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REVIEW PAPER

Revisiting landslide risk terms: IAEG commission C-37 working group on landslide risk nomenclature

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Abstract

Significant effort has been devoted during the last few decades to the development of methodologies for landslide hazard and risk assessment. All of this work requires harmonization of the methodologies and terminology to facilitate communication within the landslide community, as well as with stakeholders and researchers from other disciplines. Currently, glossaries, and methodological recommendations exist for preparing landslide hazard and risk studies. Nevertheless, there is still debate on the usage of some terms and their implementation in practice.

In 2016, the IAEG commission C-37 established a working group with the objective of preparing a standard multilingual glossary of landslide hazard and risk terms. The glossary aims for the international harmonization of the terms and definitions with those used in associated disciplines (e.g., seismology, hydrology) while considering landslides specifically. The glossary is based on previously published glossaries, including those prepared by ISSMGE TC32, FedIGS, JTC1, and UNISDR. This article presents comments on the meaning of some of the terms that have required further discussion. The English version of the glossary is also included.

Keywords Landslide · Hazard · Risk · Multilingual glossary

Introduction

Landslide research has experienced significant progress in recent decades; firstly, on the identification, analysis, and modeling of the instability mechanisms of slopes and, more recently, on landslide hazard assessment and risk quantification. Understanding the diversity of factors that control both the occurrence of slope failure and the propagation of a destabilized mass has required intensive fieldwork, geomorphic interpretation, data collection, and treatment. Numerous groups of experts have been involved in preparing landslide maps at different scales. Some of them have developed specific methodologies and have provided tools and criteria so that stakeholders, land-use managers, and civil protection authorities could make their decisions.

One of the most difficult challenges has been to estimate the probability of slope failure (or the frequency of landslides) and to map areas potentially affected. Unlike other natural processes, such as floods, landslides lack long historical records, and their spatial distribution is not defined *a priori*. This has made it difficult to estimate landslide hazard, especially in a quantitative way. This situation has

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substantially improved thanks to new dating techniques and modern data capture tools that, together with the analytical developments and modeling procedures, facilitate hazard and risk assessment and produce more reliable results. Efforts have been made to harmonize landslide risk quantification methodologies and the terms used. However, in practice, difficulties still remain. The reasons are diverse, but one of them is the challenge of expressing landslide hazard in cartographic form. A common terminology is needed to facilitate communication among stakeholders. In risk science, terms are established that convey different meanings depending on the discipline. The glossary of landslide risk terms that we present aims at convergence with those used by experts working on other natural processes that share the same space and time frame with landslides and that are subject to multi-risk analysis. In this sense, natural phenomena that have a common origin with landslides (e.g., torrential and river floods) or for which chain/cascading relationships can be established (e.g., earthquake-landslide-fluvial damming) are of particular interest.

A few glossaries on landslide risk terms exist. The proceedings of the International Workshop on Landslide Risk Assessment that took place in Honolulu in 1997 (Cruden and Fell 1997) are a commendable effort. However, a review of the publications in international journals and conferences shows that the terminologies used still differ or generate ambiguity. To address this issue, in 2016, the IAEG commission C-37 established a working group (WG) on landslide risk nomenclature with the objective of preparing a standard multilingual glossary of landslide hazard and risk terms. The glossary aims for an international harmonization of terms and definitions with those used in associated disciplines (e.g., seismology, hydrology, dam safety) while taking into account the specifics of landslides. The glossary takes as its starting point previous glossaries prepared by the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE) Technical Committee 32 (Nadim 2005), the Federation of the International Geo-engineering Societies (FedIGS), Joint Technical Committee of ISSMGE–IAEG–ISRM on Landslides (Fell et al. 2008), and the United Nations Office for Disaster Risk Reduction (UNDRR, formerly UNISDR) (UN-ISDR 2009).

Any glossary should meet several requirements:

(a) It should provide a basic vocabulary to ensure a common understanding of the meaning of terms for stakeholders.
(b) It should facilitate communication among landslide community members and with other disciplines, to address multi-hazard analysis.
(c) It should use similar terms and standards as much as possible. The intended meanings within the context of the standard should not be misinterpreted or include misleading similarities with other glossaries. Dual meanings for single terms should be avoided as much as possible.
(d) The definitions should be respectful of previous widely used terms, adopting them to the greatest extent possible, thus facilitating backward compatibility with previously published literature.
(e) The definitions should clarify the usage and overcome some contradictions that have arisen with the development and implementation of landslide risk studies.
(f) Terms should be singular nouns, and definitions should be brief and simple to facilitate translation to other languages.

The objective of this contribution is to present comments on selected landslide hazard and risk terms of the multilingual glossary that is currently under preparation by the IAEG C-37 WG. In this paper, the English version of the glossary is included as an appendix.

Specifics of landslide hazard analysis

Landslides are local phenomena that may simultaneously occur over large regions. Although the areal distribution of locations susceptible to slope failure may not be delineated with the same accuracy and resolution as areas subject to flooding, they can be located more accurately than areas subject to other hazards, such tornados or droughts (Varnes 1984).

Contrary to other hazardous processes, such as earthquakes or hurricanes, landslides are site-specific. They affect discrete locations of slopes under particular topographic and geological conditions. Their damage capability is spatially distributed and a function of both the propagation mechanism and path attributes. Furthermore, due to their local character, landslide hazard is usually managed by either local or regional authorities, which often lack resources and appropriate technical support to face the threat. This might explain why landslide risk assessment is a relatively young and less standardized discipline.

The understanding of the occurrence of the hazardous phenomenon and its prevention are common objectives in landslide risk studies. A feature of landslide risk analysis is that, unlike other disciplines, the first procedures that were developed did not evaluate hazard, but rather the predisposition of the terrain to generate landslides without quantifying its likelihood. This is known as landslide susceptibility. The results of susceptibility analyses are usually presented in cartographic form which, for a while, was mistakenly termed a hazard map.

To assess hazard, estimation of the future occurrence of the landslide event is a necessary, but not sufficient, condition. Hazard involves a number of components that are spatially distributed. In a particular location, landslide hazard is a function of the occurrence of the failure of a given slope and the runout probability and intensity which, in turn, depend on the landslide magnitude, the propagation mechanism, and the characteristics of the path. This makes hazard analysis both a challenging and fundamental activity of landslide risk analysis. A complexity arises from the fact that landslide events can involve single or multiple slope failures. Different approaches are used to predict the occurrence of single landslides, the occurrence of triggers (e.g., rainstorm, earthquake) capable of initiating few to many landslides, or the occurrence of a population of landslides generated by multiple triggers over a certain period (Guzzetti 2021).

Discussion of selected risk-related terms

Many risk-related terms have several meanings. An added difficulty is that the meaning attributed in colloquial language is often broad and not rigorous. In different scientific disciplines, the terms have been adapted, fixed by convention, and sustained, as far as possible, in the interpretation given in the first published works.

Some terms are controversial or traditionally have an ambiguous meaning. A few are briefly discussed in the following sections.

Hazard: threat, process, or event?

