ICL Contribution to Landslide Disaster Risk Reduction

Nicola Casagli
Veronica Tofani
Kyoji Sassa
Peter T. Bobrowsky
Kaoru Takara
Editors

Understanding and Reducing Landslide Disaster Risk

Volume 3 Monitoring and Early Warning

ICL

Springer

ICL Contribution to Landslide Disaster Risk Reduction

Series Editor

Kyoji Sassa, The International Consortium on Landslides, ICL, Kyoto, Japan

The ICL Contribution to Landslide Disaster Risk Reduction book-series publishes integrated research on all aspects of landslides. The volumes present summaries on the progress of landslide sciences, disaster mitigation and risk preparation. The contributions include landslide dynamics, mechanisms and processes; volcanic, urban, marine and reservoir landslides; related tsunamis and seiches; hazard assessment and mapping; modeling, monitoring, GIS techniques; remedial or preventive measures; early warning and evacuation and a global landslide database.

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Editors
Nicola Casagli
Earth Science Department
University of Florence
Florence, Italy

National Institute of Oceanography
and Applied Geophysics—OGS
Trieste, Italy

Veronica Tofani
Earth Sciences Department
University of Florence
Florence, Italy

Peter T. Bobrowsky
Geological Survey of Canada
Sidney, BC, Canada

Kyoji Sassa
International Consortium on Landslides
Kyoto, Japan

Kaoru Takara
Graduate School of Advanced Integrated Studies
in Human Survivability (Shishu-kan)
Kyoto University
Kyoto, Japan

Associate Editors
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ICL and Springer created a new book series “ICL Contribution to Landslide Disaster Risk Reduction” in 2019 which is registered as ISSN 2662-1894 (print version) and ISSN 2662-1908 (electronic version). The first books in this series are six volume of books “Understanding and Reducing Landslide Disaster Risk” containing the recent progress of landslide science and technologies from 2017 to 2020.

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Foreword by Mami Mizutori

More landslides can be expected as climate change exacerbates rainfall intensity. The long-term trend of the last 40 years has seen the number of major recorded extreme weather events almost double, notably floods, storms, landslides, and wildfires.

Landslides are a serious geological hazard. Among the host of natural triggers are intense rainfall, flooding, earthquakes or volcanic eruption, and coastal erosion caused by storms that are all too often tied to the El Niño phenomenon. Human triggers including deforestation, irrigation or pipe leakage, and mine tailings, or stream and ocean current alteration can also spark landslides. Landslides can also generate tsunamis, as Indonesia experienced in 2018.

Globally, landslides cause significant economic loss and many deaths and injuries each year. Therefore, it is important to understand the science of landslides: why they occur, what factors trigger them, the geology associated with them, and where they are likely to happen.

Landslides with high death tolls are often a result of failures in risk governance, poverty reduction, environmental protection, land use and the implementation of building codes. Understanding the interrelationships between earth surface processes, ecological systems, and human activity is the key to reducing landslide risk.

The Sendai Framework for Disaster Risk Reduction, the global plan to reduce disaster losses adopted in 2015, emphasizes the importance of tackling these risk drivers through improved governance and a better understanding of disaster risk.

One important vehicle for doing that is the Sendai Landslide Partnerships 2015–2025 for global promotion of understanding and reduction of landslide risk facilitated by the International Consortium on Landslides (ICL) and signed by the leaders of 22 global stakeholders, including the UN Office for Disaster Risk Reduction (UNDRR), during the Third UN World Conference on Disaster Risk Reduction in Sendai, Japan.

The Sendai Landslide Partnerships—featured on the Sendai Framework Voluntary Commitments online platform—helps to provide practical solutions and tools, education, and capacity building, to reduce landslide risks.

The work done by the Sendai Partnerships can be of value to many stakeholders including civil protection, planning, development and transportation authorities, utility managers, agricultural and forest agencies, and the scientific community.

UNDRR fully supports the work of the Sendai Landslide Partnerships and ICL and looks forward to an action-oriented outcome from the 5th World Landslide Forum to be held in November 2020 in Kyoto, Japan. Successful efforts to reduce disaster losses are a major contribution to achieving the overall 2030 Agenda for Sustainable Development.

Mami Mizutori
United Nations Special Representative of the
Secretary-General for Disaster Risk Reduction

Foreword by the Assistant Director-General for the Natural Sciences Sector of UNESCO for the Book of the 5th *World Landslide Forum*

As the world slowly recovers from the COVID-19 global pandemic, and looking back at the way this crisis developed, it becomes evident that as a global community we were not prepared for an event of this scale. Although not commonly perceived as such, biological hazards such as epidemics are included in the Sendai Framework for Disaster Risk Reduction 2015–2030. In that sense, the preparedness approach for a pandemic is very similar to that of a geophysical natural hazard such as landslides.

