Landslides (2010) 7:325–338
DOI 10.1007/s10346-010-0229-5
Received: 30 November 2009
Accepted: 14 June 2010
Published online: 24 July 2010

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Japanese early-warning for debris flows and slope failures using rainfall indices with Radial Basis Function Network

Abstract Early-warning systems for natural disasters are important tools for disaster risk reduction and for achieving sustainable development and livelihoods. In 2005, the Japanese government initiated a new nationwide early-warning system for landslides disasters. The main methodology of the system is to set a criterion for occurrences of debris flows and slope failures based on several rainfall indices (60-min cumulative rainfall and soil–water index) in each 5-km grid mesh covering all of Japan. Because many of the records of mass movements are lacking in scientific precision on timing and location, the system applies Radial Basis Function Network methods to set the criterion based primarily on rainfall data recorded as not triggering disasters. Since the end of March 2007, under torrential rainfall conditions, early-warning information has been disseminated as part of weather news using TV, radio, and the Internet. Because of the increasing worldwide recognition of the importance of early-warning systems for natural disaster reduction, the aim of this article is to introduce the new Japanese early-warning system to the international landslide community. In this article, the method, the system, and the result of its application to landslide disasters in 2009 are presented.

Keywords Landslides · Early-warning system · Debris flows · Slope failures · Radial Basis Function Network

Introduction

Countermeasures against landslides may be classified into structural and nonstructural measures. Structural measures are effective to prevent the occurrence of the hazard and to protect an area of livelihood from the hazard. Nonstructural measures are an important supplement to improve the effectiveness of structural measures against landslide disasters.

In the Hyogo framework for Action, 2005–2015, which was adopted by the World Conference on Disaster Reduction held from 18 to 22 January 2005 at Kobe, Japan (UN ISDR 2005), early-warning systems are recognized as important tools for disaster risk reduction and for achieving sustainable development and livelihoods. According to a United Nations global survey of early-warning systems (UN ISDR 2006), the object of people-centered early-warning systems is to enable individuals and communities threatened by hazards to act in sufficient time and in an appropriate manner so as to reduce the possibility of personal injury, loss of life and livelihood, and damage to property and the environment. Such systems consist of four elements: risk knowledge, monitoring and warning services, dissemination and communication, and response capability.

As part of the Japanese measures against landslide disasters, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has progressively installed structural measures such as catch dams and retaining walls in the valleys where the probability of occurrences of debris flows and slope failures is high and where there are many houses vulnerable to damage. However, it is difficult to install structural measures in all dangerous valleys because there are some 200,000 dangerous valleys and slopes according to MLIT statistics. Researchers and government officials in Japan have come to recognize that it is important to provide people with warning information to evacuate from disasters even where structural measures are installed. MLIT has developed a landslide early-warning system since 1984 to protect people from injury, loss of life, and loss of livelihood. Damage from landslides is less now than in the past. In the rainy season, there are still about 1,000 landslide disasters reported annually. These Japanese statistics indicate that early-warning systems are important not only in developing countries (UN ISDR 2006) but also in developed countries to reduce damage by small-magnitude and high-frequency landslides. In the context of concepts of people-centered early warning used worldwide, the Japanese system couples monitoring and warning services with dissemination and communication.

In establishing an early-warning system with practical application, it is important to: (1) establish the method for estimating the locations and timing of landslides occurrences; (2) determine the roles of the players; and (3) consider what kind of information to disseminate using mass communication.

For establishing the method for estimating the location and timing of landslides occurrences using meteorological factors, many researchers have proposed a variety of methods, because many different factors influence the occurrence of landslides. Intense rainfall is the primary meteorological factor that is recognized as directly associated with triggering landslides. Antecedent precipitation is recognized as a secondary landslide-triggering meteorological factor (for example, Wieczorek and Glade 2005). Wieczorek and Glade (2005) summarized the criteria for debris-flow triggering threshold used in various countries. Their summary shows that various rainfall indices have been used for determining the criteria. For example, Glade et al. (2000) shows that rainfall probability thresholds can be established by applying an Antecedent Daily Rainfall model which uses two variables: antecedent daily rainfall index and daily rainfall. A method similar in concept to that of Glade et al. (2000) has been used in the Japanese early-warning systems that determine the criterion of landslides occurrences using two rainfall indices.

In this article, the authors present an outline of the current landslide early-warning system which has been in operation since 2007, operated by MLIT and the Japan Meteorological Agency (JMA). "Background of the new Japanese method of setting criteria of early-warning information issue using rainfall indices" presents a brief history of Japanese early-warning systems so as to specify problems to be solved by the new method. "The way to setting