Most glossaries define *hazard* as a source, condition, or phenomenon with potential to cause harm (e.g., IPCS-WHO. 2004; Schmidt-Thomé et al. 2007; UN-ISDR 2009) or websites such as https://www.usgs.gov/glossary/earthquake-hazards-program). In these glossaries, hazard is considered an inherent property of the risk source, and the probability of an adverse outcome is not mentioned explicitly (Christensen et al. 2003). For landslides, the definition proposed by Varnes (1984) has been widely used. According to Varnes, *landslide hazard* is defined as the probability of occurrence. The definition proposed by C-37 WG aims at accommodating both points of view.

The etymology of hazard is uncertain, but some authors suggest that it derives from the Arabic term *Azzahr*, translated as "the die." Azzahr became *azar* in Spanish and *hasard* in French, in the sense of the Latin word *alea* (e.g., "alea iacta est" Suetonius quoting Julius Caesar). In the online etymology dictionary, in Old French, *hasard* was "a game of chance played with dice" (www.etymonline.com). The current meaning of azar in Spanish or hasard in French is chance or fortune. Even though chance can be for good or for bad, azar in current Spanish is identified as an unfortunate card as well as an unexpected misfortune or accident (www.rae.es). In French, hasard, particularly its derivatives, also signifies danger (e.g., *hasardeux*) and in Italian, "azzardo" has a similar meaning. The English word hazard was taken from Old French and means "chance of loss or harm, risk."

The most popular English-language dictionaries attribute various meanings to the term hazard, including (a) a source of danger, (b) the effect of unpredictable and unanalyzable forces in determining events or chance, and (c) a chance event or accident. These three meanings have been adopted in both popular and scientific language, including in glossaries. In meaning (a), hazard is a qualifier of the natural phenomenon, meaning it is an agent or process with the capability to produce harm. Thus, terms frequently found in the literature include *natural hazard*, *geological hazard*, and, by extension, *landslide hazard*, *earthquake hazard*, etc. Landslides pose hazard. This is the meaning given in one of the first compilations of thematic maps prepared by the United States Geological Survey (USGS) (Robinson and Spieker 1978) and in several multidisciplinary glossaries (e.g., EC-HCPDG 2000; IPCC 2012; IPCS-WHO 2004; Samuels 2005; UN-ISDR 2009) and landslide-specific glossaries (AGS- 2007; Fell et al. 2008; IUGS - Working Group 1997). This is, for instance, the interpretation included in UN-ISDR (2009), which defines hazard as "a dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage." Thus, landslide hazard is the condition of potential harm posed by landslides (slope instability). Here, hazard is used as an adjective qualifying the noun. Since landslides are natural geodynamic processes that can cause damage to people, property, and infrastructure, they are dangerous phenomena. Meaning (b) is found in IPCC (2018), where hazard is defined as "the potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources." Hazard as a potential harm (or threat) can be applied to existing landslides, meaning their capability for reactivation or acceleration (surges). In contrast, abandoned, stabilized, and relict landslides (WP-WLI 1993) should not pose hazard to human activities or to the environment. Meaning (c), although it is common in other disciplines (e.g., economics), is misleading. An event is the realization of the hazard. If hazard is the (landslide) event, then landslide hazard is a redundancy. Moreover, ranking hazard as an event is meaningless. High hazard is not necessarily a big landslide, while the concept of potential occurrence is lost. The event (landslide, earthquake, flood) causing disruption and losses can be qualified as a harmful landslide or a damaging earthquake, although it is probably redundant because all landslides and earthquakes are potentially damaging. The confusion arises from the fact that we call the landslide both the process and the event. Hazard as a synonym of event, therefore, should be avoided. The usage of natural hazard with the meaning of a threat from a natural source (something that has yet to occur) does not conflict with other glossaries and has the advantage that it justifies its mathematical expression.

Metrics of hazard can quantitatively be expressed as the probability of a particular danger (e.g., landslide with a given intensity) occurring within a defined time period and area. This is how it is defined in the well-known expression of Varnes (1984), who borrowed the definition of hazard from UNDRO (1980). However, the use of the term hazard within Varnes (1984) is not always consistent. In the text, it is considered an event (e.g., interaction between the hazard and the people), a potential threat (e.g., landslide hazard mitigation by areal zonation), or an adjective (e.g., hazardous place, hazardous time).

A formal procedure for assessing risk and preparing landslide risk maps was presented by Einstein (1988). He followed the Varnes' framework and introduced the term danger (which is a term seldom used in the literature) to name the natural phenomenon, while he considered hazard to be the unpredictability or limited predictability of the danger. He formally defined hazard in probabilistic terms as the probability that a particular danger occurs within a given period of time. This definition is not the same as that used by Varnes because the spatial component of the landslide is not included. Einstein (1988) included the spatial component in the definition of danger. The practical consequence of such a definition is that preparation of hazard maps for long runout landslides requires the spatial extent of the danger (which depends on the size, motion mechanism, and path attributes) to be delineated first. In other words, Einstein's definition of hazard is the probability of occurrence of a given scenario.

In the multilingual glossary prepared by the IAEG C-37 WG, hazard is defined in a wide sense as follows: "A condition with the potential of causing an undesirable consequence." Here, "potential" qualifies both the capability of causing damage and the fact that the event has not yet occurred. As noted by Hantz et al. (2021), this definition is wider than previous definitions (Fell et al. 2005; Varnes 1984), as the probability is no longer identified with the hazard, but is only a component. The concept of probability appears in the metrics. Mathematically, hazard is the probability of a particular threat occurring in an area within a defined time period.

Landslide magnitude

In colloquial language, *magnitude* has several meanings. Probably, the most widespread definitions refer to the importance of a particular circumstance or problem and to great size or scale, which are uncountable nouns. Every object on Earth has at least one feature or property that can be measured or calculated from other measurements. This property is a physical quantity, which is represented by the combination of a numerical value and a unit. Magnitude is the numerical value of the property expressed as a multiple of the standard unit. It can be assigned to various properties of an object: it is often attributed to a spatial characteristic, such as area or volume, but also to mass, density, force, or energy, among others. Assigning magnitude to a given attribute of an object is, therefore, a matter of convention.

Landslides also have magnitude. Varnes (1984) defined hazard as the probability of occurrence within a specified period of time and within a given area of a potentially damaging phenomenon. Several researchers interpreted that this definition encompasses the concepts of geographic location, recurrence time, and magnitude, although the latter did not appear in Varnes' definition (e.g., Aleotti and Chowdhury 1999; Guzzetti et al. 1999; Hutchinson 1995). In early work on hazard analysis, *landslide magnitude* was introduced to describe attributes such as size, speed, or kinetic energy (e.g., Guzzetti et al. 1999). The idea behind magnitude was characterizing the destructive power of the landslide, and, for a while, landslide magnitude meant both the dimensions of the slope failure and the energy transmitted.