Although natural hazards are naturally occurring phenomena, the likelihood of their occurrence and of associated disasters is rising. Climate change, urban pressure, under-development and poverty and lack of preparedness are increasingly transforming these natural hazards into life-threatening disasters with severe economic impacts. Therefore, Disaster Risk Reduction (DRR) is gaining momentum on the agenda of the UN system of Organizations including UNESCO. While the Sendai Framework for Disaster Risk Reduction 2015–2030 is the roadmap for DRR, other global agendas including the Sustainable Development Goals, the Paris Climate Agreement and the New Urban Agenda have targets which cannot be attained without DRR.

In shaping its contribution to those global agendas, UNESCO is fully committed in supporting its Member States in risk management, between its different mandates and disciplines and with relevant partners. The International Consortium on Landslides (ICL) is UNESCO's key partner in the field of landslide science. The Organization's support to the Consortium is unwavering. Since ICL was established in 2002, the two organizations have a long history of cooperation and partnership and UNESCO has been associated with almost all of ICL activities. I am very glad that ICL and UNESCO are mutually benefitting from their collaboration.

The 5th World Landslide Forum (WLF5) is expected to represent a milestone in the history of landslide science particularly for scientists and practitioners. One of the major outcomes of WLF5 will be the Kyoto 2020 Commitment for global promotion of understanding and reducing landslide disaster risk (KLC2020). This commitment is expected to strengthen and expand the activities of the Sendai Landslide Partnership 2015–2025. With UNESCO already engaged as a partner, the adoption of this international commitment will raise global awareness on landslide risk and mobilize wider partnerships that draw together stakeholders from all levels of society, across different regions, sectors and disciplines.

It is my great pleasure to congratulate the organizers for holding this event and assure you that UNESCO is fully committed in contributing to its success. As part of that contribution, our Organization is proud to host a session on landslides and hazard assessment at UNESCO-designated sites such as natural World Heritage sites, biosphere reserves and UNESCO Global Geoparks. This session aims to assess landslide impacts on our shared cultural and natural heritage, providing the best opportunity to generate public awareness and capacity development for landslide disaster reduction.

I am confident that WLF5 will contribute to further advance the knowledge of both scientists and practitioners regarding landslide disaster risk reduction. This book paves the way for the science, knowledge and know-how which will feature in the deliberations of the Forum. UNESCO commends all of the contributors to this publication. I look forward to an enhanced collaboration between UNESCO and ICL in future activities and undertakings.

Shamila Nair-Bedouelle
Assistant Director-General for Natural Sciences
UNESCO

Preface I

Understanding and Reducing Landslide Disaster Risk

Book Series: ICL Contribution to Landslide Disaster Risk

The International Consortium on Landslides (ICL) was established in pursuance of the 2002 Kyoto Declaration "Establishment of an International Consortium on Landslides," with its Statutes adopted in January 2002. The Statutes define the General Assembly of ICL as follows: in order to report and disseminate the activities and achievements of the Consortium, a General Assembly shall be convened every 3 years by inviting Members of the International Consortium on Landslides, individual members within those organizations, and all levels of cooperating organizations and individual researchers, engineers, and administrators. The General Assembly developed gradually prior to, during and after its first meeting in 2005. In the light of the 2006 Tokyo Action Plan, the Assembly was further facilitated at, and following the First World Landslide Forum held in November 2008. On the occasion of each of its triennial forums, ICL publishes the latest progress of landslide science and technology for the benefit of the whole landslide community including scientists, engineers, and practitioners in an understandable form. Full color photos of landslides and full color maps are readily appreciated by those from different disciplines. We have published full color books on landslides at each forum. In 2019, ICL created a new book series "ICL Contribution to Landslide Disaster Risk Reduction" ISSN 2662-1894 (print version) and ISSN 2662-1908 (electronic version). Six volumes of full color books *Understanding and Reducing Landslide Disaster Risk* will be published in 2020 as the first group of books of this series.

The Letter of Intent 2005 and the First General Assembly 2005

The United Nations World Conference on Disaster Reduction (WCDR) was held in Kobe, Japan, 18–22 January 2005. At this Conference, ICL organized session 3.8 "New international Initiatives for Research and Risk Mitigation of Floods (IFI) and Landslides (IPL)" on 19 January 2005 and adopted a "Letter of Intent" aimed at providing a platform for a holistic approach in research and learning on 'Integrated Earth System Risk Analysis and Sustainable Disaster Management'. This Letter was agreed upon and signed, during the first semester of 2005, by heads of seven global stakeholders including the United Nations Educational, Scientific and Cultural Organization (UNESCO), the World Meteorological Organization (WMO), the Food and Agriculture Organization of the United Nations (FAO), the United Nations International Strategy for Disaster Risk Reduction (UNISDR-currently UNDRR), the United Nations University (UNU), the International Council for Science (ICSU-Currently ISC), and the World Federation of Engineering Organizations (WFEO).

The first General Assembly of ICL was held at the Keck Center of the National Academy of Sciences in Washington D.C., USA, on 12–14 October 2005. It was organized after the aforementioned 2005 World Conference on Disaster Reduction (WCDR). ICL published the first full color book reporting on Consortium activities for the initial 3 years, 2002–2005 titled "Landslides-Risk analysis and sustainable disaster management". In the preface of this book, the Letter of Intent for Integrated Earth System Risk Analysis and Sustainable Disaster Management was introduced. Results of the initial projects of the International Programme on Landslides (IPL) including IPL C101-1 Landslide investigation in Machu Picchu World Heritage, Cusco, Peru and previous agreements and MoU between UNESCO, ICL and the Disaster Prevention Research Institute of Kyoto University including UNESCO/KU/ICL UNITWIN Cooperation programme were published as well in this book.

