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# Development of an initiation criterion for debris flows based on local topographic properties and applicability assessment at a regional scale

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A B S T R A C T

Damages caused by landslides have been increasing because of the greater frequency of localized heavy rain. To prevent landslide disasters more efficiently, more studies in relation to predicting the initiation areas of debris flows that cause large-scale damage are necessary. The main purpose of this study is to develop a criterion for detecting debris flow initiation areas by using an empirical method that was chosen from several types of approaches to debris flow initiation detection. In this study, ten GIS-based geomorphological datasets were obtained from slide and debris flow initiation areas located in Seoul, Gyeonggi Province and Gangwon Province. The geomorphological characteristics of slide and debris flow occurrence areas were analyzed through a comparative analysis to identify relationships between debris flow initiation and each topographic index. An initiation criterion for debris flows based on the geomorphological characteristics was suggested using an Artificial Neural Network (ANN) model combined with a modified threshold for the relationship between slope and upslope contributing area. To validate the suitability of the initiation criterion for debris flow, sequential applications of slope failure analysis and debris flow initiation analysis were conducted on a case study site to simulate the actual debris flow events. As a result of the debris flow initiation analysis, the prediction capture rate of the debris flow initiation criterion was determined to be 88.9%. Debris flow initiation areas totaling 143,300 $m^2$ were identified among 1,935,400 $m^2$ of slope failure areas predicted in the slope failure analysis. It is efficient to apply the debris flow initiation criterion in the debris flow simulation because slope failure areas are only partly transformed into debris flows.

## 1. Introduction

According to the National Institute of Meteorological Research (2012), the frequency of occurrence and intensity of localized heavy rain has been recently increasing in Korea because of climate change and global temperature rise. Annual rainfall is also gradually increasing. Seventy percent of the total annual rainfall is normally concentrated from June to September, and localized heavy rain occurs during the same period. The Korea Meteorological Administration (2011a) analyzed the frequency of occurrence of localized heavy rain, which is defined as > 50 mm per hour, measured from a network of 60 meteorological observatories in Korea. Localized heavy rain occurred 143 times from 1977 to 1986, 159 times from 1987 to 1996, and 254 times from 1997 to 2006. This result reveals a rapid increase in the frequency of occurrence of localized heavy rainfall. The localized concentration of large amounts of rainfall in a short period can cause natural disasters, such as landslides and floods. Additionally, an increase in the frequency of occurrence of localized heavy rain is one of the immediate causes of increased damage related to landslides.

In Korea, 70% of the territory consists of mountainous areas, and slope failures occur across the country during the summer season, when the rainfall is concentrated. The results of the analysis for the annual rehabilitation expense related to landslide and debris flow disasters in Korea from 1976 to 2012 show that the cost of restoration has been growing consistently and has exceeded 88 million US dollars per year since the 2000s. In the future, the amount of damage related to slope failures is expected to grow based on the increasing amounts of annual rainfall and the increasing frequency of occurrence of localized heavy rain (Lee et al., 2013).

Slides (rotational and translational) and debris flows are the most frequently occurring of the various types of landslides in Korea (Park, 2014). The Korea Forest Research Institute (2014) stated that debris flows caused greater damage than slides in mountainous areas because debris flows, composed of a mixture of water, sediment, rocks and soils, flow down with rapid velocity and enormous force, causing both human losses and the destruction of buildings and infrastructure. In contrast,

