2011 Seoul Debris Flow and Risk Analysis

Coulée de boue à Séoul en 2011 et analyse des risques

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ABSTRACT: A series of debris flow events occurred around 8:00 to 8:50 a.m. on July27, 2011 in the Umyeon Mountain area located in central Seoul, Korea. Umyeon Mountain is a relatively small one with a height of 250m and slopes with the average angle of around 15°. Due to the debris flows with runout distances ranging from 300m to 1,000m, 16 people were killed and more than 150 houses had been damaged in the area. In this work, we seek to understand the physical characteristics of the initiation and propagation behavior of debris flows from field investigation in the area and the analysis of rainfall data collected by AWS (Automatic Weather Stations) rain gauges. Field investigation shows that about 33 debris flows occurred in the Umyeon Mountain area and most of these debris flows were initiated from small slope failures induced by high-intensity rains. The application of landslide hazard map which has been recently developed by taking slope angle and direction, strength of soil, hazard record, rainfall condition and plantation into account demonstrates its good performance to highlight areas that are vulnerable of heavy-rainfall-induced slope failure and the resulting debris flow disasters.

RÉSUMÉ : Une série de coulées de boue s'est produite vers 8h00 ~ 8h50 le 27 Juillet 2011 dans la région du mont Umyeon situé dans le centre de Séoul, en Corée. La montagne Umyeon est relativement petite avec une hauteur de 250m et des pentes à angle moyen d'environ 15°. En raison de ces coulées de boue sur une distance allant de 300 à 1000m, 16 personnes ont été tuées et plus de 150 maisons ont été endommagées dans la région. Dans cette étude, nous chercherons à comprendre les caractéristiques physiques de l'initiation et du la développement de la propagation des coulées de boue à partir d'une enquête sur place dans la zone concernée et de l'analyse des informations de précipitations recueillies par les pluviomètres de l'AWS (« Automatic Weather Stations », Station météorologique automatique). L'enquête sur place montre que près de 33 coulées de boue ont eu lieu dans la région du mont Umyeon et la plupart de ces coulées de boue ont pris naissance à partir de petites ruptures de pente provoquées par des pluies très intenses. L'application de la carte des risques de glissement de terrain qui a été récemment mise au point en prenant en compte l'angle et la direction des pentes, la résistance du sol, l'historique des désordres, les conditions des précipitations et des plantations démontre sa bonne performance pour mettre en évidence les zones qui sont vulnérables à des ruptures de pente provoquées par de fortes pluies et des catastrophes résultant de ces coulées de boue.

KEYWORDS: debris flows, field investigation, rainfall, hazard map

1 INTRODUCTION

Most of the debris flow hazard has been concentrated during the rainy season from June to August in Korea. In 2011, there were Typhoon Meari (22 June to 27 June), Typhoon Muifa (28 July to 9 August) and the seasonal rain front that stayed in the middle part of the Korean peninsula. They poured much more rainfall compared to the average value, and eventually led to debris flows around the country (Yune and Jun, 2011). A series of debris flow events occurred around 8:00 to 8:50 a.m. on July27, 2011 in the Umyeon Mountain area located in southern part of Seoul, Korea.

Debris flows which generally contain more than 50% of granular materials larger than sand particles flow fast (Johnson and Rahn, 1970; Hutchinson, 1988). Because of their fast movement, it is very hard to take refuge, even though people recognize beforehand the outbreak of the debris flow. Between 8:00 to 8:50 a.m. on July 27, 2011, many debris flows occurred simultaneously at Umyeon Mountain in Seoul where there had been a previous debris flow event in 2010 caused by Typhoon Kompasu. Because the mountain is located at the center of a dense residential area in Seoul, the hazard had a great impact on the society compared to debris flows that occur in rural areas, and it led to careful scrutiny of the hazard area and the causes of debris flows.

In this research, a site survey on the debris flow at Umyeon Mountain was carried out to analyze the causes of the event, and rainfall records were also collected to investigate the triggering characteristics of the rain. In addition, risk analysis based on the hazard map of the landslide and debris flow was performed.