In the field of natural hazards, the term magnitude expresses how big an event is. The difficulty in unifying magnitude definitions is that the size of the different natural processes is not based on a common metric. In seismology, magnitude quantifies the relative size or overall energy released during the earthquake. Different magnitude scales have been proposed for earthquakes (https://www.usgs.gov/programs/earthquake-hazards). The Richter scale, which is seldom used directly anymore, is based on the maximum amplitude of the seismic waves recorded by standard seismographs at various epicentral distances. Currently, the most accepted magnitude scale of earthquakes is the moment magnitude (M_w), which is calculated from seismic moment, Mo ($Mw = 2/3 \times \log Mo - 9.1$). The latter considers the strength of the rock along the fault, the area of the fault that slipped, and the slip distance. For snow avalanches, magnitude describes the size of an avalanche, classified by the destructive potential, runout length, and dimensions (https://www.avalanches.org/glossary/ or https://www.avalanche-center.org/Education/glossary/; Fierz et al. 2009). Hydrology glossaries do not usually define terms such as magnitude and intensity of floods (Samuels 2005; UNESCO 2012). However, the use of size or magnitude-frequency relationships has a long tradition in hydrology. These relationships plot frequency vs. the size of the associated floods in terms of either flood stage (local magnitude), peak flow discharge, or total runoff volume calculated from hydrographs ((England et al. 2019) and references therein).

Much has been written about landslide mapping and the development of landslide inventories, but it is not the purpose of this article to review existing procedures. In the suggested nomenclature for landslides (WP/WLI - 1990), the industry standard for landslide nomenclature was proposed. A review of the literature shows that landslide magnitude is mostly used to describe the size in terms of volume for debris flows (e.g., Hungr et al. 1999; Hupp 1984; Innes 1985; Jakob 2005; Stoffel 2010; Zimmermann et al. 1997), rockfalls (e.g. Agliardi et al. 2009; Douglas 1980; Santana et al. 2012; Williams et al. 2018) and slides (Guzzetti et al. 2009). In addition, in the last few decades, there has been a growing interest in the analysis of the relationship between the size (either volume or area) and the associated frequency of landslides (cumulative or not), in a similar way to earthquakes and floods. These relationships have been presented as volume distributions (Brunetti et al. 2009), volume-frequency relationships (Hunter et al. 2022; Moon et al. 2005), but also magnitude-frequency relationships (Crozier and Glade 1999; Dai and Lee 2001; Hovius et al. 1997; Hungr et al. 1999; Pelletier et al. 1997; Riley et al. 2013). The construction and interpretation of landslide magnitude-frequency relationships have been discussed intensively in the literature (e.g.,Brardinoni and Church 2004; Guthrie and Evans 2004; Guzzetti et al. 2002; Malamud et al. 2004; Ohmori and Hirano 1988; Sugai et al. 1995). The extensive use of these relationships has consolidated the association of size of a mobilized mass with landslide magnitude. Some variants have also been proposed for the term magnitude. Thus, the magnitude of a landslide event is assigned to the number and geographical distribution of slope failures generated by the occurrence of an earthquake or a rainstorm (Malamud et al. 2004; Tanyaş et al. 2018). Recently, a simple and logical classification of landslide size was proposed by McColl and Cook (2023).

The proposed IAEG C-37 WG definition of magnitude is "a measure of the landslide size." This definition keeps some ambiguity because the term size has not been defined. However, the ambiguity can be overcome by specifying whether the term refers to landslide volume, area, or another physical quantity. When the term landslide area is used, it is advisable to specify how it is obtained. The most mapped landslide feature in landslide inventories worldwide is an outer margin encircling all sub-features of a landslide, hence the term *landslide affected area*. This area includes the entire original landslide feature, in plan view, including the crown above the main scarp and both lateral margins or flanks, and extends downslope to the tip and toe of the deposit (WP/WLI 1990). In cross-section, the landslide affected area includes both the zone of depletion and the zone of accumulation. In the case of long-runout landslides, such as rockfalls, debris flows, and rock avalanches, the term affected area is also used to designate the envelope of the area affected by the arrival of debris (Agliardi et al. 2009; Dorren et al. 2004; Guthrie and Evans 2004; Hürlimann et al. 2008; Wang et al. 2014). In the latter cases, a distinction is often made between the landslide source area and the total affected area (Hungr et al. 2008). A good correlation has been found between the product of the volume and height drop and the observed runout and affected area (Strom et al. 2019).

One attribute of magnitude as a dimension of landslides is that it can be measured in the field or from images and can be included in event inventories and represented on maps. The magnitude of a potential landslide is required to estimate hazard. The probability that any exposed element is affected by a landslide depends on the frequency of initiation of landslides of a given magnitude, which must be scaled according to the frequency of reach, which in turn depends on landslide dynamics (Crosta and Agliardi 2003). For hazard zonation purposes, the magnitude-frequency relationships prepared for the landslide source must be combined with suitable runout models to obtain the areal frequency of different landslide magnitudes.

Landslide intensity

The size of a landslide does not determine the damage expected from a landslide in the same way that the energy released in an earthquake does not determine it either. The reason is that landslide magnitude values do not determine the probability of a certain degree of damage (assessed through vulnerability curves). Large (e.g., millions of cubic meters), slow landslides moving at a rate of a few millimeters per year can be less damaging than debris flows of a few thousand cubic meters traveling at several meters per second.

There is wide consensus that *intensity* is the appropriate parameter to describe the damage capability of landslides. Hungr (1997) defined *landslide intensity* as follows: "A set of spatially distributed parameters related to the destructive potential of a landslide." The parameters may be described quantitatively or qualitatively and may include maximum movement velocity, total displacement, differential displacement, depth of the moving mass, peak discharge per unit width, and kinetic energy per unit area. The choice of the appropriate intensity parameter depends on the typology of the landslide and the nature of the elements at risk. For rockfalls, intensity is commonly characterized by the velocity of the blocks or their kinetic energy (Agliardi et al. 2009; Corominas et al. 2005). For debris flows, peak discharge (Jakob 2005), velocity (Calvo and Savi 2009; Hungr 1997), impact pressure (Quan Luna et al. 2011), depth (Fuchs et al.

2007), and velocity squared multiplied by depth (Jakob et al. 2012) are used. For earthflows and other large, slow-moving landslides, total ground displacement, differential displacement or displacement rate (Mansour et al. 2011; Saygili and Rathje 2009), or combining landslide volume and velocity (Cardinali et al. 2002; Reichenbach et al. 2004) are used. In 1997, the Swiss guidelines defined hazard levels based on the landslide intensity and its probability of occurrence. This definition aligns with the definition of earthquake intensity used in most scales, such as the USGS glossary (https://www.usgs.gov/glossary/earthquake-hazards-program), and in the USGS seismic hazard maps (https://www.usgs.gov/programs/earthquake-hazards). The latter define intensity as the severity of an earthquake in terms of its effects on the Earth's surface and on humans and their structures. Similarly, *flood intensity* or severity are terms commonly used to designate the damage capacity of floods. In this case, flood severity is quantified by considering the water depth, flow velocity, or a combination of both (AIDR - Australian Institute for Disaster Resilience 2017; EU Directive 2007/60/EC 2007; Scawthorn et al. 2006). Typical metrics used to describe magnitude and intensity for different processes are shown in Table 1.

The concept of landslide intensity was rapidly incorporated into recommendations (AGS 2007; Corominas et al. 2014; Fell et al. 2008) and books (Glade and Crozier 2005; Lee and Jones 2004). Landslide intensity is undetermined beforehand. Its assessment is not straightforward because it is not an intrinsic characteristic of the landslide. It changes along the path and must be either measured or computed using dynamic models that take the landslide volume and slope geometry as input parameters (Archetti and Lamberti 2003; Friele et al. 2008; Jaboyedoff et al. 2005), and intensity-frequency curves must be prepared for each location on a slope (Jakob et al. 2012). It can also be back-estimated from observed damage.