The 2006 Tokyo Action Plan and the First World Landslide Forum 2008

Based on the Letter of Intent, the 2006 Tokyo Round-Table Discussion—"Strengthening Research and Learning on Earth System Risk Analysis and Sustainable Disaster Management within UN-ISDR as Regards Landslides"—towards a dynamic global network of the International Programme on Landslides (IPL) was held at the United Nations University, Tokyo, on 18–20 January 2006. The 2006 Tokyo Action Plan—Strengthening research and learning on landslides and related earth system disasters for global risk preparedness—was adopted. The ICL exchanged Memoranda of Understanding (MoUs) concerning strengthening cooperation in research and learning on earth system risk analysis and sustainable disaster management within the framework of the United Nations International Strategy for Disaster Reduction regarding the implementation of the 2006 Tokyo action plan on landslides with UNESCO, WMO, FAO, UNISDR (UNDRR), UNU, ICSU (ISC) and WFEO, respectively in 2006. A set of these MoUs established the International Programme on Landslides (IPL) as a programme of the ICL, the Global Promotion Committee of IPL to manage the IPL, and the triennial World Landslide Forum (WLF), as well as the concept of the World Centres of Excellence on Landslide Risk Reduction (WCoE).

The First World Landslide Forum (WLF1) was held at the Headquarters of the United Nations University, Tokyo, Japan, on 18–21 November 2008. 430 persons from 49 countries/regions/UN entities were in attendance. Both Hans van Ginkel, Under Secretary-General of the United Nations/Rector of UNU who served as chairperson of the Independent Panel of Experts to endorse WCoEs, and Salvano Briceno, Director of UNISDR who served as chairperson of the Global Promotion Committee of IPL, participated in this Forum. The success of WLF1 paved the way to the successful second and third World Landslide Forum held in Italy and China respectively.

The Second World Landslide Forum 2011 and the Third World Landslide Forum 2014

The Second World Landslide Forum (WLF2)—Putting Science into Practice—was held at the Headquarters of the Food and Agriculture Organization of the United Nations (FAO) on 3–9 October 2011. It was jointly organized by the IPL Global Promotion Committee (ICL, UNESCO, WMO, FAO, UNDRR, UNU, ISC, WFEO) and two ICL members from Italy: the Italian Institute for Environmental Protection and Research (ISPRA) and the Earth Science Department of the University of Florence with support from the Government of Italy and many Italian landslide-related organizations. It attracted 864 participants from 63 countries.

The Third World Landslide Forum (WLF3) was held at the China National Convention Center, Beijing, China, on 2–6 June 2014. A high-level panel discussion on an initiative to create a safer geoenvironment towards the UN Third World Conference on Disaster Risk Reduction (WCDRR) in 2015 and forward was moderated by Hans van Ginkel, Chair of Independent Panel of Experts for World Centers of Excellence (WCoE). In a special address to this high-level panel discussion, Irina Bokova, Director-General of UNESCO, underlined that countries should be united to work against natural disasters and expressed commitment that UNESCO would like to further deepen cooperation with ICL. Ms. Bokova awarded certificates to 15 World Centres of Excellence.

The Sendai Landslide Partnerships 2015 and the Fourth World Landslide Forum 2017

The UN Third World Conference on Disaster Risk Reduction (WCDRR) was held in Sendai, Japan, on 14–18 March 2015. ICL organized the Working Session "Underlying Risk Factors" together with UNESCO, the Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and other competent organizations. The session adopted ISDR-ICL Sendai Partnerships 2015–2025 (later changed to Sendai Landslide Partnerships) for global promotion of understanding and reducing landslide disaster risk as a Voluntary Commitment to the World Conference on Disaster Risk Reduction, Sendai, Japan, 2015 (later changed to Sendai Framework for Disaster Risk Reduction). After the session on 16 March 2015, the Partnerships was signed by Margareta Wahlström, Special Representative of the UN Secretary-General for Disaster Risk Reduction, Chief of UNISDR (UNDDR), and other representatives from 15 intergovernmental, international, and national organizations. Following the Sendai Landslide Partnerships, the Fourth World Landslide Forum was held in Ljubljana, Slovenia from 29 May to 2 June in 2017. On that occasion, five volumes of full color books were published to disseminate the advances of landslide science and technology. The high-level panel discussion on 30 May and the follow-up round table discussion on 31 May adopted the 2017 Ljubljana Declaration on Landslide Risk Reduction. The Declaration approved the outline of the concept of "Kyoto 2020 Commitment for global promotion of understanding and reducing landslide disaster risk" to be adopted at the Fifth World Landslide Forum in Japan, 2020.