2 2011 SEOUL DEBRIS FLOW

2.1. *Overview of Umyeon Mountain*

Located in southern part of Seoul (Fig. 1) with the height of 312.6 m above the sea level, Umyeon Mountain includes lots of eco-friendly facilities, such as natural ecological park and mineral spring which can be easily accessed by local residents. It has a main ridge formed from the northeast to the southwest, including several valleys perpendicular to the main ridge. Most of the mountain consists of highly-weathered banded gneiss with subordinate granitic gneiss. Directions in ENE- and NW to NNW-striking faults are predominant with strike- or normal-slip sense. The groundwater level in the basin seems high because six mineral springs are located side by side at the altitude of 220 to 250 meters on the slope. Field observation of Son et al. (2012) also showed that groundwater level at locations where debris flows initiated reaches to the surface so that surface runoff occurs at the continuous rainfall condition of more than 250 mm, even if there is no significant antecedent rainfall. In

2010, regional intensive rainfall following Typhoon Kompasu caused a few landslides, and some of them developed as debris flows at the northern valleys in Umyeon Mountain (Fig. 2). However, the damage in 2010 was not great compared with the debris flow hazard in 2011.

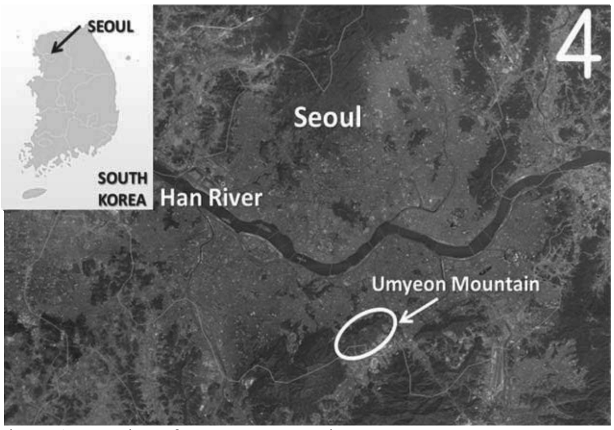


Figure 1. Location of Umyeon Mountain

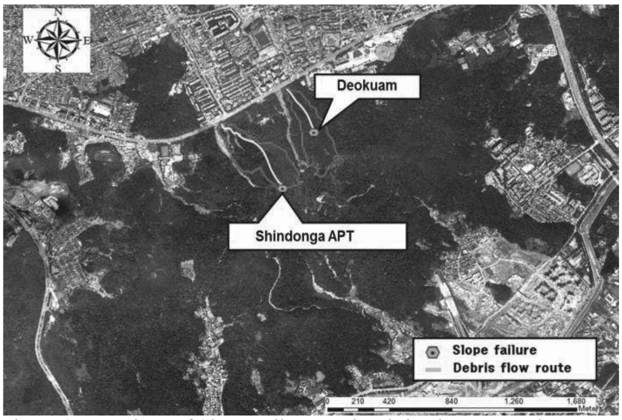


Figure 2. Locations of Slope Failures and Debris Flows around Umyeon Mountain in 2010

2.2. *Field Survey*

Field survey was performed to get data, such as longitude/latitude and topographical/geotechnical characteristics in places where debris flows were initiated, transported, and accumulated using a portable GPS, a laser ranger, and a clinometer. Based on the data from field survey, coordinates regarding initiation zones and debris flow routes were indicated on an aerial photograph around Umyeon Mountain as shown in Fig. 3. In this figure, the initiation slope failures are marked by blue dots, and debris flow routes are marked by yellow lines. Orange dots and green dots are also the initiation slope failure at the boundary and inside of air force base at the summit of the mountain, respectively. Most of the debris flows were initiated by slope failure and flowed down the valley. It was determined that they occurred simultaneously in the whole Umyeon Mountain area. The total number of slope failure that initiated debris flow was about 150. Based on the outlet in which the debris flows accumulated, the number of debris flows was about 33.

When we classified debris flows by direction, it was found that many of the slope failures occurred on the southern slope but many of the debris flows occurred on the northern slope. The debris flows moving towards the south were channelized debris flows which flowed down the valley and merged together. On the other hand, debris flows on the northern slope were hillslope debris flows which moved rapidly without being confined in an established channel. Therefore, the northern slope has fewer initiation zones but more debris flows compared to the southern slope.