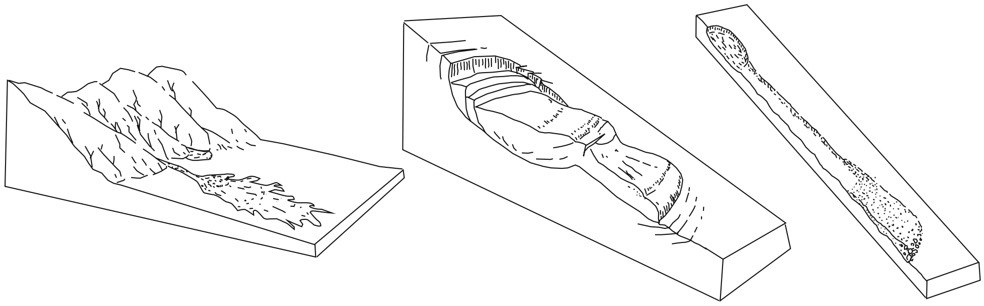

Fig. 1 Sketches of typical debris flow (*left*; after Varnes (1978) revised by the authors), deep-seated landslide (*middle*; after Ohyagi (2007) revised by the authors), slope failure (*right*; after Ohyagi (2007) revised by authors). In Japan, a debris flow is a flow mixed with water, sand, and stones driven by gravity; a deep-seated landslide is a slow soil-block movement on a slip surface deeper than 2 m below the ground surface, and a slope failure is a fast, shallow, soil movement on a slope steeper than 30°

criteria of early-warning information issue" shows the theory and technique of setting the criterion of disaster occurrence. "Japanese early-warning system for debris flows and slope failures" shows an outline of the whole Japanese early-warning systems including how it operates, the flow of transmission of early-warning information, and the format of early-warning dissemination. In "Use of early-warning information," some results of applying the method to actual disasters in 2009 are presented. Conclusions are presented in "Conclusion and future issues."

Note that in this article, the meaning of the term *landslide* differs from its usual international meaning. The term *landslide* is widely used internationally to represent the whole phenomena of mass movement; for example, the classification system as defined by Varnes (1978). However, from the viewpoint of the Japanese administration, these international classification systems cannot be used, because the Japanese law, dealing with prevention works that include structural and nonstructural measures against disasters related to mass movement, defines the types of landslides as (1) debris flows, (2) slope failures, and (3) landslides in a limited sense (deep-seated landslide). Also in the law, the types of material of these three phenomena are defined as soil excluding rock (corresponding to the international definition of engineering soil). Figure 1 shows the typical diagrams of debris flows, slope failures, and landslides. Thus, in this article, *landslides* means deep-seated landslide only, and *mass movement* is used as the term representative of the broader phenomenon.

Background of the new Japanese method of setting criteria of early-warning information issue using rainfall indices

Basic concept

Since 1984, the basic concept for issuing early-warning information in Japan has been based on two hypotheses which have not changed. The first hypothesis is that mass-movement occurrence can be predicted using both a short-term rainfall index and a long-term rainfall index, because mass movements are driven by both surface water and ground water. The second hypothesis is that, on the plane with short- and long-term rainfall index axes respectively, the area of mass-movement occurrence and non-occurrence can be identified by the plot of rainfall with disasters (occurrence rainfall) and without disasters (non-occurrence rainfall).

Based on these hypotheses, the underpinning issues are: (1) to select appropriate rainfall indices; (2) to improve on the method of discriminating the boundary between occurrence and non-occurrence rainfall; and (3) to collect locations and timing of many rainfall-related mass-movement occurrences.

Figure 2 presents a sketch of the basic concept, showing that it is possible to draw various lines as the criterion of disaster occurrence line (*Critical Line*, *CL*) depending on the method. A linear CL is the easiest to set, but an arbitrary shaped CL seems to be the most precise discrimination line based on the data of occurrence and non-occurrence rainfall.

Table 1 shows the history of various rainfall indices used by MLIT (Terada and Nakaya 2001). These indices were revised according to analysis of records of mass-movement disasters and their associated rainfall. The methods before 2005 used a researcher or senior engineer to draw the Critical Line as a straight line fitted by eye, because adequate records of disasters for statistical analysis do not exist in many regions.

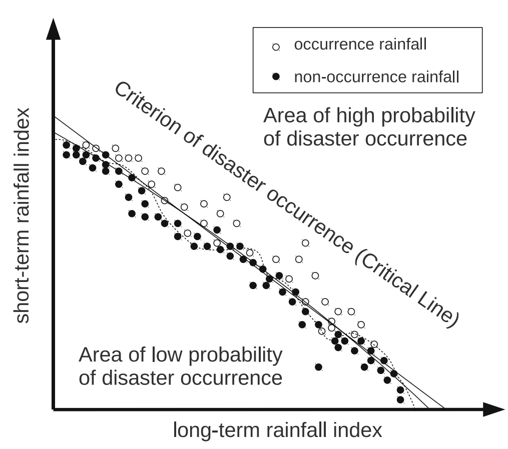

Fig. 2 The basic concept used for setting the criterion for issuing early-warning information in Japan. The criterion of disaster occurrence is defined as the line discriminating between the area of high and low probability of disaster occurrence. This line has been termed the CL, which may be linear, curved, or arbitrary shaped depending on the choice of the fitting method and is based on the distribution of "occurrence" rainfall (rainfall with disasters) and "non-occurrence" rainfall (rainfall without disasters). This illustration omits many of the non-occurrence rainfalls from the low-probability area