The Fifth World Landslide Forum 2020 and the Kyoto Landslide Commitment 2020

The Fifth World Landslide Forum was planned to be organized on 2–6 November 2020 at the National Kyoto International Conference Center (KICC) and the preparations for this event were successfully ongoing until the COVID-19 pandemic occurred over the world in early 2020. The ICL decided to postpone the actual Forum to 2–6 November 2021 at KICC in Kyoto, Japan. Nevertheless, the publication of six volumes of full color books *Understanding and Reducing Landslide Disaster Risk* including reports on the advances in landslide science and technology from 2017 to 2020 is on schedule. We expect that this book will be useful to the global landslide community.

The Kyoto Landslide Commitment 2020 will be established during the 2020 ICL-IPL Online Conference on 2–6 November 2020 on schedule. Joint signatories of Kyoto Landslide Commitment 2020 are expected to attend a dedicated session of the aforementioned Online Conference, scheduled on 5 November 2020 which will also include and feature the Declaration of the launching of KLC2020. Landslides: Journal of the International Consortium on Landslides is the common platform for KLC2020. All partners may contribute and publish news and reports of their activities such as research, investigation, disaster reduction administration in the category of News/Kyoto Commitment. Online access or/and hard copy of the Journal will be sent to KLC2020 partners to apprise them of the updated information from other partners. As of 21 May 2020, 63 United Nations, International and national organizations have already signed the KLC2020.

Call for Partners of KLC2020

Those who are willing to join KLC2020 and share their achievements related to understanding and reducing landslide disaster risk in their intrinsic missions with other partners are invited to inform the ICL Secretariat, the host of KLC2020 secretariat (secretariat@iclhq.org). The ICL secretariat will send the invitation to the aforementioned meeting of the joint signatories and the declaration of the launching of the KLC2020 on 5 November 2020.

Eligible Organizations to be Partners of the KLC2020

1. ICL member organizations (full members, associate members and supporters)
2. ICL supporting organization from UN, international or national organizations and programmes
3. Government ministries and offices in countries having more than 2 ICL on-going members
4. International associations /societies that contribute to the organization of WLF5 in 2021 and WLF6 in 2023
5. Other organizations having some aspects of activities related to understanding and reducing landslide disaster risk as their intrinsic missions.

Kyoji Sassa
Chair of WLF5/
Secretary-General of ICL
Kyoto, Japan

Peter T. Bobrowsky
President of ICL
Sidney, Canada

Kaoru Takara
Executive Director of ICL
Kyoto, Japan

Appendix: World Landslide Forum Books

WLF	Place/participants	Title	Editors	Publisher/pages
WLF0 (1st General Assembly) 2005	Washington D.C., USA 59 from 17 countries/UNs	Landslides-Risk Analysis and Sustainable Disaster Management	Kyoji Sassa, Hiroshi Fukuoka, Fawu Wang, Goghui Wang	Springer/377 pages ISBN: 978-3-540-2864-6
WLF1 2008	Tokyo, Japan 430 from 49 countries/regions/UNs	Landslides-Disaster Risk Reduction	Kyoji Sassa, Paolo Canuti	Springer/649 pages ISBN: 978-3-540-69966-8
WLF2 2011	Rome, Italy 864 from 63 countries	Landslide Science and Practice Vol. 1 Landslide inventory and Sustainability and Hazard Zoning	Claudia Margottini, Paolo Canuti, Kyoji Sassa	Springer/607 pages ISBN: 978-3-642-31324-0
		Vol. 2 Early Warning, Instrumentation and Monitoring		Springer/685 pages ISBN: 978-3-642-31444-5
		Vol. 3 Spatial Analysis and Modelling		Springer/440 pages ISBN: 978-3-642-31309-7
		Vol. 4 Global Environmental Change		Springer/431 pages ISBN: 978-3-642-31336-3
		Vol. 5 Complex Environment		Springer/354 pages ISBN: 978-3-642-31426-1
		Vol. 6 Risk Assessment, Management and Mitigation		Springer/789 pages ISBN: 978-3-642-31318-9
		Vol. 7 Social and Economic Impact and Policies		Springer/333 pages ISBN: 978-3-642-31312-7
WLF3 2014	Beijing, China 531 from 45 countries/regions/UNs	Landslide Science for a Safer Geoenvironment Vol. 1 The International Programme on Landslides (IPL)	Kyoji Sassa, Paolo Canuti, Yueping Yin	Springer/493 pages ISBN: 978-3-319-04998-4
		Vol. 2 Methods of Landslide Studies		Springer/851 pages ISBN: 978-3-319-05049-2
		Vol. 3 Targeted Landslides		Springer/717 pages ISBN: 978-3-319-04995-3
WLF4 2017	Ljubljana, Slovenia 588 from 59 countries/regions/UNs	Advancing Culture of Living with Landslides Vol. 1 ISDR-ICL Sendai Partnerships 2015-2025	Kyoji Sassa, Matjaž Mikoš, Yueping Yin	Springer/585 pages ISBN: 978-319-53500-5

(continued)