The field survey result showed that the average moving distance of debris flows in Umyeon Mountain was about 615m, ranging from 95 to 1,584m. Also, the average gradient of initiation slopes was about 27 degrees, ranging from 11 to 37 degrees. The initiation volume of the slope failure was measured from 73 to 4,000 m^3.

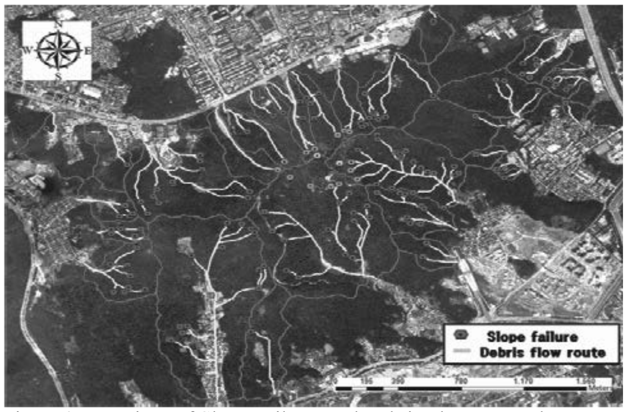
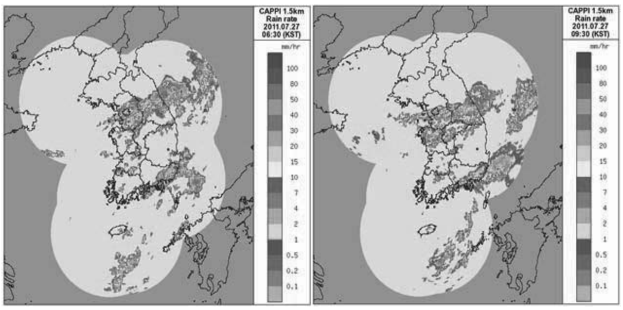


Figure 3. Locations of Slope Failures and Debris Flows around Umyeon Mountain in 2011

2.3. *Rainfall Conditions*

Korea Meteorological Administration (KMA) reported that the torrential heavy rain which triggered landslides at Umyeon Mountain in 2011 was due to unstable atmospheric conditions mainly determined by cold and dry air from inland China along with the hot and humid air masses from the strong Southwestern wind alongside the Western North Pacific subtropical high (Fig. 4).



(a) 6:30 a.m. 27 July 2011 (b) 9:30 a.m. 27 July 2011

Figure 4. Spatial patterns of rainfall in Korea peninsula by KMA

There are two automatic weather stations (AWSs) operated by KMA near Umyeon Mountain as shown in Fig. 5. Namhyeon and Seocho stations are located at west and northeast part of Umyeon Mountain, respectively. Rainfall records from Namhyeon and Seocho stations were analyzed as daily and cumulative rainfall for 2 months as shown in Fig. 6. The cumulative rainfall for 2 months before debris flow event was 1,489.5mm and 1,105.0 mm at Namhyeon and Seocho station, respectively. Those values were comparable to the average annual rainfall in Seoul (1,450.5 mm). A significant amount of rainfall (681.5 mm at Seocho station) was concentrated during the period from 21 June to 18 July which was 10 to 36 days before the occurrence of the debris flows. Then there was no rainfall up to 4 days before the debris flow event and 88.5 mm of rainfall was recorded 1 to 3 days before debris flow. On the day of the debris flows, 359 mm and 281 mm of rainfall at Namhyeon and Seocho station were recorded. Unlike neighboringGwanak Mountain, which is primarily composed of granite, the geological structure of Umyeon Mountain is made up of gneiss. Therefore, the prolonged rainfall one month prior to the debris flow event might have caused saturation of the ground and made it more vulnerable to collapse. Average return period of rainfall for the duration of one hour and more was about 120 and 20 year for the Namhyeon and Seocho stations, respectively.