Fast-moving landslides (e.g., rockfalls, debris flows, flow slides, rock avalanches) are often considered high-intensity events. The reason is that the stretch where these landslides decelerate is generally short, and for regional mapping purposes (medium- to small-scale maps), a high intensity can be assigned to all of them. Although the spatial variation of the intensity might be overestimated for long-runout events, this assumption can be acceptable for land-use planning purposes. Similarly, in transportation corridors in which the exposed elements (vehicles and people) are highly vulnerable to low-intensity impacts, risk analysis is performed without computing landslide velocity or kinetic energy. Intensity is replaced by the magnitude of the event as the input parameter to estimate the number of affected traffic lanes and then to calculate the encounter probability and the probability of loss of life (Bunce et al. 1997; Ferlisi et al. 2012; Hungr et al. 1999; Jaiswal and van Westen 2009; Jaiswal et al. 2010). Furthermore, in areas affected by slow-moving landslides, magnitude has been used as a proxy for the landslide intensity, assuming that large landslides usually cause higher damage than small landslides (Guzzetti et al. 2005). This type of analysis is usually carried out for landslides that are short runout and have displacements that cannot be represented outside of the analyzed spatial unit (e.g., cell, pixel, or polygon). These simplifications are acceptable in risk analysis and evaluation, but must be explicitly stated.

Table 1 Metrics used to describe magnitude and intensity for landslides, earthquakes, and floods

Process	Magnitude metrics	Intensity metrics
Landslides	Volume, area	Velocity, kinetic energy, impact load, absolute displacement, differential displacement
Earthquakes	Energy released	Peak ground acceleration, peak ground velocity, peak ground displacement, spectral parameters
Floods	Peak discharge, total runoff volume	Flow depth and velocity

Landslide hazard levels

Hazard level is a measure of the intensity of the potential event and its associated probability. It is interesting to note that, although hazard refers to the probability of a future landslide event, hazard level is characterized by the consequences. This distinction is illustrated in Table 2, in which hazard levels are ranked based on the probability of the expected consequences and the intensity of the potential event.

Hazard maps

Hansen (1984) defined a *hazard map* as "a map showing the areal extent of any threatening process." Brabb (1984) argued that, ideally, a *landslide hazard map* would show where the landslide processes have operated in the past, where they occur now, and the probability that a landslide will occur in the future. It would also describe the kind of landslide movement, the rate and recurrence of landslide movement, and any other information needed to judge the impact of a landslide on any person or structure, such as the anticipated direction of movement, the thickness or height, viscosity, and density of the material. This concept of hazard map was used by the International Union of Geological Sciences (IUGS) Working Group on Landslides (Cruden and Fell 1997).

A hazard map should thus display the spatial distribution of the expected damaging potential of landslides and

Table 2 Example of hazard levels for land-use planning. Each level has associated pairs of frequency-intensity values (modified from (Lateltin et al. 2005))

High hazard	People at risk both inside and outside of buildings. A rapid destruction of buildings is possible
	Events occurring with a lower intensity, but with a higher probability of occurrence. People are mainly at risk outside the buildings, or buildings can no longer house people
Moderate hazard	People at risk or injury outside of buildings. Risk considerably lower inside of buildings
	Damage to buildings should be expected but not a rapid destruction, as long as the construction type has been adapted to the present conditions
Low hazard	People at low risk or injury. Slight damage to buildings is possible
	Damage might occur inside the building but not at the structure
Residual hazard	Very low probability of a high-intensity event
No danger	Or negligible hazard, according to currently available information

their likelihood. Consequently, a hazard map conveys the concept of hazard level, which encompasses the landslide intensity and the related probability (Lateltin et al. 2005; OFAT, OFEE, OFEFP 1997). This definition of landslide hazard map is analogous to the National Seismic Hazard Maps prepared by the USGS, which display earthquake ground motion for various probability levels (https://www.usgs.gov/programs/earthquake-hazards/hazards).

The preparation of a landslide hazard map is not straightforward. It requires estimation of the spatial distribution of the intensity for a range of landslide magnitudes and their associated probabilities of occurrence. This will result in a number of hazard scenarios, in which the probability of occurrence, the runout probability, and the vulnerability are combined (Agliardi et al. 2009).

In the case of geographically-contained landslides, the combination of spatially distributed hydrological and stability models is often used as a proxy for hazard. The probability of failure of the slope is computed at each terrain unit as the conditional probability of slope failure once a critical amount of rainfall or a critical earthquake intensity is exceeded (Baum et al. 2005; Jaedike et al. 2014; Salciarini et al. 2008; Savage et al. 2004). In this case, hazard is calculated assuming no runout or very short landslide runout, as well as constant magnitude and implicitly, intensity. In study areas having a sufficiently complete landslide inventory, it is then feasible to calculate the probability of a failure of a given size for each land unit. The intensity or the damage potential is assumed to be a function of the landslide size (Guzzetti et al. 2005).

Hazard mapping

A distinction should be made between *landslide hazard mapping* and landslide hazard map. Landslide hazard mapping involves all of the activities necessary to prepare a hazard map. These activities include literature review, landslide inventory compilation, interpretation of remote sensing images, field reconnaissance, and data treatment. As a result of these activities, different maps are obtained, such as landslide inventory maps, landslide probability maps, and landslide runout maps. These activities and outputs can be considered part of the landslide hazard mapping activities. However, these maps by themselves are not hazard maps because they do not fulfill the requirements. A landslide hazard map is a map on which different areas are related to particular landslide hazard levels; that is to say, a map displaying areas having similar landslide intensity-frequency values.

It is possible that the general public and decision-makers may expect a hazard map to be equivalent to mapping of hazardous events or a map that shows extents of existing landslides. However, this interpretation should be avoided. The latter fits into the definition of a landslide inventory map.

Hazard zonation

Varnes (1984) defined *zonation* as the division of the land surface into homogeneous areas that are ranked according to degrees of actual or potential hazard from landslides or other mass movements on slopes. It does not necessarily imply legal restriction or regulation by *zoning* ordinances or laws. In other words, zonation is distinct from land-use zoning. However, throughout the text, the terms zonation and zoning are used interchangeably. In some countries, the term zoning has legal implications. It is a prescriptive tool for the administration and management of the territory through which residential, industrial, and other land uses are assigned. Major cities often have zoning ordinances. Because of this, in the C-37 WG glossary, the use of zonation, which does not have such restrictions, is recommended.

Hazard zonation is not straightforward. The definition of hazard zonation implies that hazard maps should display the location of the actual and potential slope failures, the probability of their future occurrence, and their damage capability for both the source area and the runout zone. These zones should be ranked according to their hazard level, which may be addressed with a hazard matrix. Another often ignored complexity is the difference between hazard areas posed by different classes of landslides, such as falls, flows, and slides.