WLF	Place/participants	Title	Editors	Publisher/pages
		Vol. 2 Advances in Landslide Science	Matjaž Mikoš, Binod Tiwari, Yueping Yin, Kyoji Sassa	Springer/1197 pages ISBN: 978-319-53497-8
		Vol. 3 Advances in Landslide Technology	Matjaž Mikoš, Željko Arbanas, Yueping Yin, Kyoji Sassa	Springer/621 pages ISBN: 978-3-319-53486-2
		Vol. 4 Diversity of Landslide Forms	Matjaž Mikoš, Nicola Casagli, Yueping Yin, Kyoji Sassa	Springer/707 pages ISBN: 978-3-319-53484-8
		Vol. 5 Landslides in Different Environments	Matjaž Mikoš,Vít Vilímek,Yueping Yin, Kyoji Sassa	Springer/557 pages ISBN: 978-3-319-53482-4
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Preface II

Landslides represent a major cause of loss of life, injuries, property damage, socio-economic disruption and environmental degradation. Froude and Petley (2018) determined that, in the period from January 2004 to December 2016, 55.997 people were killed in 4.862 landslide events, with Asia representing the dominant geographical area in terms of distribution.

A contribution to the implementation of effective disaster risk reduction strategies is provided by landslide monitoring and early warning, which are tools to forecast the potential occurrence of disasters.

Landslide monitoring means comparing landslide conditions (e.g. areal extent, rate of movement, surface topography or soil moisture) over time, in order to assess a landslide's activity. The measurement of the superficial displacement of a slope often represents the most effective method for defining its behaviour, allowing for the observation of the response to triggering factors and for the assessment of the effectiveness of the mitigation measures (Tofani et al., 2013).

The retrieval over time of superficial ground displacements can be based on conventional geotechnical techniques, topographical techniques and remote sensing. In particular, remote sensing images represent a powerful tool to measure landslide displacement, as they offer a synoptic view that can be repeated at different time intervals and can be available at various scales.

Earth Observation (EO) techniques are very effective for landslide detection, mapping, monitoring and hazard assessment. Applications are originating from nearly all types of sensors available today (Tofani et al., 2013). Rapid developments in this field are fostered by the very high spatial resolution obtained by optical systems (currently in the order of tens of centimetres) and by the launching of SAR sensors, purposely built for interferometric applications with revisiting times of few days, such as TerraSAR-X, COSMO-SkyMed and Sentinel-1.

Synthetic Aperture Radar (SAR) techniques have been demonstrated to be highly valuable in measuring land motion. Unlike conventional geodetic monitoring systems, SAR-based applications permit the measurement of surface deformation over vast areas with millimetre to centimetre accuracy and at a frequency varying between 1 month to several days with the earliest satellites. In 2014, the launch of the Sentinel-1 mission provided a new opportunity for InSAR (Interferometric SAR) monitoring applications due to increased acquisition frequency and the regularity of acquisitions (Raspini et al., 2019).

Advanced terrestrial remote sensing technologies, such as Ground-Based SAR (GB-InSAR), Terrestrial Laser Scanner (TLS), Infrared Thermography (IRT) and Digital Photogrammetry (DP) are nowadays applied in the field of slope instability detection, mapping and monitoring, for short-/long-term landslide management (real-time, near real-time and deferred time) (Casagli et al., 2017). They are characterized by operational efficiency and accuracy of data not reached by traditional methods: high-resolution acquisition, multifunction versatility, device portability, low-cost sensors, easy and fast data processing. Such equipment allows for systematic and easily updatable acquisitions of data that may also enhance the implementation of effective early warning systems (EWSs)at slope scale (Casagli et al. 2017).

According to United Nations International Strategy for Disaster Reduction (UNISDR, 2009), an EWS is defined as "the set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss". This definition encompasses both technical-scientific and social-economic elements, that altogether mark the important, and often neglected, difference between a mere monitoring system and an EWS.

The definition above also includes the concept that EWSs must be people-centred, that is the objective must be to empower individuals and communities threatened by hazards to act and reduce the possibility of loss (UNISDR, 2006), meaning that the population is not a passive recipient of authorities' instructions but is an active participant of the civil protection system.

Two categories of EWSs can be defined on the basis of their scale of analysis: local systems for single slopes and regional systems. Local-scale landslide EWSs are based on reliable continuous monitoring of relevant indicators (e.g. displacements, rainfall, groundwater level) that are assumed to be precursory of landslides triggering or reactivations and that can be different depending on landslide typology. There are two main approaches for forecasting aimed at early warning (Intrieri et al., 2019): one makes use of thresholds, i.e. quantitative signals whose exceeding suggests a probable failure but no time frame for such an occurrence can be provided; the other approach employs empirical or semi-empirical forecasting methods, typically based on creep models, that implement equations and/or graphical solutions to obtain the time of failure.

In a regional-scale EWS two approaches are mainly used: empirical approaches based on rainfall thresholds and physically based deterministic models. While the first is widely used for operational applications at the regional scale, the latter are more commonly applied in smaller areas, since the main constraint to their application at the regional scale is the poor knowledge of the spatial organization of the hydrological and geotechnical parameters due to the extreme heterogeneity and inherent variability of the soil when considered at the large scale (Tofani et al., 2016).