Figure 5. Locations of automatic weather stations around Umyeon Mountain

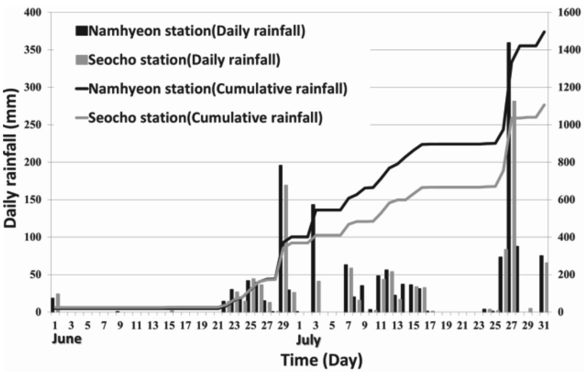


Figure 6. Locations of automatic weather stations around Umyeon Mountain

3 RISK ANALYSIS

3.1 Landslide susceptibility assessment

There are two general approaches for landslide susceptibility assessment. The first approach is based on a physical mechanism and the second is based on a statistical method. In this work, statistical model developed in Gangneung-Wonju national university was used (Lee et. al., 2012). This model can directly yields the probability of landslide because the equation of the model was derived from logistic regression. The landslide susceptibility map is created by using GIS data which includes geomorphological characteristics, soil properties, rainfall, vegetation, and forest fire history. Figure 7 shows the landslide susceptibility map which was made with 329 mm of accumulated rainfall for 3 days, and the field survey result which included the initial slope failure and flow path of the debris flows was overlayed. As shown in figure 7, most of the slope failures were occurred in highly susceptible regions for landslide.

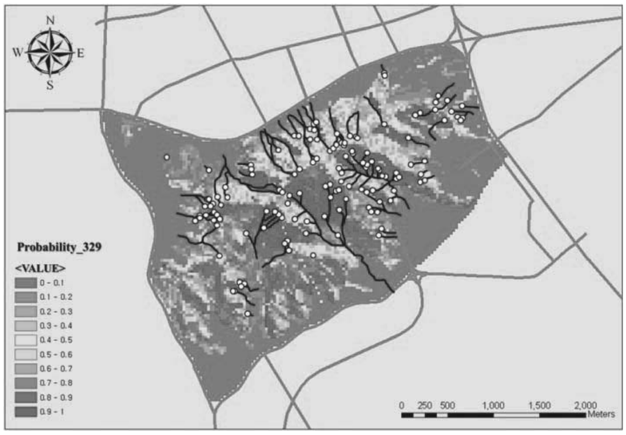


Figure 7. Landslide susceptibility map with field survey results

3.2 Debris flow risk assessment

A methodology for the evaluation of debris flow risk in a watershed incorporated with GIS was proposed in this work. This model predicts the debris flow hazard risk on any given watershed. The model was developed using statistical analysis of debris flow hazard data in Korea from 2005 to 2011. These data was obtained from field surveys, disaster reports on national roads of Korea, aerial photos, and digital maps. Each set of data in the database includes geomorphologic factors influencing debris flow size, rainfall information, bedrock types, and run out distance of the debris. Figure 8 shows flow chart of the methodology.

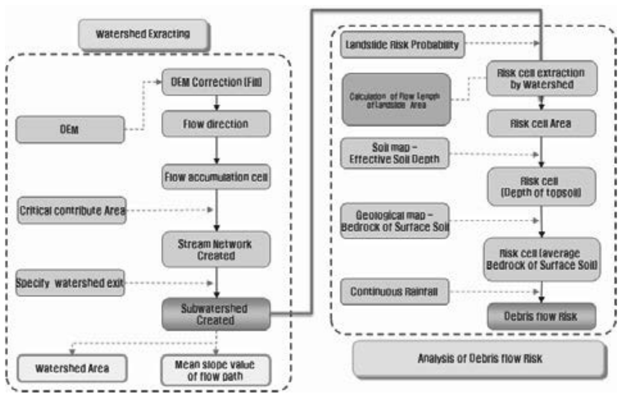


Figure 8. Flow chart of the debris flow risk assessment

Debris flow hazard probability is calculated by equation (1).

Debris flow hazard probability = (1)

where Logit(p) = -5.4 -1.3E-5×(area indicating landslide probability higher than 50%×depth of surface soil) +0.005×(amount of continuous rainfall) +4.522×(bedrock type) +2.1E-8×(mean slope of flow path-area of watershed). Table 1 shows the data and data acquisition method used in the model.

