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The Rio de Janeiro early warning system for rainfall-induced landslides: Analysis of performance for the years 2010–2013

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ABSTRACT

The paper deals with the citywide landslide early warning system "Alerta-Rio" operated by the municipality of Rio de Janeiro (Brasil). The city is divided, for warning purposes, into four alert zones. Two different alert sets co-exist within Alerta-Rio: rainfall warnings and landslide warnings. The landslide warning levels are four and they are related to an expected spatial density of landslides. The presented study focuses on the evaluation of the efficiency of the correlation models and rainfall thresholds employed by Alerta-Rio to issue the landslide warnings. The analyses refer to the four-year time frame 2010–2013; they are conducted considering the spatial and temporal distribution of rainfall, landslides and alert phases. An alert phase is herein defined as the time when the landslide warning level is associated to the possibility of diffuse or widespread landsliding within the alert zone. The performance of the system is evaluated by looking at the errors generated by the landslide alerts, computed as a function of the temporal overlap between alert phases and landslide events. Landslides are grouped in events so as to explicitly consider the extent of the landslide disasters in relation to the alerts issued. The discussion on the results of the performed analyses mainly focuses on the following issues: false and missed alerts; duration of alerts; zoning for early-warning purposes.

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1. Introduction

The United Nations define early warning systems as "the set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organisations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss" [1]. This definition encompasses the range of factors necessary to achieve effective responses to warnings. Complete and effective early warning systems should indeed comprise four inter-related elements: i) knowledge of risks; ii) monitoring, analysis and forecasting of hazards; iii) communication and dissemination of alerts and warnings; iv) local capabilities to respond to warnings [2]. Best practice early warning systems have strong inter-linkages between all the elements.

Fast moving rainfall-induced landslides are dangerous phenomena widespread in many regions of the world. The risk to life associated with these phenomena can be mitigated either acting on the landslide hazard (e.g., reducing the probability of occurrence, the spatial distribution or the intensity of the phenomena) or on the consequences they pose for the elements at risk (e.g., reducing the vulnerability or the time of exposure of people at risk). Among the many mitigation measures available for reducing the risk to life related to these phenomena, early warning systems certainly constitute a significant option available to the authorities in charge of landslide risk management and governance.

This paper deals with the citywide landslide early warning system developed and operated by the municipality of Rio de Janeiro, Brasil. The system, called Alerta-Rio, is a prominent part of the current municipal landslide risk reduction program which also includes, besides the early warning strategy, susceptibility, hazard and risk zoning at different scales and engineering works aimed at reducing the areas subjected to intolerable risk levels. The main objective of the paper is the analysis of the performance of the Alerta-Rio system. In particular, the study focuses on the

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evaluation of the efficiency of the correlation models and rainfall thresholds employed within Alerta-Rio between 2010 and 2013.

2. Landslide early warning systems

2.1. Elements and issues

Landslide early warning systems are risk mitigation measures designed to issue timely alerts to people when the level of risk to which they are exposed is judged to be intolerably high. Intrieri et al. [3] highlights the main elements of the structure of landslide early warning systems using a schematic representation of the following four activities: planning, monitoring, forecasting, education. Effective warning systems should be based on a balanced combination of these activities. An alternative schematic of the structure of landslide warning systems is the one proposed by [4], who use a block diagram to outline the four main steps of a landslide warning system: monitoring; data analysis and forecasting; warning; response. According to them, the key technical issue for the realisation of an effective landslide warning system is the identification, monitoring and measurement of precursors that precede the occurrence of landslides. The choice of precursors to be monitored varies with the type of system that is to be realised and with the objective to be pursued. Typical examples of precursors are heavy rains, ground vibrations from earthquakes, accelerations and velocities of existing phenomena, rapid increase of pore water pressures. Depending on the type of precursor, typical instruments used within the monitoring network of a landslide warning system include: rain gauges, geophones, seismographs, piezometers, inclinometers, extensometers and other devices measuring ground or subsurface movements. More generally, effective design of early warning systems always require proper synergy between technical and social know-hows [5, 6]. Fig. 1 shows an original schematic representative of the process of designing and managing landslide early warning systems. Once the objectives of the system are defined depending on the scale of analysis and the type of landslides, it is necessary to detail, as shown by the 4 concentric rings of the proposed "wheel" scheme: the necessary skills, the activities to be performed, the means to be used and the basic elements of the system. The arrows indicate the direction of the conceptual design and management process, highlighting the temporal continuity of the activities to be undertaken for the continuous updating of the system. As shown in the ring's outer wheel, the design of landslide warning systems require synergy between technical and social skills. The main objective of the designers of the technical subsystem is the definition of "efficient" processes; the procedures defined within the social subsystem are important in making landslide early warning systems an "effective" tool to reduce the risk to life.

