Original Paper

Landslides
DOI 10.1007/s10346-017-0892-x
Received: 9 March 2017
Accepted: 1 September 2017

Moonhyun Hong · Junghwan Kim · Sangseom Jeong

Rainfall intensity-duration thresholds for landslide prediction in South Korea by considering the effects of antecedent rainfall

Abstract This study was conducted to determine the rainfall intensity-duration thresholds (ID curves) for landslide prediction by considering the effects of antecedent rainfall. Data for the time and location of landslides that occurred in South Korea from 1999 to 2016 were collected. Overall, 231 landslide histories from 1999 to 2013 were used to determine the rainfall thresholds, and 12 landslide histories from 2014 to 2016 were used to verify the proposed rainfall thresholds. Probabilistic ID curves were proposed to reflect the influence of other factors except rainfall, and ID curves for various inter-event time definitions (IETDs) were suggested to analyze the variation in the ID curves with the effects of antecedent rainfall. The results suggest that the IETD indicates the duration for which the antecedent rainfall affects the ground condition. It was also found that the ID curve for 12 h of the IETD was the most reliable of the verification procedures using the receiver operating characteristic (ROC) plot and threat score (TS).

Keywords Rainfall threshold · Antecedent rainfall · Inter event time definition (IETD) · ID curve · Probability

Introduction

A landslide is one of the most pervasive disasters in the world; however, because there is still no clear solution, landslides continue to cause damage to lives and property. Over the past decade, landslides were responsible for over 10,000 deaths and left 2.5 billon people homeless from 2001 to 2010 (DAT 2011).

Landslides are primarily caused by a reduction in shear strength due to an increase of pore pressure originating from rainfall infiltration, and they are closely related to antecedent rainfall, cumulative rainfall, and rainfall duration (Campbell 1975; Guzzetti et al. 2007; Jeong et al. 2014). When rainfall occurs, the slope instability increases because the water infiltrates into the soil to form a wetting front. When the wetting front advances the soil water, the soil water content and unsaturated permeability decrease the matric suction, which then increases the soil strength (Ng and Shi 1998; Fourie et al. 1999; Cho and Lee 2000; Jeong et al. 2009).

To analyze rainfall-induced landslides, the rainfall during the occurrence of landslide is not the only cause of the landslide, but antecedent rainfalls also have significant effects on the landslide (Tan et al. 1987; Wei et al. 1991; Rahardjo et al. 2001; Yune et al. 2010; Kim et al. 2013). Rahardjo et al. (2001) confirmed that antecedent rainfall plays an important role in slope stability based on a numerical analysis. Yune et al. (2010) analyzed rainfall-induced landslides in Korea and confirmed that the occurrence of landslides was not only caused by the short-term rainfall but was also influenced by antecedent rainfalls. Kim et al. (2013) found that antecedent rainfall determines the initial state and matric suction of the soil when a landslide occurs. There have been several studies based on antecedent rainfall. Govi et al. (1985) determined that the 60-day antecedent rainfall required to trigger landslides in the Piedmont region varied seasonally, with a minimum value of 140 mm of precipitation, and the total precipitation needed to initiate slope failures was at least 300 mm. Kim et al. (1991) correlated the cumulative rainfall for a 3-day period before a landslide triggering event with the total daily rainfall for the day of the slope failure. They determined that the landslides in central South Korea were influenced by the antecedent precipitation, whereas those in southern South Korea were controlled by the amount and intensity of the daily rainfall. Chleborad (2003), working in the Seattle area, established a rainfall threshold to predict the number of days with three or more landslides based on two precipitation measurements: the 3-day antecedent rainfall (i.e., the event rainfall) and the total accumulation of rainfall for the 15-day period before the 3-day rainfall event (i.e., the antecedent rainfall). Recently, De Luca and Versace (2017) provided a general framework to reproduce all ID schemes and those based on antecedent rainfall as particular cases. The proposed generalized FLaIR Model (GFM) is an empirical model that allows the use of nonstationary thresholds, depending on the antecedent rainfall amounts and, thus, on initial soil moisture conditions (De Luca and Versace 2017).

There have been various studies on using the rainfall threshold to predict landslides. The rainfall threshold can be generally classified into two categories: rainfall thresholds based on physical methods and rainfall thresholds based on empirical methods (Corominas 2000; Crosta and Frattini 2001; Aleotti 2004; Wieczorek and glade 2005). Rainfall thresholds based on physical methods can predict landslides by considering the topography, geological information, and vegetation of the study area. However, since it is difficult to obtain detailed data of the study area, there is a limitation in usage of these methods, regardless there is an excellent model. Empirical rainfall thresholds are based on the assumption that rainfall is the most important factor for determining the occurrence of landslides, as proposed by researchers who used rainfall data for landslide inventories (Kim and Jung 2000; Korea forest service 1993; Caine 1980; Dahal and Hasegawa 2008; Guzzetti et al. 2007; Ikeya 1989; Saito et al. 2010; Hong et al. 2016).

As stated above, rainfall is a major cause of rainfall-induced landslides, and antecedent rainfall influences the occurrence of landslides. When using antecedent rainfall measurements to predict a landslide occurrence, a key difficulty is defining the period over which the precipitation should be accumulated. In this study, some of the rainfall intensity-duration thresholds (ID curves) for predicting a landslide consider the effects of antecedent rainfall based on the probability of a landslide occurrence. The effects of antecedent rainfall were considered by analyzing all rainfall events before each landslide occurred. Overall, 231 rainfall data measurements, including domestic landslide and rainfall records, were used to suggest ID curves using the empirical method.

Published online: 12 September 2017