador (49;8), El Salvador (16;7), Equatorial Guinea (1;0), Eritrea (1;0), Ethiopia (19;6), Fiji (4;1), French Guiana (0;0), Gabon (0;0), Ghana (0;0), Grenada (4;1), Guadeloupe (10;3), Guam (0;0), Guatemala (15;3), Guinea (29;1), Guinea-Bissau (0;0), Guyana (1;1), Haiti (27;9), Honduras (15;8), India (430;139), Indonesia (97;35), Ivory Coast (0;0), Jamaica (7;2), Kenya (8;6), Laos (8;3), Liberia (2;0), Madagascar (4;1), Malawi (5;1), Malaysia (159;39), Mali (0;0), Martinique (8;1), Mauritius (1;0), Mexico (160;29), Mozambique (7;2), Myanmar (15;3), Namibia (3;1), Netherlands Antilles (0;0), New Caledonia (4;3), Nicaragua (26;5), Niger (4;2), Nigeria (19;3), Oman (9;1), Panama (14;2), Papua New Guinea (22;4), Paraguay (1;0), Peru (62;17), Philippines (71;23), Puerto Rico (37;8), Réunion (15;0), Rwanda ((2;0), São Tomé & Principe (0;0), Senegal (3;0), Sierra Leone (1;0), Solomon Islands (3;1), Somalia (2;1), Sri Lanka (21;11), St. Lucia (5;4), Sudan (3;2), Suriname (0;0), Tanzania (6;2), Thailand (68;24), The Bahamas (4;1), The Gambia (0;0), Timor-Leste (0;0), Togo (0;0), Trinidad & Tobago (3;1), Uganda (18;4), Vanuatu (4;0), Venezuela (36;7), Vietnam (17;4), Virgin Islands (4;1), Yemen (6;3), Zambia (1;0), Zimbabwe (1;0) |
| ***Not landslide-prone tropical countries*** *(n = 39)* |
| American Samoa, Anguilla, Aruba, Baker Island, Barbados*, British Indian Ocean Territory, British Virgin Islands, Christmas Island, Cocos Islands, Cook Islands, French Polynesia*, Glorioso Islands, Howland Island, Jarvis Island, Johnston Atoll, Juan De Nova Island, Kiribati, Maldives, Marshall Islands, Mauritania, Mayotte*, Micronesia*, Montserrat*, Nauru, Niue, Northern Mariana Islands, Palau, Samoa*, Seychelles*, Singapore*, St. Helena, St. Kitts & Nevis, St. Vincent & the Grenadines*, Tokelau, Tonga, Turks & Caicos Islands, Tuvalu, Wake Island, Wallis & Futuna |

Table 2. Number of publications on landslides (# pubs LS) and landslide risk reduction (# pubs LS-DRR) in the 99 tropical landslide-prone countries found in Web of Science, Scopus and Google Scholar for the period Jan. 2005 - Jan. 2015. The average number of publications per country (average #pubs/co), the median number of publications per country (median #pubs/co), the total number of publications (total #pubs) and the number of countries with publications (# countries with pubs) are also included. (Note: The keywords and Boolean search criteria were applied to the 'title', 'abstract' and 'keywords' simultaneously in the case of Scopus and WoS and to the 'title' of the publications in the case of Google Scholar as it is only possible to search in the entire body of text or only in the title. Patents were excluded from our search; NA means Not Applicable)

| | | *Average #pubs/co* | *Median #pubs/co* | ***Total #pubs*** | ***# countries with pubs*** |
|---|---|---|---|---|---|
| ***Scopus (SC)*** | pubs LS (1) | 20 | 4 | 1928 | 81 |
| | pubs LS-DRR (2) | 5 | 1 | 536 | 61 |
| | Ratio (2)/(1) | 0.25 | 0.25 | 0.28 | NA |
| ***Web of Science (WoS)*** | pubs LS (1) | 17 | 4 | 1715 | 78 |
| | pubs LS-DRR (2) | 3 | 0 | 340 | 44 |
| | Ratio (2)/(1) | 0.18 | 0 | 0.20 | NA |
| ***Google Scholar (GS)*** | pubs LS (1) | 8 | 0 | 753 | 46 |
| | pubs LS-DRR (2) | 1 | 0 | 68 | 19 |
| | Ratio (2)/(1) | 0.13 | NA | 0.09 | NA |