A hazard matrix can be built from the values of intensity-frequency pairs, in other words, the severity of an event and its probability. The matrix assumes that the hazard level associated with events of high intensity and low frequency might be equivalent to events of lesser intensity and higher frequency. Although this assumption is a criterion often used to make decisions, it is debatable. The fragility curves (intensity-damage relationships) are not linear and are a function of the vulnerability of the exposed element. There are different damage thresholds, and it may be possible that multiple small events do not reach the level of damage of a single large event. In this sense, the spatial zoning of hazard is a challenge. In practice, the spatial distribution of landslide intensity-frequency pairs that are characteristic of long-runout landslides is calculated numerically or estimated. Examples of hazard zonation are found in the procedure developed in Switzerland that calculates the spatially distributed probability curves of the kinetic energy of rockfall blocks (Abruzzese et al. 2009; Jaboyedoff et al. 2005).

Landslide susceptibility

When the time frame is not considered explicitly, hazard is not fully assessed, and the analysis is called a *susceptibility* analysis (Fell et al. 2008). Susceptibility maps are exclusive of the landslide hazard analysis. This type of map has been dominant due to the difficulty of estimating the probability of failure or the frequency of landslides (in the first instance) and then applying this information spatially to different zones on maps. Historically, maps for landslide hazard prevention were developed in the 1970s, in countries such as France, to support urban planning and regional development (i.e., ZERMOS maps). The latter required the identification of areas threatened by landslides in order to introduce restrictions on urban expansion. This approach was in response to the challenges generated by recent catastrophes (Antoine et al. 2010; Champetier de Ribes 1987). The first ZERMOS maps were prepared using heuristic criteria (expert judgment) through geomorphological mapping, in which active and dormant landslides were shown. Landslide activity indicators were identified, as well as the determining factors of instability, whether permanent (relief, geological composition) or transient. The zonation of ZERMOS maps used a color code to indicate the likelihood that landslides will occur in a given location, without prejudging the date of occurrence or considering the expected damage to existing or future developments (Champetier de Ribes 1987; Humbert 1977). Examples of ZERMOS maps appear in the compilation presented by Varnes (1984) under the heading of either landslide hazard zonation or zoning. At the same time, in the USA, systematic procedures for evaluating the landslide propensity were developed by superimposing landslide inventories on geological and slope angle maps. The objective was to associate greater or lesser presence of landslides within each geological formation to various ranges of slope angles. These maps were called relative slope stability (Nilsen et al. 1979) or landslide susceptibility maps (Brabb et al. 1972).

Subsequently, susceptibility maps were prepared with more sophisticated data treatment (for example, statistics) in different countries (Carrara 1983; Carrara et al. 1991; Neuland 1976). To prepare these maps, landslide inventories and environmental variables were combined, applying the principle of actualism in the reverse direction (the past is the key to the present and the future). According to this principle, landslides will occur on slopes that have conditions similar to those that failed in the past. Implicitly, probability is behind susceptibility, as most susceptible slopes will likely fail first. All of this pioneering work was carried out within the context of relatively limited knowledge of landslide mechanisms and tools for recognition and treatment of data that were available at the time. It is not surprising that the terms used then were imprecise. Thus, hazard and risk were used colloquially and interchangeably (as currently occurs in non-specialized dictionaries).

Brabb (1984) defined landslide susceptibility maps as those depicting areas likely to have landslides in the future by correlating the principal factors that contribute to landsliding, such as steep slopes and weak geologic units, with the past distribution of landslides. Moreover, he argued that a landslide susceptibility map should contain information on the type of landslides that might occur, the initiation areas ranked by the likelihood of occurrence, and the possible extent. This definition introduces a relevant point: susceptibility maps must include the area affected by landslides. This area cannot be determined without considering the propagation mechanism, the size of the landslide mass, and the conditions of the path. In practice, however, most landslide susceptibility maps simply present the propensity of terrain to slope failures (Reichenbach et al. 2018). Einstein (Einstein 1988) argued that landslide susceptibility corresponds to hazard by equating spatial probabilities to temporal probabilities. To conform with this definition, the spatial probability must be considered in a broader sense than that proposed by C-37 WG, and it must include the probability of failure for a range of magnitudes combined with the probability of propagation and the associated intensity:

$$P_s = P_A \times P_r$$

where:

P_s is the spatial probability of landslides,

P_A is the probability of landslides of size A,

P_r is the runout probability of landslides of size A.

The debate on whether or not susceptibility should include propagation and intensity is not strictly relevant. The essential point is that hazard maps show areas that may be affected by landslides based on their intensity and probability. The reality is that the vast majority of published susceptibility maps only show the propensity of the slopes to fail, as well as the existing landslides. Therefore, for the benefit of transparency and reproducibility, it is convenient to present the probability of failure and the runout analysis separately (e.g., Leroi 1996; Jaboyedoff et al. 2005). In fact, most quantitative risk assessment (QRA) procedures segregate the risk components (e.g., Fell and Hartford 1997; Fell et al. 2005). This approach makes it possible to identify uncertainties and limitations. In areas with well-developed landslide inventories, such as in the local government area of Wollongong in New South Wales, Australia, susceptibility for different types of landslides can be assessed, and the resulting total susceptibility may be considered (Flentje et al. 2018).

Risk

Risk is defined as "a measure of the probability and severity of an adverse effect to life, health, property, or the environment." Quantitatively (Einstein 1988):

$$Risk = hazard \times potential\ worth\ of\ loss$$

Risk requires existing or potential vulnerable elements. The assessment of risk encompasses the identification and characterization of the hazard with reference to a time frame, the exposure of the elements at risk and their vulnerability, and the estimation of the consequences. All of these components are defined by both spatial and non-spatial attributes.

Once the landslide event has occurred, the exposure and vulnerability of the elements at risk determine the consequences. The exposure indicates whether or not an element at risk is actually located in the path of the landslide. Vulnerability is the measure of the degree of loss to a given element or set of exposed elements in case they are reached by the landslide (Galli and Guzzetti 2007). Losses may be described with different metrics according to the goal of the assessment and the nature of the exposed elements. They can be either a conditional probability of loss, loss exceedance probability, or cumulative losses within a period of time (see the following section on risk analysis).

Since landslide risk requires elements at risk, its definition is conceptually different from the definition of landslide hazard. The latter is an attribute of the natural (physical) environment, whereas landslide risk is a property of the vulnerable elements that may be affected by a potential hazardous event (a single landslide or a population of landslides), including the population (Guzzetti 2000; Rossi et al. 2019; Salvati et al. 2010; Strouth and McDougall 2021; Strouth and McDougall 2022), the built environment (e.g., structures, infrastructure, private, and public properties), the natural environment and related ecological services, and the economy.

It is worth noting that the same landslide may pose very different threats to different types of vulnerable elements. For example, the threat posed by a soil slip to a person walking along a road is different from the threat posed by the same soil slip to the road, to a vehicle traveling along the road, or to a utility line beneath the road. Hence, when assessing risk, the focus should be on the vulnerable elements subject to the threat (the landslide). This has two consequences.

The first consequence is that it makes sense to classify and rank the vulnerable elements present in an area based on their individual landslide risk levels. Then, the landslide risk levels attributed to each vulnerable element can be shown on a map using different colors or symbols. Should a vulnerable element (e.g., a person, a house, a road) be subject to multiple threats (e.g., different landslides, or different landslide types), a common situation in real cases, risk should be evaluated for all of the individual landslides and for all of the different landslide types (Reichenbach et al. 2004).