The importance of EWSs for Disaster Risk Reduction (DRR) is highlighted in several risk reduction policies proposed by international organizations such as the Sendai Framework for Disaster Risk Reduction 2015–2030 that was adopted at the Third UN World Conference on Disaster Risk Reduction in Sendai, Japan, on 18 March 2015.

Also the ISDR-ICL Sendai Partnership 2015–2025 (Sassa, 2015), that proposes tools for implementing and monitoring the post-2015 framework for disaster risk reduction and the sustainable development goals, agree on the development of fields of cooperation in research and capacity building focused on the development of people-centred early warning technology for landslides with increased precision and reliable prediction both in time and location, especially in a changing climate context. Furthermore, the 2020 Kyoto Commitment (KC2020) for global promotion of understanding and reducing landslide disaster risk that is duty to the Sendai Landslide Partnerships 2015–2025, the Sendai Framework for Disaster Risk Reduction 2015–2030, the 2030 Agenda Sustainable Development Goals, the New Urban Agenda and the Paris Climate Agreement (Sassa, 2019), clearly highlights the promotion of people-centred early warning technologies for landslides.

This volume compiles the results of the studies on landslide monitoring and early warning conducted all over the world. The volume collects one Theme lecture, one Keynote paper and 37 research papers from 17 countries (Australia, China, Czech republic, France, Germany, Greece, India, Indonesia, Italy, Japan, New Zealand, Norway, Switzerland, Taiwan, United Kingdom, Uzbekistan, Vietnam).

The volume starts with the Theme lecture entitled "Monitoring and Early Warning Systems: Applications and Perspectives" which illustrates and discusses several case studies in which different risk mitigation strategies based on EWSs are adopted. Each of the cases presented shows a peculiarity that can help in the definition of a modern and reliable landslide EWS, while the recent and upcoming technological and scientific advancements are the premise of even more accurate and meaningful landslide EWSs.

The volume is then divided into two parts: Part I: Monitoring and Remote Sensing for Landslide Risk Mitigation which collects 18 papers and Part II: Landslide Early Warning Systems, Forecasting Models and Time Prediction of Landslides which includes 20 papers.

Part I includes the Keynote lecture entitled "Defining Kinematic and Evolutive Features of Earth Flows Using Integrated Monitoring and Low-Cost Sensors" in which an integrated monitoring system based on traditional monitoring techniques and specifically developed low-cost sensors has allowed for the reconstruction of the relationship among basal-slip surface geometry, deformation styles and pattern, geomorphic structures, movement velocity and sediment discharge during ordinary and extraordinary movements for three earthflows in southern Italy. Part I includes also manuscripts on the application of different monitoring techniques for landslide investigation and risk management, comprising conventional geotechnical techniques, remote sensing images with special reference to PSI techniques and geophysical techniques.

Part II contains papers concerning the development and application of EWSs, the forecasting of landslides at the regional scale and papers on the time prediction of the landslide occurrence. The majority of the papers of this part focuses on the development and application of regional-scale EWSs based on the use of rainfall thresholds, some papers focus on the application of innovative monitoring techniques for the set-up of local EWSs while few others propose innovative methods for time prediction of landslides at the regional and local scale.

Florence, Italy

Nicola Casagli
Veronica Tofani

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Contents

Monitoring and Early Warning Systems: Applications and Perspectives

Nicola Casagli, Emanuele Intrieri, Tommaso Carlà, Federico Di Traglia, William Frodella, Giovanni Gigli, Luca Lombardi, Massimiliano Nocentini, Federico Raspini, and Veronica Tofani

Abstract

One of the most efficient and cost-effective tools for landslide risk mitigation is often the setup of an early warning system (EWS). Even if the latter encompass both technical-scientific and social-economic topics, the focus of this note is on the monitoring and forecasting components of a slope-scale landslide EWS. In this framework, a landslide monitoring system is required to provide reliable and continuously updated data for quantitatively catching the scenario evolution, thus allowing for correct forecasting analyses and prompt actions for risk mitigation. Landslide monitoring systems based on remote sensing techniques represent efficient and robust tools for risk mitigation, allowing for a low environmental and economic impact and high operator safety in difficult environments. Among these techniques, radar interferometry is one of the most widely adopted and reliable methods, whose advantages include very high accuracy, operation during all weather conditions, and high spatial and temporal coverage. Radar interferometry output data, due to their high accuracy and acquisition frequency (which is getting higher and higher for satellite applications too), perfectly fit in the prediction activity, enabling very often to make accurate and prompt time of failure or scenario evolution forecasts. In this note, a number of case studies are presented, describing the employed monitoring systems and the associated techniques adopted for risk mitigation. In particular, an integrated EWS for rockslide risk mitigation, a landslide EWS in a volcanic environment, a landslide failure prediction using satellite InSAR and a rockfall monitoring and associated time of failure prediction are presented. Each of the cases presented shows a peculiarity that can help in the definition of the characteristics and potential of a modern and reliable landslide EWS, while the recent and upcoming technological and scientific advancements are the premise of even more accurate and meaningful landslide EWSs.