Table 3. Correlations (Spearman rho's with * p < 0.01; ** p < 0.001) between the number of publications per country on landslides (# pubs LS/co) and on landslide risk reduction (# pubs LS-DRR/co), and the Human Development Index of a country (HDI/co) (Malik et al., 2014), the absolute physical exposure of people to landslides per country (NGI, 2013), the relative physical exposure of people to landslides per country (NGI, 2013), and the national population in 2010 (UN, 2010) (n = 85 landslide-prone countries, for which the HDI is available)

| | ***HDI/co*** | ***Absolute physical exposure/co (#inhabitants/year)*** | ***Population/co (#inhabitants)*** | ***#pubs LS-DRR/co*** | ***Relative physical exposure/co (#exposed inhabitants/ #inhabitants/year)*** |
|---|---|---|---|---|---|
| ***#pubs LS/co*** | 0.35** | 0.77** | 0.55** | 0.90** | 0.49** |
| ***#pubs LS-DRR/co*** | 0.32* | 0.73** | 0.61** | | |
| ***Population/co (#inhabitants)*** | -0.17 | 0.52** | | | |
| ***Absolute physical exposure/co (#inhabitants/year)*** | 0.19 | | | | |

Table 4. Number of publications (#pubs) in Scopus for the period Jan. 2005 – Jan. 2015 that cite implemented (I) and recommended (R) landslide risk reduction (LS-DRR) measures in tropical landslide-prone countries (see Table 1). According to Twigg (2007), 'early warning systems' are part of the preparedness and response component, while according to Vaciago (2013), these are part of exposure reduction measures and thus the risk management and vulnerability reduction component. As some publications cite several measures, a difference is made between the total number of cited LS-DRR measures (total # citations) and the total number of individual publications that cite LS-DRR measures (total # individual pubs) (NA means Not Applicable).

| ***DRR component*** | ***Landslide risk reduction measures*** | | ***I*** | | ***R*** | | ***I/R*** |
|---|---|---|---|---|---|---|---|
| | | | ***#pubs*** | ***%*** | ***#pubs*** | ***%*** | |
| **Governance (G)** | | | 66 | 11 | 184 | 20 | 0.36 |
| | Policy, planning, priorities and political commitment | | 13 | 2 | 34 | 4 | 0.38 |
| | Legal and regulatory systems | | 1 | 0 | 14 | 2 | 0.07 |
| | Integration with development policies and planning | | 2 | 0 | 21 | 2 | 0.1 |
| | Integration with emergency response and recovery | | 3 | 0 | 3 | 0 | 1 |
| | Institutional mechanisms, capacities and structures; allocation of responsibilities | | 24 | 4 | 63 | 7 | 0.38 |
| | Partnerships | | 9 | 2 | 12 | 1 | 0.75 |
| | Accountability and community participation | | 14 | 3 | 37 | 4 | 0.38 |
| **Risk Assessment (RA)** | | | 325 | 57 | 108 | 12 | 3.01 |
| | Unspecified | | 8 | 2 | 31 | 3 | 0.26 |
| | Collection of hazard/risk data and assessment | | 255 | 44 | 59 | 7 | 4.32 |
| | Assessment of vulnerability/capacity and impact data | | 52 | 9 | 15 | 2 | 3.47 |
| | Scientific and technical capacities and innovation | | 10 | 2 | 3 | 0 | 3.33 |
| **Knowledge and Education (K&E)** | | | 62 | 11 | 133 | 15 | 0.47 |
| | Public awareness, knowledge and skills | | 11 | 2 | 62 | 7 | 0.18 |
| | Information management and sharing | | 31 | 5 | 35 | 4 | 0.89 |
| | Education and training | | 13 | 2 | 24 | 3 | 0.54 |
| | Cultures, attitudes, motivation | | 3 | 1 | 2 | 0 | 1.5 |
| | Learning and research | | 4 | 1 | 10 | 1 | 0.4 |
| **Risk Management and Vulnerability Reduction (R&V)** | | | 84 | 15 | 342 | 38 | 0.25 |
| | Unspecified | | 3 | 1 | 27 | 3 | 0.11 |
| | Landslide hazard reduction | Unspecified | 2 | 0 | 19 | 2 | 0.11 |
| | | Surface protection; erosion control of landslide-toe | 7 | 1 | 49 | 6 | 0.14 |
| | | Modifying the geometry and/or mass distribution | 2 | 0 | 13 | 2 | 0.15 |
| | | Modifying surface water regime | 15 | 3 | 39 | 4 | 0.38 |
| | | Modifying groundwater regime | 4 | 1 | 8 | 1 | 0.5 |
| | | Modifying the mechanical characteristics of unstable mass | 2 | 0 | 1 | 0 | 2 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Transfer of loads to more competent strata | 2 | 0 | 5 | 1 | 0.4 |
| | | Retaining structures | 12 | 2 | 22 | 2 | 0.55 |
| | Vulnerability reduction | Measures to improve capacities of people to cope with landslides | 7 | 1 | 21 | 2 | 0.33 |
| | | Measures to increase the resistance of critical infrastructures | 5 | 1 | 1 | 0 | 5 |
| | | Measures to stop or to deviate the path of landslides | 2 | 0 | 3 | 0 | 0.67 |
| | Exposure reduction | Measures to decrease number of elements-at-risk potentially affected | 16 | 3 | 121 | 13 | 0.13 |
| | | Relocation and migration | 5 | 1 | 13 | 2 | 0.38 |
| **Preparedness and Response (P&R)** | | | 38 | 7 | 139 | 15 | 0.27 |
| | Unspecified | | 1 | 0 | 21 | 2 | 0.05 |
| | Early warning systems | | 36 | 7 | 74 | 8 | 0.49 |
| | Risk transfer (Insurance) | | 0 | 0 | 10 | 1 | 0 |
| | Organisational capacities of and coordination by local communities | | 0 | 0 | 6 | 1 | 0 |
| | Contingency planning | | 1 | 0 | 14 | 2 | 0.07 |
| | Emergency resources and infrastructures | | 0 | 0 | 9 | 1 | 0 |
| | Emergency response and recovery by local communities | | 0 | 0 | 3 | 0 | 0 |
| | Participation, voluntarism, accountability | | 0 | 0 | 2 | 0 | 0 |
| | | Total # citations | 575 | 100 | 906 | 100 | 0.63 |
| | | Total # individual pubs | 304 | | 279 | | 1.09 |