The second consequence is that different stakeholders may need different evaluations (and representations) of landslide risk, depending on their assets and interests. Imagine a road subject to rock fall hazard. A pedestrian walking along the road is interested in knowing the probability of loss of life while they are walking across the dangerous area. A road maintenance office is interested in the average annual costs due to rockfall occurrence to compare against the risk in other road sections and develop maintenance plans and mitigation measures. A utility company that has securely placed their cables under the road ranks rockfall risk as nil because their assets (the cables) are not vulnerable to rockfalls. In this idealized example, the hazard is the same, but the landslide risk is different.

Risk analysis

The landslide risk framework is well established and consistent (AGS 2007; Corominas et al. 2014; Fell et al. 2008; Fell et al. 2005; Reichenbach et al. 2004; Van Westen et al. 2006). In quantitative *risk analysis* (QRA), landslide risk is broken down into its components. First, landslide hazard is obtained by combining the conditional probabilities of the landslide occurrence based on magnitude, runout distance, and intensity (e.g., Agliardi et al. 2009; Jaboyedoff et al. 2005; Lateltin et al. 2005; Macciotta et al. 2016). Then, the impact probability on the elements at risk and the associated damages are calculated. Following this procedure, risk is expressed as follows (Corominas et al. 2014):

$$R = \sum_{i=m}^{M} f_i \times P\left(X_j|M_i\right) \times P\left(T|X_j\right) \times V \times C$$

where:

R is the risk due to the occurrence of a landslide of magnitude M_i on an element at risk located at a distance X from the landslide source,

f_i is the frequency (or probability of occurrence: $P(M_i)$) of a landslide of magnitude M_i,

$P(X_j \mid M_i)$ is the probability of the landslide reaching a point located at a distance X from the landslide source with an intensity j,

$P(T \mid X_j)$ is the probability of the element being at the point X at the time of the landslide occurrence (exposure),

V_{ij} is the vulnerability of the element being impacted by a landslide of magnitude i and intensity j,

C is the value of the element at risk.

The total risk is the integration of all scenarios (each scenario of M_i has a probability of occurrence).

NASA (2002) states that, in the context of making decisions about complex, high-hazard systems, risk is usefully conceived as a set of triplets: scenarios, associated frequencies, and associated consequences. Therefore, risk analysis aims at giving answers to the following questions: What can go wrong? How likely is it? What are the consequences? In the risk equation above, each landslide magnitude defines a particular scenario that has an associated frequency (or probability of occurrence) and expected consequences. On occasion, full segregation is not required, as occurs in the risk analysis of linear infrastructure, in which landslide inventories and the calculation of their probability (or frequency) are based on the record of events that have reached the infrastructure itself (Bunce et al. 1997; Ferlisi et al. 2012; Hungr et al. 1999; Macciotta et al. 2016).

For some researchers, vulnerability includes exposure, but for the purposes of transparency of the procedure, it is advisable to determine them separately. The product of $P(M_i)$ and $P(X_j \mid M_i)$ is the "H" of Einstein, which incorporates all of the spatial components, and risk has to be calculated for all possible event magnitudes. The product of $P(M_i)$, $P(X_j \mid M_i)$, and $P(T \mid X_i)$ has been defined as impact probability (Agliardi et al. 2009; Galli and Guzzetti 2007). It describes the probability of an element at risk being impacted by a landslide and includes exposure of the element at risk. Working with impact probability may be of interest when performing risk analysis from the exposed element point of view. Impact probability is different from the runout or passage probability (Hantz et al. 2021). The latter refers to the probability of reaching a given point or distance regardless of whether or not there is an element at risk. This approach facilitates the risk analysis of moving elements (i.e., people, vehicles), to which the spatio-temporal probability or exposure $P(T \mid X)$ can be associated. When the exposed elements move along a path in which the probability (or frequency) and size of landslides are known, the exposure $P(T \mid X)$ is given by the following expression, which assumes flow is uniformly distributed in space and time (Nicolet et al. 2016):

$$\mathrm{P}(\mathrm{T}|X) = \frac{f_e \times \left(Wr_i + l_e\right)}{24 \times 1000 \times v_e}$$

where:

$P(T \mid X)$ is the probability that the element at risk is in the landslide path at the time of its occurrence (exposure),

f_e is the flow of elements (e.g., elements/day),

v_e is the velocity of the moving element (e.g., km/h),

W_{ri} is the width of the landslide front,

L_e is the length of the moving element.

This expression highlights that the probability of impact is a function of several variables, as shown in the rock fall fragmentation example in Figure 1.

Vulnerability

Vulnerability is a term that encompasses the various consequences that result from the impact of the landslide on the exposed element(s). The different understandings of vulnerability in the natural and social sciences have given rise to the concepts of physical and social vulnerability (Glade 2003). In the early stages, vulnerability often refers to physical vulnerability (Birkmann 2007). As the study of natural hazards deepens in social science aspects, the definition of vulnerability has expanded (Birkmann 2005; Birkmann 2007), resulting in a complex and diverse concept of social vulnerability.

Physical vulnerability

Physical vulnerability is used in quantitative landslide risk assessment. The purpose of the quantitative landslide risk assessment is to calculate fatalities and loss of property (Fell et al. 2008; Fell et al. 2005). Quantifying the degree of damage to the elements at risk is therefore the basis for quantitative landslide risk assessment. Varnes (1984) uses the definition of vulnerability proposed by UNDRO and UNESCO, which quantifies the degree of loss to a given elements at risk resulted from