Keywords

Risk management • Disaster risk reduction • Remote sensing • Forecasting • Landslides • Interferometry

Introduction

Among natural hazards, landslides play a relevant role in terms of life loss. Varnes and IAEG Commission on Landslides (1984) found out that ca. 14% of total casualties from 1971 to 1975 were due to slope failure, although accurate estimations are difficult since landslides are frequently considered secondary effects and deaths are often attributed to the primary trigger (storms, earthquakes) (Petley 2012). Focusing on more recent years, Froude and Petley (2018) determined that, in the period from January 2004 to December 2016, 55.997 people were killed in 4.862 landslide events, with Asia representing the dominant geographical area in terms of distribution. On the other hand, the global annual cost related to landslides is about $19.8 billion, which is about 17% of the average annual global natural disaster losses (Haque et al. 2016).

These numbers highlight the importance of continuous work from both researchers and practitioners in the field of landslide risk mitigation. Among the many possible approaches, one that is generally considered cost-effective and complementary is the setup of early warning systems (EWS) (Intrieri et al. 2013).

According to United Nations International Strategy for Disaster Reduction (UNISDR 2009), an EWS is defined as “the set of capacities needed to generate and disseminate

N. Casagli · E. Intrieri (✉) · T. Carlà · F. Di Traglia · W. Frodella · G. Gigli · L. Lombardi · M. Nocentini · F. Raspini · V. Tofani
Department of Earth Science, Università Degli Studi Di Firenze, Via G. La Pira 4, 50121 Florence, Italy
e-mail: emanuele.intrieri@unifi.it

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timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss".

This definition encompasses both technical-scientific and social-economic elements, that altogether mark the important, and often neglected, difference between a mere monitoring system and an EWS. These elements can be resumed as:

- knowledge of the risks;
- monitoring and analysis of the hazards;
- forecasting;
- communication or dissemination of alerts and warnings;
- local capabilities to respond to the warnings received (which includes the education of the population in "normal times").

These and other components of an EWS have been further detailed by Intrieri et al. (2012) and Fathani et al. (2016).

The expression "end-to-end warning system" is also used to emphasize that warning systems need to span all steps from hazard detection through to community response (UNISDR 2009).

The definition above also includes the concept that EWSs must be people-centred, that is the objective must be to empower individuals and communities threatened by hazards to act and reduce the possibility of loss (UNISDR 2006), meaning that the population is not a passive recipient of authorities' instructions but is an active participant of the civil protection system.

The importance of EWSs for Disaster Risk Reduction (DRR) is highlighted in several Risk reduction policies proposed by international organizations such as the Sendai Framework for Disaster Risk Reduction 2015–2030 that was adopted at the Third UN World Conference on Disaster Risk Reduction in Sendai, Japan, on March 18, 2015.

The Sendai Framework for Disaster Risk Reduction 2015–2030 outlines seven clear targets and four priorities for action to prevent new and reduce existing disaster risks: (i) Understanding disaster risk; (ii) Strengthening disaster risk governance to manage disaster risk; (iii) Investing in disaster reduction for resilience and; (iv) Enhancing disaster preparedness for effective response, and to "Build Back Better" in recovery, rehabilitation and reconstruction.

It aims to achieve the substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries over the next 15 years.

Also the ISDR-ICL Sendai Partnership 2015–2025 (Sassa, 2015) that proposes Tools for implementing and Monitoring the Post-2015 Framework for Disaster risk Reduction and the Sustainable Development Goals agree on the development of fields of cooperation in research and capacity building focused on the development of people-centered early warning technology for landslides with increased precision and reliable prediction both in time and location, especially in a changing climate context.

The 2020 Kyoto Commitment (KC2020) for global promotion of understanding and reducing landslide disaster risk is a duty to the Sendai Landslide Partnerships 2015–2025, the Sendai Framework for Disaster Risk Reduction 2015–2030, the 2030 Agenda Sustainable Development Goals, the New Urban Agenda and the Paris Climate Agreement (Sassa 2019). The KC2020 clearly highlights as Action 1 among all the priority actions the promotion of people-centered early warning technologies for landslides.

The focus of this paper is on the monitoring and forecasting components of a slope-scale landslide EWS, which will be discussed through the description of some real cases of early warning experiences, each one peculiar in its own right. However, by no means it is intended that the social and cultural side of EWSs are secondary. On the contrary, activities such as communication campaigns, information about the risk and the EWS, education about the safe behaviours, drills, questionnaires to verify the knowledge, the risk perception and gather feedback are often underrated but necessary and relatively not expensive activities, as the Hong Kong experience clearly shows (Mak et al. 2007; Kong et al. 2020); otherwise, if the operational systems do not meet the expectations of the end-users, they might not trust the system (Thiebes and Glade 2016). In fact, monitoring and forecasting are but two steps in a longer process that starts from engaging the community in "normal times" and finishes with communicating an easily understandable warning using the proper media (Intrieri et al. 2020).