Table 5. Landslide risk management and vulnerability reduction measures as suggested by the SafeLand project (Vaciago, 2013). The number of publications on landslide risk reduction (# pubs LS-DRR) in Scopus for the period Jan. 2005 – Jan. 2015 recommending (R) a specific 'risk management and vulnerability reduction' measure to reduce landslide risk (total number of citations, reported in 169 individual publications, is 342) and describing that a specific 'risk management and vulnerability reduction' measure to reduce LS risk is being implemented (I) (total number of citations, reported in 52 individual publications, is 84).

| **Landslide risk reduction measures** | **# pubs LS-DRR** | | **Countries** |
|---|---|---|---|
| | **I** | **R** | |
| Unspecified | 3 | 27 | I: Mexico, Sri Lanka, St. Lucia<br>R: Bangladesh, India, Indonesia, Kenya, Malaysia, Mexico, Myanmar, Nicaragua, Oman, Peru, Philippines, Sri Lanka, St. Lucia, Tanzania, Thailand, Venezuela, Yemen |
| Landslide hazard reduction | 46 | 156 | |
| Unspecified | 2 | 19 | I: Malaysia<br>R: Ethiopia, India, Malaysia, New Caledonia |
| Surface protection; erosion control | 7 | 49 | |
| Unspecified | 0 | 15 | R: Bolivia, Brazil, Ethiopia, India, Indonesia, Kenya, Malaysia, Mexico, Nigeria, Sri Lanka, Thailand |
| Bio-engineering techniques (hydroseeding, turfing, trees/bushes) | 6 | 32 | I: Ecuador, Guatemala, Honduras, India, Philippines,<br>R: Bolivia, Brazil, Ecuador, Guatemala, Haiti, India, Indonesia, Kenya, Mexico, Nigeria, Philippines, Thailand, Sri Lanka |
| Geosynthetics | 1 | 2 | I: India<br>R: India |
| Not mentioned (Fascines/brush; Drainage blanket; Beach replenishment, rip-rap; Dentition) | | | |
| Modifying geometry and/or mass distribution | 2 | 13 | |
| Removal of material from area driving the landslide | 1 | 6 | I: India<br>R: Bolivia, India, Kenya, Mexico |
| Addition of material to area maintaining stability | 1 | 5 | I: Bolivia<br>R: Bolivia, Kenya, Nigeria |
| Reduction of general slope angle | 0 | 1 | R: India |
| Scaling | 0 | 1 | R: India |
| Modifying surface water regime | 15 | 39 | |
| Unspecified | 4 | 17 | I: Bangladesh, Bolivia, Malaysia, Peru<br>R: Bangladesh, Bolivia, Brazil, Cameroon, Ethiopia, India, Kenya, Malaysia, Mexico, Nigeria, Puerto Rico |
| Diversion channels | 2 | 5 | I: India<br>R: India, Indonesia, Mexico |
| Check dams | 1 | 3 | I: India<br>R: India, Philippines |
| Surface drains to divert flows from slide area | 7 | 9 | I: India, St. Lucia<br>R: Bolivia, Cameroon, Honduras, India, Philippines, St. |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | Lucia |
| | | Sealing tension cracks | 0 | 1 | R : India |
| | | Impermeabilisation | 1 | 2 | I: India<br>R: Kenya, Mexico |