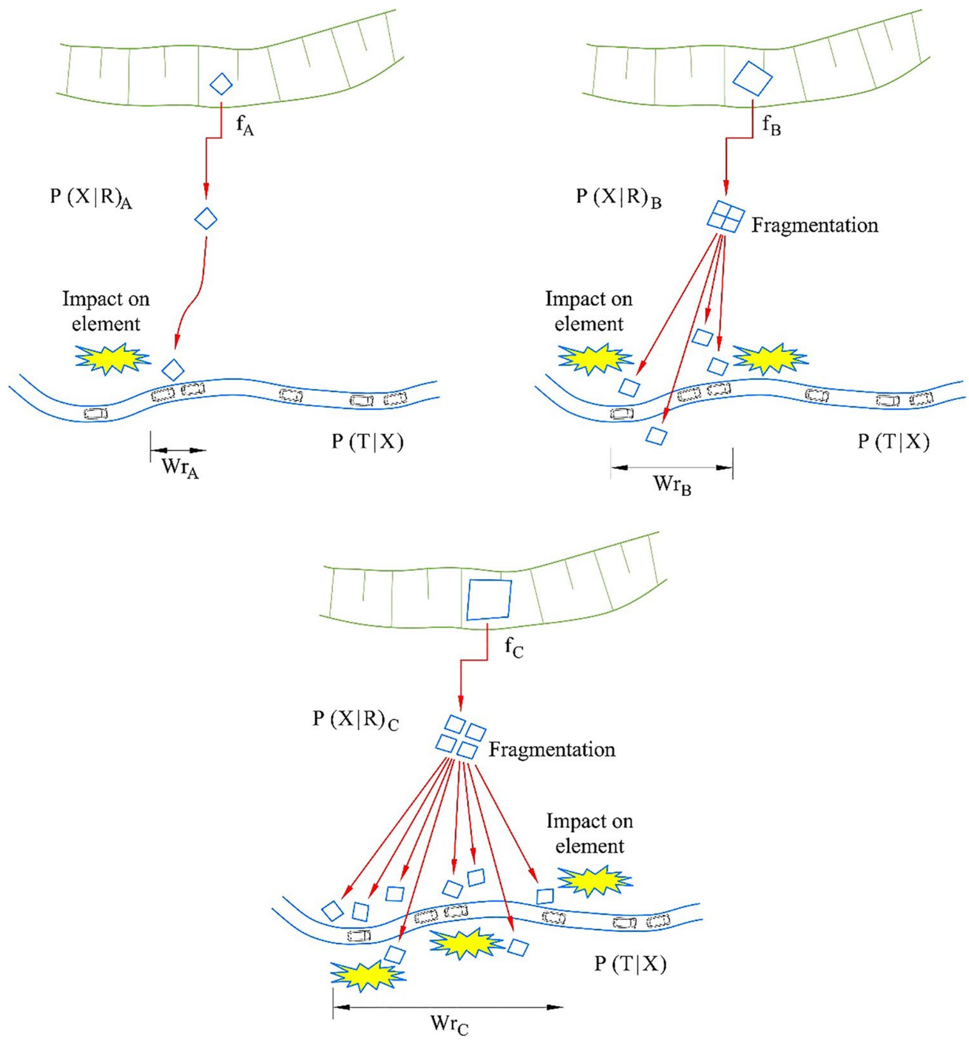

Fig. 1 Exposure variation (probability of impact and number of elements exposed) as a function of the size (R_A, R_B, R_C) of the rockfall and its fragmentation

the occurrence of a natural phenomenon of a given magnitude, and is expressed on a scale from 0 (no damage) to 1 (total loss). This definition meets the need for quantitative landslide risk assessment. Then, Fell (1994) defined vulnerability in landslide risk assessment as "the degree of loss to a given element or set of elements within the area affected by the landslide(s)," which is also expressed on a scale of 0 (no damage) to 1 (total loss). The definitions of physical vulnerability suggested by Varnes (1984) and Fell (Fell 1994) have been widely used in quantitative landslide risk assessment (Corominas et al. 2014; Crozier and Glade 2005; Dai et al. 2002; Fell et al. 2005; Papathoma-Köhle et al. 2017; Uzielli et al. 2008; Van Westen et al. 2006). Physical damage results from the kinematic interaction between the landslide and the elements at risk. The physical vulnerability is therefore determined by the kinematics of the landslides and the characteristics of the exposed elements (including people) (Dai et al. 2002; Lan et al. 2013; Papathoma-Köhle et al. 2017; Uzielli et al. 2008).

Social vulnerability

Social vulnerability is also determined by the characteristics of the hazard and the elements at risk, specifically focused on the social system. However, the interaction between the social system and landslides involves multiple variables, and the complexity of the social system makes it difficult to quantify losses. The study of social vulnerability therefore emphasizes more on the features or factors that influence the social system's ability to coping natural hazards (Birkmann 2005; Birkmann 2007; Fuchs et al. 2012; Tapsell et al. 2010). In the extension of the social vulnerability concept, more and more capabilities and features are included. For example, Turner et al. (Turner et al. 2003) indicate that exposure, sensitivity, and resilience are components of social vulnerability, and Birkmann (Birkmann 2005; Birkmann 2007) indicates that susceptibility, coping capacity, exposure, and adaptive capacity are components of social vulnerability.

Many researchers had discussed the definition of social vulnerability (Cutter 1996; Fuchs et al. 2007; Manyena

2006; Ran et al. 2020; Weichselgartner 2001), yielding widespread inconsistencies. Typical definitions are (a) the likelihood that an individual or group will be exposed to and adversely affected by a hazard (Cutter 1993). It is the intersection of the hazard level with the social profile of communities; (b) the characteristics of an individual or group in terms of their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard (Blaikie et al. 1994). It involves a combination of factors that determine the degree to which someone's life and livelihood are put at risk by a discrete and identifiable event in nature or in society; (c) the degree to which a system, subsystem, or system component is likely to experience harm due to exposure to a hazard, either a perturbation or stress/stressor (Turner et al. 2003); (d) the conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazardous events (UN-ISDR 2005); (e) the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt (Adger 2006); and (f) the characteristics and circumstances of a community, system, or asset that make it susceptible to the damaging effects of a hazardous event (UN-ISDR 2009).

Although it is difficult to unify various definitions of social vulnerability, all considerations more or less suggest the significant role of social capabilities for risk. The challenge for quantitative landslide risk assessment is how to consider the impact of these capabilities on risk.

Risk tolerance

An important consideration is the notion that the *risk tolerance* of individuals and organizations reflects their risk appetite (willingness to take on risk for a benefit) in light of the perceived risk of an activity, or exposure to landslide activity in particular. Perceived risk is a construct of individual or organizational experience, any available estimates of risk, and the confidence in such estimates (e.g., knowledge available for risk estimation) (Creighton et al. 2022). Therefore, risk is not perceived as only the combination of failure probability and consequence, but the amount of knowledge available when estimating probability and consequence (Macciotta et al. 2021). The role of uncertainty and how risk is a function of knowledge (as well as probability and consequence) is discussed by Paltrinieri et al. (Paltrinieri et al. 2019). They postulate that risk tolerability changes for a given failure probability and consequence, if the knowledge available for such calculations varies. This implies that landslide risk management is dependent on estimated risk, available resources, and the risk perception of stakeholders; the latter factor is guided by their experience and knowledge of the hazard and potential consequences.

Risk management

In the context of *landslide risk management*, landslide risk reduction strategies are sometimes referred to as landslide risk mitigation. This use of *mitigation* has become state-of-practice and can be understood by landslide practitioners as the reduction in the probability or the consequences associated with a potential landslide. This notion is supported by the definition in Note 2 of Section 2.25 of ISO 31000 (ISO 2009). However, in other risk management contexts, risk mitigation can have a connotation of risk *treatment*, which aims at reducing the scale of the potential consequences of a negative event, while risk *prevention* can have a connotation of risk treatment that aims at reducing the probability of the event itself. This distinction could become important when communicating risks within a multidisciplinary environment.

Risk reduction typically aims at lowering landslide risks below tolerable and acceptable limits. However, these reductions seldom eliminate risks due to technical and/or financial constraints. The remaining risk is known as residual risk, which is not static. Changes in internal factors (e.g., progressive failure, piezometric changes) or external factors (e.g., loading conditions due to climate change, exposure changes due to population density changes) can lead to progressive increases in residual risk. If this increase continues, residual risks could eventually exceed risk tolerance criteria. Landside early warning systems (LEWS) are one means to monitor landslide behavior to evaluate potential changes in landslide likelihood. Other aspects also require consideration, such as changes in exposed population (e.g., urban developments, increased road traffic) that could increase landslide risk.

Final comments

This work has reviewed a few selected definitions for landslide risk-related terms in order to harmonize them with those used in related disciplines. The terms defined can be easily integrated into quantitative risk analysis. The main feature of landslide-specific risk components is that they are spatially distributed and must be obtained using procedures developed ad hoc. These procedures introduce additional uncertainty into the risk calculation. Furthermore, landslides involve diverse initiation and propagation mechanisms, the analysis of which requires a multi-hazard approach.