Based on the analysis of DEM (Digital Elevation Map) of Umyeon Mountain, 31 watersheds can be generated as shown in Figure 9. The probability of debris flow hazard for individual watershed in Umyeon Mountain is summarized in Table 2. As shown in Table 2, most of the watershed where debris flow took place showed high probability for the debris flow hazard except one watershed (Seonbawi) where debris flow hazard did not occur. Unlike the other watersheds, the bedrock of Seonbawi watershed was granite and the bedrock condition might be one of the important factor in the occurrence of debris flow. These results confirmed the applicability of the developed risk assessment model for the landslide and debris flow hazard.

Table 1. Data of the debris flow hazard occurrence

Dataset	Data acquisition
Potential landslide area ()	Landslide susceptibility map
Depth of top soil (m)	Soil classification map
Possible sediment area ()	Field survey, DEM
Mean slope gradient of flow path(°)	Field survey, DEM
Watershed area()	GIS tool, DEM
Rainfall(mm)	AWS
Bedrock type	Geological map
Mean flow distance(m)	GIS tool, DEM

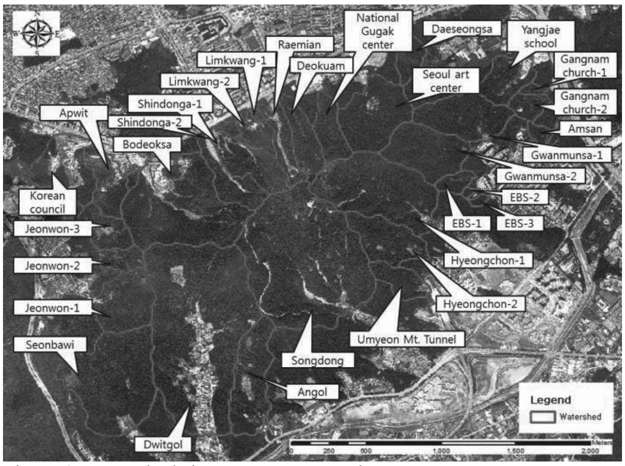


Figure 9. Watersheds in Umyeon Mountain

Table 2. The probability of debris flow hazard for individual watershed

Watershed	Prob.	Watershed	Prob.
Raemian	84%	EBS-1	77%
Limkwang-1	72%	EBS-2	70%
Limkwang-2	76%	EBS-3	71%
Shindonga-1	87%	Gwanmunsa-1	96%
Shindonga-2	87%	Gwanmunsa-2	97%
Hyeongchon-1	99%	Amsan	73%
Hyeongchon-2	92%	Gangnam church-1	71%
Jeonwon-1	94%	Gangnam church-2	79%
Jeonwon-2	80%	Yangjae school	84%
Jeonwon-3	75%	Daeseongsa	79%
Bodeoksa	99%	Seoul art center	96%
Apwit	69%	National gugak center	87%
Korean Council	73%	Dwitgol	99%
Songdong	99%	Angol	90%
Umyeon Mt. tunnel	83%	Seonbawi	17%
Deokuam	85%		

4 CONCLUSIONS

A series of debris flow events occurred around 8:00 to 8:50 a.m. on July 27, 2011 in the Umyeon Mountain area located in Seoul, Korea. Field survey on the debris flow at Umyeon Mountain was carried out to understand the comprehensive situation of the hazard. The field survey result showed that debris flows occurred all around Umyeon Mountain and the average moving distance of debris flows was about 615m, ranging from 95 to 1,584m. Also, the average gradient of initiation slopes was about 27 degrees, ranging from 11 to 37 degrees. The initiation volume of the slope failure was measured from 73 to 4,000 m^3.

In addition, risk analysis based on the hazard map of the landslide and debris flow was performed. Risk assessment of the landslide hazard showed the most of the slope failures were occurred in highly susceptible regions for landslide. And debris flow risk assessment also showed that the most of the watershed experienced debris flow hazard showed high probability of debris flow occurrence. And these results confirmed the applicability of the developed risk assessment model for the landslide and debris flow hazard.

5 ACKNOWLEGEMENT

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