| | | Vegetation | 0 | 2 | R : Haiti, Kenya |
| | Modifying groundwater regime | | 4 | 8 | |
| | | Unspecified | 0 | 5 | R: India, Kenya, Mexico |
| | | Shallow or deep trenches with free-draining geo-materials and synthetics | 2 | 0 | I: India |
| | | Sub-horizontal drains | 1 | 3 | I : India<br>R : Honduras, India |
| | | Wells and caissons | 1 | 0 | I: Philippines |
| | | Not mentioned (Drainage tunnels, galleries, adits) | | | |
| | Modifying mechanical characteristics of unstable mass | | 2 | 1 | |
| | | Compaction | 1 | 0 | I: Malaysia |
| | | Permeation or pressure grouting with cementitious or chemical binders | 0 | 1 | R: India |
| | | Jet grouting | 1 | 0 | I: Philippines |
| | | Not mentioned (Substitution; Deep mixing with lime and/or cement; Modification of groundwater chemistry) | | | |
| | Transfer of loads to more competent strata | | 2 | 5 | |
| | | Shear keys, barrettes and caissons | 1 | 2 | I: Peru<br>R: India, Peru |
| | | Anchors: soil nails, dowels, rock bolts, multi-strand anchors | 1 | 2 | I: India<br>R: India, Philippines |
| | | Anchored walls | 0 | 1 | R: India |
| | Retaining structures | | 12 | 22 | |
| | | Unspecified | 2 | 13 | I: India<br>R: Cameroon, India, Kenya, Malaysia, Mexico, Philippines |
| | | Gravity walls (e.g. masonry, mass concrete and gabions) | 5 | 4 | I: India, Mexico, Peru<br>R: Peru, India |
| | | Reinforced soil systems | 5 | 5 | I: India, Laos, Malaysia, Peru, Thailand<br>R: Bolivia, India, Malaysia, Mexico, Peru |
| | | Not mentioned (Cantilever walls) | | | |
| Vulnerability reduction | | | 14 | 25 | |
| | Measures to increase resistance of critical infrastructures | | 5 | 1 | |
| | | Strengthening of shallow foundations and improved structural design | 5 | 1 | I: Colombia, Ecuador, Philippines<br>R: Cameroon |
| | | Not mentioned (Deep anchoring with or without foundation elements) | | | |
| | Measures to stop or to deviate path of the landslide | | 2 | 3 | |
| | | Re-modelling of the slope | 1 | 0 | I : India |
| | | Planting vegetation on slope | 1 | 1 | I : India<br>R : Brazil |
| | | Rockfall sheds | 0 | 2 | R: Colombia |
| | | Not mentioned (Diversion channels; Catch trenches; Rockfall barriers; Rockfall nets or drapery) | | | |
| | Measures to improve capacities of people to cope with landslides | | 7 | 21 | |
| | | Unspecified | 1 | 10 | I: Indonesia<br>R: Bolivia, Dominican Republic, India, Indonesia, Mexico, Sri Lanka, Thailand |
| | | Improve human capital (knowledge sharing, education, health) | 2 | 5 | I: Bolivia, Uganda<br>R: India, Kenya, Mexico |
| | | Improve social capital (social relations) | 1 | 1 | I: Costa Rica<br>R: Bangladesh |
| | | Improve financial capital | 3 | 5 | I : Bolivia, India, Uganda<br>R: Bangladesh, India, Malaysia, Mexico |

