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The 27 July 2011 debris flows at Umyeonsan, Seoul, Korea

Abstract On 27 July 2011, a total of 33 debris flows occurred in Umyeonsan, Seoul, Korea, resulting in 16 fatalities and extensive damage to houses, roads, and other properties. The debris flows originated during an intense rainstorm with a peak intensity of 112.5 mm/h and a cumulative rainfall of 306.5 mm over 16 h. The debris flows were triggered by a combination of two processes: (1) shallow translational landslides in colluvium at the ridge crest along a fault plane associated with the Chugaryeong Fault Zone and (2) the progressive entrainment of loose material due to surface water runoff in the channel. The ensuing debris flows extensively eroded the colluvial deposits overlying the bedrock along their paths and transported large quantities of soil and woody debris. Two watersheds with catastrophic debris flows in the study area were chosen for a forensic investigation to analyze the geomorphological features of the debris flow gullies and to study several factors influencing the debris flows. The debris flow activity was found to be primarily related to rainfall, as well as to the loose, compressible colluvium overlying the gneiss bedrock, the watershed topography with >30° slopes, and the vegetation.

Keywords Debris flow · Landslide · Colluvium · Rainfall · Umyeonsan · Korea

Introduction

Debris flows are a common mass movement process in mountainous terrain. The term "debris flow" is defined as a very rapid to extremely rapid surging flow of saturated debris in a steep channel that involves a high degree of entrainment of material and water along the flow path (Hungr et al. 2013). Debris flows differ from other forms of landslides in that they occur along existing paths, typically, gullies or a series of drainage channels. Debris flows represent a significant natural hazard because they are fast moving and difficult to predict. Debris flow activity depends on hydrology, lithology, topography, vegetation, and drainage conditions, which contribute to the magnitude, frequency, initiation mechanism, and morphology of a debris flow (Innes 1983; Coussot and Meunier 1996).

The development of debris flows in weak heterogeneous deposits such as colluvium has been previously observed in East Asia (Chen 1987; Fuchu et al. 1999) and North America (Fleming et al. 1989; Coe et al. 2008) because these regions experience intense rainfall. Channels are often eroded in thick unconsolidated soils that generate large quantities of poorly sorted debris. The relationship between rainfall and debris flow initiation is not simple and depends on factors such as the rainfall pattern, antecedent moisture content, and topographic relief (Deganutti et al. 2000; Zhou et al. 2014).

On 27 July 2011, 33 debris flows and 151 landslides were triggered by an extreme rainfall event in Umyeonsan (Mt.), Seoul, Korea. Immediately after the debris flows occurred, a field and laboratory investigation was conducted to explore the causes and mechanisms of the debris flows. This paper presents an overview of the debris flows with the following specific objectives: (1) the identification of the spatial distribution and geomorphological features of the debris flows, (2) the analysis of the characteristics of the triggering rainfall, and (3) the discussion of the contributing factors relevant to the debris flows and their possible evolution.

Study area

Umyeonsan is located southeast of the city of Seoul, Korea, as shown in Fig. 1. The topography is characterized by steep hills, gullies, and valleys (slopes are normally less than 40°), with elevations ranging from approximately 50 to 312.6 m above sea level. The area is underlain by metamorphic Precambrian gneissic rocks that belong to the Gyeonggi massif. The bedrock is primarily composed of quartz, plagioclase, biotite, amphibole, and feldspar. The fault system in the study area is oriented NE-SW and is related to the Chugaryeong Fault Zone. Some folds and foliations exist, causing relative displacements in the rock. The bedrock is heavily fractured, intensely weathered, and covered by a layer of colluvium varying in thickness from a few centimeters to 13 m (increasing in thickness at the lower elevations). The colluvial deposit consists of a very poorly sorted mixture of sands and gravels in a silty matrix. The vegetation cover is dense and comprises coniferous and deciduous forests, mixed forests of soft and hardwood, and understory vegetation. The colluvium and vegetation are directly associated with the origin and development of mass movement in this area.

The Umyeonsan region is situated in the temperate monsoon zone: The area is generally hot and humid with abundant rainfall events in summer and cold and dry in winter. The average annual precipitation ranges between 1100 and 1500 mm with 70 % of the annual average falling in June to September. In the area, small landslides and debris flows commonly occur during the summer season, although the 27th July 2011 disaster has been the most catastrophic of all the recorded debris flows. The intensity of this event is, to some extent, attributable to the climate change, in terms of the higher intensity and longer duration of rainfall not only in the Umyeonsan region but also in the majority of the regions in Korea (Kim et al. 2012; Le and Bae 2013).

Methods

A comprehensive field and laboratory study was carried out to investigate the spatial distribution and geomorphological features of the debris flows and to determine the hydrogeological, geotechnical, and vegetation characteristics of the near-surface deposits. This investigation included visual inspection, interpretation of aerial photographs, construction of a digital elevation model (DEM), analysis of rainfall records, in situ and laboratory tests, and a plant community survey.

Aerial photography was used to examine the location and characteristics of the debris flows. A combination of 1:5000-scale topographic maps and global positioning system (GPS) data was used to establish the topography of the debris flows. Geodetic data