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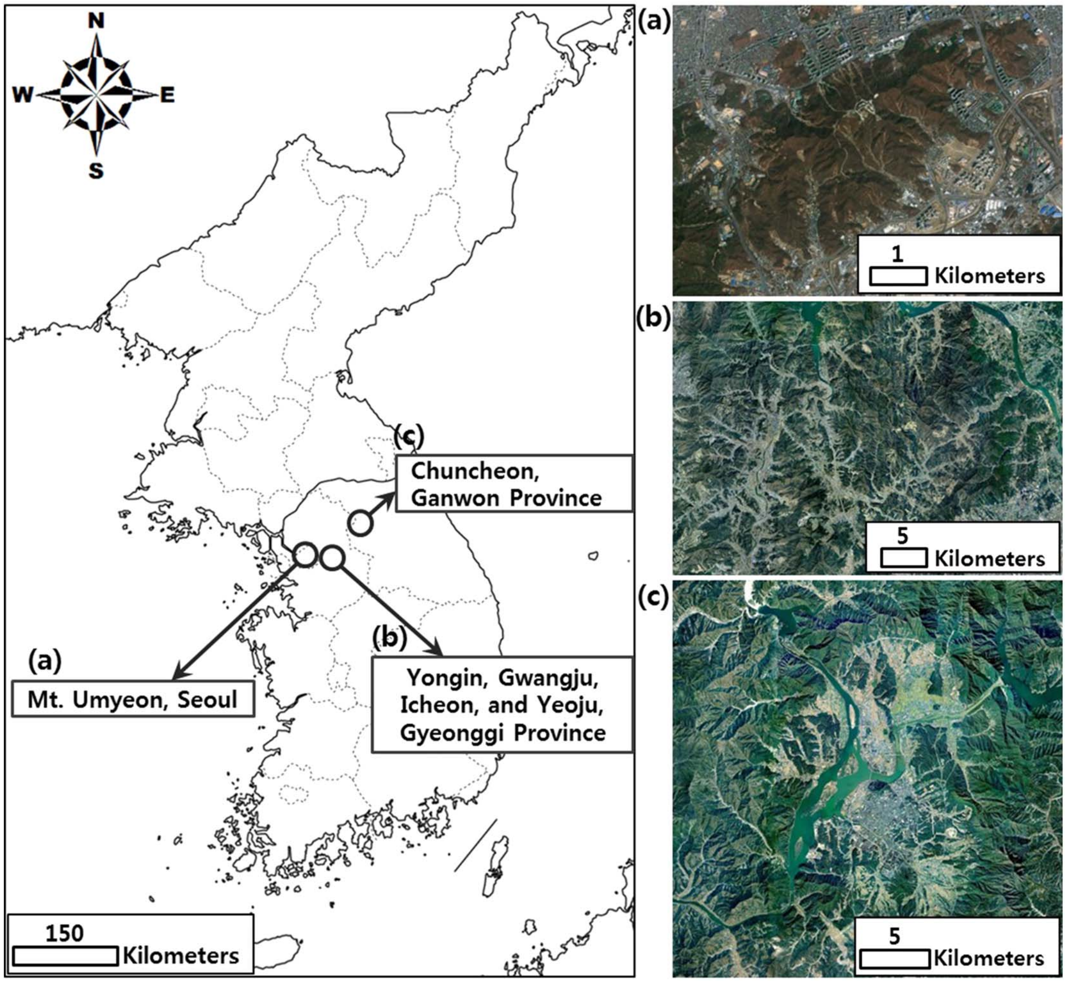


**Fig. 1.** Study areas to acquire topographic data for development of debris flow initiation criterion: (a) Umyeon Mountain, Seoul; (b) Yongin, Gwangju, Icheon and Yeoju, Gyeonggi Province; (c) Chuncheon, Gangwon Province.

slide material moves a short distance and stops around the middle of the mountain after a slope failure occur.

There are four general types of debris flows, as suggested by Brayshaw and Hassan (2009) and based on the causes of the debris flow occurrence: (i) transition from slope failures on planar slopes into debris flows during the downslope movement of failure materials (Iverson et al., 1997); (ii) transition from slope failures in low-order streams into debris flows after failure materials join the stream channel (Campbell, 1975); (iii) initiation of debris flows in low-order streams caused by surface water flow due to high runoff without associated slope failure (Berti et al., 1999); and (iv) initiation of debris flows caused by concentrated erosion of colluvial deposits due to overbank flow, which is caused by high runoff at the lower limit of bedrock channels (Johnson and Rodine, 1984). Transition from slope failures into debris flows, such as in the first and second types, is the most commonly occurring type of debris flow (Iverson et al., 1997; Park, 2014). According to Park (2014), most debris flows in Korea begin with slope failures. In this study, the type of debris flow has been considered to be the transition from slope failure to debris flow.

The initiation conditions of debris flows have been assessed by various methods. Guo et al. (2014) categorized these debris flow initiation models into four types: (1) debris flow mobilization from slope failures (Iverson et al., 1997); (2) coupling models of hydraulics and soil mechanics assessing the stability of the slope (Takahashi, 1978); (3) empirical statistical models using the data obtained from field survey and laboratory tests (Cui, 1992); and (4) surface runoff models using the equilibrium of single particles with hydrodynamic forces (Berti and Simoni, 2005). According to Park et al. (2016), it is necessary to separate debris flow initiation areas from slope failure areas because not every slope failure evolves into a debris flow. Additionally, it is not efficient to apply the debris flow initiation model at a regional scale, based on geotechnical and hydrological triggers, because of the high cost of resources and time-consuming process for simulation. Various local topographic properties, such as elevation, slope angle, slope direction, profile curvature, plan curvature, upslope contributing area, sediment transport capacity index, stream power index, terrain characterization index, and topographic wetness index, have been used at the point where the debris flow occurs to analyze correlations between debris flow initiation and topographic indices (Griswold and Iverson, 2008; Horton et al., 2008; Chen and Yu, 2011; Park, 2014; Kang et al., 2015; Park et al., 2016). Hydrological-topographic factors, such as sediment transport capacity index, stream power index, terrain characterization index, and topographic wetness index, are important parameters for research dealing with landslides (Oh, 2010). Use of topographic properties has some merits, such as the convenience of collecting topographic data and its applicability to the regional scale area. In this study, an empirical statistical method with topographic properties was used to analyze the initiation conditions of debris flow.

In Korea, research related to landslide susceptibility and hazard analysis has been actively conducted (Kim et al., 2004; Lee et al., 2005; Cho et al., 2007; Oh, 2010; Kim et al., 2014; Song et al., 2016; Vasu et al., 2016), but research of an initiation condition analysis for debris flow in mountains is still in its early stages. The application of existing debris flow initiation models to specific areas, based on local