| | | | | | |
|---|---|---|---|---|---|
| | | Not mentioned (Improve natural and physical capital) | | | |
| Exposure reduction | | | 21 | 134 | |
| | Measures to decrease number of elements at risk | | 16 | 121 | |
| | | Risk zoning for land use planning | 15 | 117 | I: Brazil, Colombia, Costa Rica, El Salvador, Honduras, India, Indonesia, Malaysia, Sri Lanka<br>R: Bangladesh, Bolivia, Brazil, Cameroon, Colombia, Dominican Republic, El Salvador, Ethiopia, Guatemala, Honduras, India, Indonesia, Kenya, Malaysia, Mexico, Myanmar, Nicaragua, Oman, Panama, Peru, Philippines, Puerto Rico, Sri Lanka, Tanzania, Thailand, Venezuela, Yemen |
| | | Traffic restrictions | 1 | 4 | I : India<br>R: India |
| | Relocation and migration | | 5 | 13 | I: Dominican Republic, El Salvador, Haiti, India<br>R: Bangladesh, Brazil, Cameroon, Honduras, India, Peru, Thailand |

Table 6. Number of publications on landslide risk reduction (# pubs LS-DRR) in Scopus for the period Jan. 2005 – Jan. 2015 and number of countries (# countries) citing bottlenecks for implementing landslide risk reduction measures (n total = 109) by tropical region and in total.

| | | ***# pubs LS-DRR*** | | | | ***Total (%)*** | ***# countries*** |
|---|---|---|---|---|---|---|---|
| *Category* | ***Bottlenecks*** | *Africa* | *Asia-Pacific* | *Latin America* | ***Total*** | | |
| ***Scientific*** | | 1 | 15 | 17 | **33** | 30 | 20 |
| | Lack of (reliable) data on hydro-meteorology and landslide inventory | 1 | 8 | 10 | **19** | 17 | 10 |
| | Lack of risk communication | 0 | 4 | 1 | **5** | 5 | 2 |
| | Lack of scientific knowledge and scientific capacities | 0 | 1 | 3 | **4** | 3 | 4 |
| | Lack of proper risk/hazard assessment to suggest DRR measures | 0 | 1 | 2 | **3** | 3 | 3 |
| | Poor translation of landslide hazard mapping into DRR measures | 0 | 1 | 1 | **2** | 2 | 2 |
| ***Political*** | | 1 | 15 | 16 | **32** | 29 | 25 |
| | Lack of stable environment | 0 | 2 | 9 | **11** | 10 | 10 |
| | Lack of institutionalisation of DRR | 0 | 8 | 2 | **10** | 9 | 6 |
| | Focus on post-disaster emergency actions instead of pre-disasters measures | 1 | 2 | 3 | **6** | 6 | 5 |
| | Lack of community participation | 0 | 2 | 0 | **2** | 2 | 2 |
| | Lack of law enforcement | 0 | 1 | 0 | **1** | 1 | 1 |
| | Lack of enabling policies | 0 | 0 | 1 | **1** | 1 | 1 |
| | Lack of institutional capacity | 0 | 0 | 1 | **1** | 1 | 1 |
| ***Social*** | | 1 | 10 | 4 | **15** | 14 | 11 |
| | Underestimation or denial of landslide risk | 0 | 6 | 2 | **8** | 7 | 5 |
| | Lack of community acceptance and ownership | 0 | 3 | 2 | **5** | 5 | 4 |
| | DRR measures in conflict with short-term livelihood | 1 | 0 | 0 | **1** | 1 | 1 |
| | Poor awareness on underlying causes and triggering factors of landslides | 0 | 1 | 0 | **1** | 1 | 1 |
| ***Economic*** | | 1 | 8 | 4 | **13** | 12 | 8 |
| | Lack of financial resources of government and groups at risk | 1 | 8 | 4 | **13** | 12 | 8 |
| ***Disaster Risk Management*** | | 0 | 4 | 7 | **11** | 10 | 10 |
| | Lack of coordination/cooperation between agencies | 0 | 3 | 1 | **4** | 4 | 4 |
| | Scattered and local efforts by NGOs and by governments | 0 | 1 | 2 | **3** | 3 | 3 |
| | Lack of multi-hazard approach instead of single-hazard approach | 0 | 0 | 2 | **2** | 2 | 2 |
| | No standardisation of data compilation and DRM procedures | 0 | 0 | 2 | **2** | 2 | 1 |
| ***Geographic*** | | 2 | 2 | 1 | **5** | 5 | 5 |
| | Inaccessibility of areas at risk of landslides | 2 | 2 | 1 | **5** | 5 | 5 |
| | **Total # pubs** | **6** | **54** | **49** | **109** | **100** | |