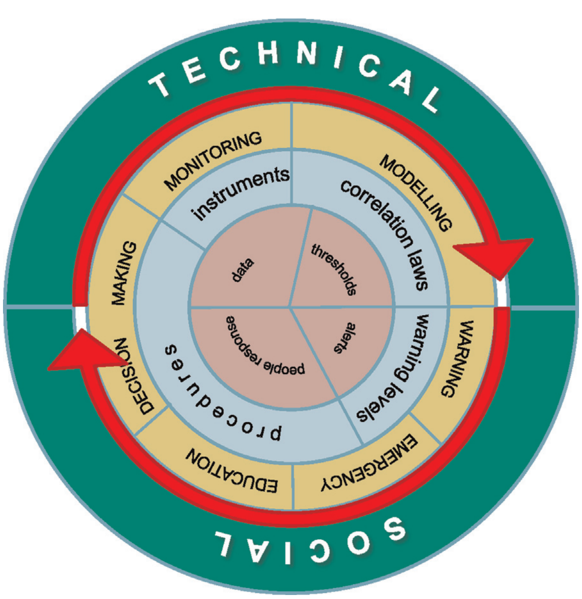

Fig. 1. Designing and managing landslide early warning systems: a schematic.

2.2. Models and thresholds for rainfall-induced landslides

Early warning systems for rainfall-induced landslides are the most diffuse class of landslide warning systems operating around the world. The modelling phase of such systems consists in defining a correlation law between landslide occurrences in the area of interest and rainfall events triggering the phenomena. Within such systems, a good correlation model must be able to issue warnings which maximise correct alerts while minimising false and missed alerts. The rainfall thresholds established by the correlation models can be either based on a conceptual schematisation of the causal relationship between rainfall and landslides or on empirical laws derived from a statistical analysis of historical data. Concerning the latters, a comprehensive investigation on rainfall thresholds for the initiation of landslides is presented by [7]. They identify three main categories of rainfall thresholds: i) thresholds that combine precipitation measurements obtained from specific rainfall events; ii) thresholds that consider the antecedent conditions; iii) other thresholds. For the first category four sub-categories of thresholds are also defined depending on the rainfall measurements used to characterise a rainfall event: intensity-duration (ID); total event rainfall (E); rainfall event-duration (ED); rainfall event-intensity (EI). Regardless of the type of rainfall threshold, the operational efficiency of a correlation model to be adopted within a landslide early warning system is strongly dependent on how rainfall events are recognised, i.e. how rainfall data are collected and analysed. Despite the importance of such issue is acknowledged in the literature [7], standards for measuring landslide-triggering rainfall conditions are lacking and criteria for the definition of the rainfall events responsible for landslides are too often ill-defined, poorly formalised or ambiguous [8]. Probably, the most relevant attempt to change the current state of practise in this matter is the algorithm recently proposed by [9], which is specifically devised to objectively and reproducibly detect rainfall events and sub-events from rainfall measurements.

2.3. Regional rainfall-induced landslide warning systems

Depending on the scale of analysis and operation, it is possible to identify two categories of landslide early warning systems: local systems and regional systems [10, 11]. The main aim of local landslide warning systems is the temporary evacuation of people from areas where, at specific times, the risk level to which they are exposed is considered to be intolerably high. The design and management of such systems is significantly influenced by site-specific factors and constraints. The main aim of regional landslide warning systems is to provide generalised warnings to the population over appropriately-defined homogeneous alert zones. Warning systems for rainfall-induced landslides to be employed at regional scale typically assess the probability of occurrence of landslides in these zones using both atmospheric monitoring data and rainfall predictions. The examples reported in the literature for landslide early warning systems defined at local scale are numerous [12–15]; among others. Much rarer are the scientific references dealing with regional systems. A few examples of regional rainfall-induced landslide warning systems are herein presented

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