It is unavoidable that some terms in different languages, either by tradition or by their meaning, do not have a good fit with English. Varnes (1984) already warned, for example, that in French *risque* meant *danger*. This should not be an impediment to the determination of hazard and risk including the same components and giving rise to the same results.

The fact that some terms contain ambiguity is not in itself relevant. However, transparency is essential to understand the meaning of each term. An example of this is the concept of susceptibility. Some authors consider it to be the propensity to produce a slope failure, while others consider it to be affected by the landslide, which includes runout. This distinction must be declared. In any case, hazard analysis must incorporate both aspects, as well as the intensity. In our opinion, some terminological dilemmas can be overcome by performing quantitative risk analysis, in which all of the components are disaggregated. Hence standardized, commonly accepted and clearly formalized procedures for landslide hazard and risk assessment are necessary.

Appendix. English version of the multilingual glossary

Term	Definition
Acceptable risk	A risk that everyone potentially impacted is prepared to accept. Action to further reduce such risk is usually not required
ALARP (as low as reasonably practicable) principle	The principle that risks that are higher than the limit of acceptability are tolerable only if risk reduction is impracticable or if its cost is grossly disproportionate (depending on the level of risk) to the improvement gained
Conditional probability	The probability of an outcome, given the occurrence of some event
Consequence	The adverse impact resulting from the realization of the hazard
Countermeasures	Measures taken to oppose and reduce risk
Danger (threat)	A natural phenomenon that could lead to damage, described in terms of its geometry, mechanical, and other characteristics
Elements at risk	Population, buildings and engineering works, infrastructure, environmental features, cultural values, and economic activities in the area affected by an event
Environmental risk	(a) The potential for an adverse effect on the natural system (environment) and (b) the probability of suffering damage because of exposure to some environmental circumstance
Event	The realization of a hazard
Exposure	People, property, systems, or other elements present in hazard zones that are thereby exposed to potential losses

Term	Definition
Extreme event	An event that has a very low annual exceedance probability
Failure	A fracturing or giving way under stress
Fault tree analysis	A systems engineering method for representing the logical combinations of various system states and possible causes, which can contribute to a specified problematic (fault) event (called the top event)
Forecast	A definite statement or statistical estimate of the likely occurrence of a future event or conditions for a specific area
f, N pairs	Refers to “f,” the probability of life loss due to failure for each scenario studied, and “N,” the number of lives expected to be lost in the event of such a failure scenario
F-N curves	Curves relating the probability per year of causing N or more fatalities (F) to N
Fragility curve	Defines the probability of exceeding a given damage state as a function of an applied load level
Hazard	A condition with the potential of causing an undesirable consequence. Mathematically, the probability of a particular threat occurring in an area within a defined time period
Hazard level	A measure of the intensity and probability of occurrence of a hazardous event
Hazard zonation	Mapping of an area in which particular zones correspond to different hazard levels.
Individual risk to life	The increment of risk imposed on a particular individual by the existence of a hazard
Involuntary risk	A risk imposed on people by a controlling body and not assumed by free choice of the people at risk
Landslide inventory	A record of recognized landslides in a particular area
Landslide hazard analysis	The use of available information to estimate the zones where landslides of a particular type, volume, velocity, and runout may occur within a given period of time
Landslide hazard map	A map on which different areas are characterized by different landslide hazard levels

Term	Definition
Landslide intensity	A set of spatially distributed parameters related to the destructive potential of a landslide
Landslide magnitude	A measure of the landslide size
Landslide probability	Can refer specifically to the following: (i) Spatial probability: the probability of occurrence of a landslide in a given area (ii) Temporal probability: the probability that a landslide will occur in a given period of time in a specified area (iii) Size/volume probability: the probability that a landslide has a specified size/volume (iv) Runout probability: the probability that a landslide will reach a specified distance or affect a specified area downslope
Landslide risk map	A map on which different areas are characterized by different probabilities of losses (physical, societal, economic, environmental) that might occur due to landslides of a given type within a given period of time
Landslide susceptibility	A quantitative or qualitative assessment of the volume (or area) and spatial distribution of landslides that exist or potentially may occur in an area. Susceptibility may also include a description of the velocity and intensity of the existing or potential landslides
Landslide susceptibility map	A map on which different areas are characterized by different likelihoods that landslides of a given type may occur
Mitigation	Measures taken to limit the adverse impact of, for instance, natural hazards
Phases of landslide activity	Stage in the development of a landslide
Population at risk	All of the people who would be directly exposed to the consequences of landslides
Preparedness	Activities and measures taken in advance to plan for effective response to hazards and their consequences
Prevention	Measures and actions taken to stop adverse impacts (consequences)
Recurrence interval	The long-term average elapsed time between landslide events at a particular site or in a specified area. Also known as return period

Term	Definition
Residual risk	The remaining level of risk at any time after a program of risk mitigation measures has been implemented
Retrofitting	Reinforcement or upgrading of existing structures to become more resistant and resilient to the damaging effects of hazards
Risk	A measure of the probability and severity of an adverse effect to life, health, property, or the environment. Quantitatively, Risk = hazard × potential worth of loss
Risk analysis	The use of available information to estimate the risk to individuals, populations, property, or the environment, from hazards
Qualitative risk analysis	An analysis that uses verbal or relative rating scales to estimate and describe the magnitude of potential consequences and the likelihood that those consequences will occur
Quantitative risk analysis	An analysis that uses numerical values of the probability of occurrence of a potentially damaging event, vulnerability of the exposed elements and consequences, and resulting in a numerical value of the risk
Reach probability	See runout probability
Risk assessment	The process of making a recommendation on whether existing or future risks are acceptable, and if not, whether risk control measures are justified or should be implemented
Risk control	The implementation and enforcement of actions to restraint risk and the periodic re-evaluation of the effectiveness of these actions
Risk evaluation	The stage at which values and judgement enter the decision-making process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental, and economic consequences, in order to identify a range of alternatives for managing the risks, if necessary
Risk management	The systematic application of policies, procedures, and practices to the tasks of identifying, analyzing, assessing, evaluating, communicating, monitoring, and mitigating risk

Term	Definition
Risk mitigation	Application of appropriate techniques and principles to reduce either the probability of an occurrence, its adverse consequences, or both
Runout probability	The probability that a specified landslide will reach a certain distance downslope or affect a specified area
Scenario	A single realization of the consequences of a given event (or a sequence of events) having a given probability of occurrence
Societal risk	The cumulative estimated risk to all individuals exposed to a landslide hazard within a consultation zone
Susceptibility	See landslide susceptibility
Spatio-temporal probability of the element at risk	The probability that the element at risk is in the landslide path at the time of its occurrence. It is the quantitative expression of the exposure
Tolerable risk	A risk that is within a range that society can live with so as to secure certain net benefits
Voluntary risk	A risk that a person faces by choice in order to gain some benefit
Vulnerability	The degree of loss of a given element or set of elements exposed to the occurrence of a landslide of a given magnitude and intensity
Zonation	The division of land into homogeneous areas or domains and their ranking according to degrees of actual or potential landslide susceptibility, hazard, or risk

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