As far as the technical aspect are concerned, the first stage is probably defining the most representative parameters for assessing the stability of the slope (e.g. rainfall, water level, pore pressures, vibrations, surficial movements, displacements at some depth and so on). Generally, regional-scale EWSs rely on rainfall (Guzzetti et al. 2020). At slope-scale, which is the focus of this paper, the choice of the indicators depends on the type of landslide. For debris flows, pendulums or trip-wires detecting the passage of the material can be used (Bossi et al. 2015), while for creep landslides the monitoring of displacement and its derivatives is usually preferred because they are direct indicators of the stability of a slope (Intrieri and Gigli 2016; Pecoraro et al. 2019).

What is invariable is that the monitoring frequency must keep up with the presumed activation of the landslide (which means that near real-time monitoring is not always necessary, in some cases daily measurements or less can be enough, as shown in Gigli et al. 2011). Furthermore, robustness should be preferred over accuracy. In fact, pre-failure accelerations follow power-law trends (usually with a high exponent, which makes them very similar to an exponential law; Intrieri et al. 2019) which typically cause very high signal-to-noise ratios. On the other hand, communication failures or damages to the instrumentation (maybe caused by the landslide's movements) can compromise the whole system.

Once the key indicators are identified, the appropriate technology for monitoring must be selected.

Then monitoring data must then be elaborated so that they can provide input for the prediction activity. There are two main approaches for forecasting aimed at early warning (Intrieri et al. 2019): one makes use of thresholds, i.e. quantitative signals whose exceeding suggests a probable failure but no time frame for such an occurrence can be provided; the other approach employs empirical or semi-empirical forecasting methods, typically based on creep models, that implement equations and/or graphical solutions to obtain the time of failure.

Concerning the first approach, the major problem is the specifying thresholds that are both reliable and effective. Usually this is done based on past (personal) experience (the so called "expert judgment"), past trends in the measurements and the knowledge of the rupture mechanism(s), rather than in objective data (Nadim and Intrieri 2011). The scientific literature has many cases where expert judgement is implemented for thresholds definition (Blikra 2012; Iovine et al. 2006; Lombardi et al. 2017; Zavodni and Broadbent 1978). This is because, in most cases, even for reactivated landslides, there is no measured record of the indicators preceding failure.

Thresholds can also be defined using more general, not site-specific methods, with a certain degree of exportability, such as those proposed by Brox and Newcomen (2003), Carlà et al. (2017c), Crosta and Agliardi (2003), Xu et al. (2011). A more detailed dissertation on this topic can be found on Intrieri et al. (2019).

Whether the case, warning thresholds should be used carefully, and there is no justification to define too many warning levels or too precise limits. For a slope scale EWS, thresholds derived from kinematic indicators (displacement, velocity, acceleration) and pore pressure/water table measurements are preferable to rainfall intensity since they are more directly correlated with the stability conditions of the slope. Rainfall thresholds could be implemented as well, but mainly as a support to decision makers or as simple pre-warnings. In any case, the design of the early warning system must be flexible such that the threshold parameters can be changed as more information is gathered on the performance of the monitoring system and on the behaviour of the slope or the region being monitored (Nadim and Intrieri 2011).

The second approach is based on forecasting methods such as those invented by Azimi et al. (1989), Fukuzono (1985), Hao et al. (2016), Mufundirwa et al. (2010), Saito (1969), Voight (1989). Among these, the most used is by far Fukuzono's (1985) method, mostly because of its intuitive graphical solution (Atzeni et al. 2015; Carlà et al. 2017a, b; Dick et al. 2015; Intrieri et al. 2019; Kothari and Momayez 2018; Rose and Hungr 2007); its rationale is that, if the displacement velocity of a landslide during the tertiary creep stage increases (theoretically toward infinite), its inverse number will tend to decrease to zero. Therefore, extrapolating the inverse velocity until when it intercepts the time axis will give the time of failure. A common simplification when applying this method and that can lead to mistakes is that the interpolation is generally assumed to be linear.

More details on the forecasting methods and their applications have been discussed by Intrieri et al. (2019).

Of the four case histories presented in this paper, the first two (Quincinetto landslide and Stromboli volcano) use the first approach and thresholds defined through expert judgement. The last two (Xinmo and Gallivaggio landslides) employed the second approach; in particular, Fukuzono's method (1985) has been used with hindsight for Xinmo landslide while for Gallivaggio landslide it ensured the clearance of the area and the lack of injuries or victims.

Landslide Monitoring

The aim of this section is to describe the landslide monitoring systems and the adopted techniques of the following presented case studies.

The purpose of a landslide monitoring system is to provide reliable data for catching the characteristic information of collapses in time, and make a correct analysis, evaluation, prediction and control of the kinematics and evolutionary process (Pinggen 2004). The current availability of advanced remote sensing technologies in the field of landslide analysis allows for rapid and easily updatable data acquisitions, improving the monitoring traditional capabilities (Guzzetti et al. 2012). Landslide monitoring systems based on remote sensing techniques represent cost-effective means to reduce the risk, allowing for a low environmental and economic impact (Intrieri et al. 2012, 2013). Amongst the remote sensing techniques adopted in an integrated real-time monitoring and warning system, radar interferometry represents one of the most widely adopted and reliable method for the remote monitoring of landslide displacements (Casagli et al.