Proposed Korea Rainfall Thresholds for Landslides over bedrock

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ABSTRACT: The rainfall threshold (ID curve) triggering landslides were investigated by considering the effects of antecedent rainfnall in South Korea. The time and location data of landslides occurred in South Korea from 1999 to 2016 were collected. 231 landslide histories from 1999 to 2013 were used to suggest rainfall thresholds. Each of Threshold curves was inferred by using a Bayesian statistical technique. For metropolitan area, the effect of geological characteristics on rainfall thresholds was also investigated. Based on this study, it is shown that the slope of rainfall threshold for metamorphic rock is slightly higher than that of igneous rock. It is also found that applying the longer IETD implies the effect of antecedent rainfall lasts longer, and it can be predicted that landslides may occur even at lower rainfall intensity for long duration rainfall.

KEYWORDS: Rainfall threshold, antecedent rainfall, bed rock, Inter event time definition (IETD)

1 INTRODUCTION

The landslide is one of the most pervasive disasters in the world, but there is still no clear solution, so landslides are causing damage to lives and properties. Rainfall at the time of landslide occurrence are also important for rainfall induced landslides, but they are greatly affected by antecedent rainfall (Tan et al. 1987; Chatteriea 1989; Wei et al. 1991; Rahardjo et al. 2001; Yune et al. 2010; Kim et al. 2013). The antecedent rainfall determines the initial state and matric suction of the ground at the time of landslide occurrence (Kim et al. 2013).

Antecedent precipitation influences groundwater levels and soil moisture, and can be used to determine when landslides are likely to occur (Guzzetti et al. 2007). A simple way of considering the effects of antecedent precipitation consists of establishing a threshold based on the amount of the antecedent rainfall and rainfall duration. However, it has limitations in that it does not accurately simulate the influence of the antecedent rainfall on the hydrological characteristics of soil.

In this study, some rainfall intensity-duration thresholds (ID curves) for predictions of landslide considering the effects of antecedent rainfall based on the probability of landslide occurrence. For metropolitan area, the effect of geological characteristics on rainfall thresholds was also investigated. 231 rainfall data including domestic landslide and rainfall records were used to suggest ID curves by the empirical method.

2 BACKGROUND

2 .1 *Effects of the antecedent rainfall with Inter-event time definition (IETD)*

In order to define a rainfall event that influenced on the landslide occurrence, it is necessary to define when the event begins and ends. Adams et al. (1986) defined "Inter-event time definition (IETD)" as a period of time that separates two different rainfall events. Two consecutive rainfall pulses are separated by the IETD as shown in Figure 1.

The effective rainfall event that influenced on the landslide occurrence can be defined by an IETD and changed with various IETDs. The antecedent rainfall can be defined as the rainfall that occurred before the directly continuous rainfall until the occurrence of the landslide among the effective continuous rainfall determined by the IETD. As the IETD increases, the antecedent rainfall increases, which implies a larger effect of the antecedent rainfall on the landslide occurrence in analyzing the rainfall. In this study, statistical properties of rainfall events and ID curves were analyzed to determine how they change with different IETDs which reflect the effects of the antecedent rainfall on the landslide occurrence.

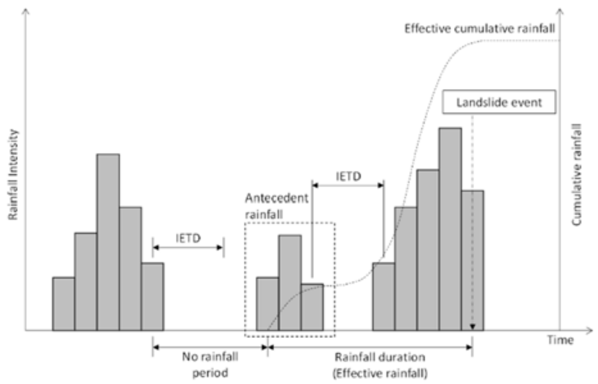


Figure 1. Definitions of antecedent rainfall, effective rainfall and rainfall duration based on IETD

2 .2 *Bayesian approach*

Berti et al. (2012) reported that the case of deep-seated landslides is difficult to identify a threshold because rainfall events that result in landslides are not clearly distinguished from those that do not. In this case, it is difficult to set a specific rainfall threshold for landslides. However, few authors addressed the problem of rainfall identification (Berti et al., 2012). In this study, we propose probabilistic rainfall thresholds by using a Bayesian approach that proposed by Berti et al. (2012) to estimate the probability of landsliding conditional to characteristics of rainfall events.

Bayes' theorem is a direct application of conditional probabilities (Campbell, 1975). The conditional probabilities means the probability that event A will occur under the condition that event B has occurred. In this study, event A means landslide occurrence and event B means rainfall occurrence with specific rainfall intensity and duration. This conditional probability can be provided as followings:

$$\mathrm{P(A|I,D)} = \frac{P(I,D|A)\cdot P(A)}{P(I,D)} \tag{1}$$

where I, D indicates the joint probability of having specific rainfall intensity and duration (replacing B to apply in two dimensional case), and A indicates the occurrence of landslide.

In this study, the specific range of intensity was set to 0.3 mm/h and that of duration was set to 3 h. The conditional probability based on Bayesian approach of each pixel was calculated, and probabilistic rainfall thresholds were proposed by regression analysis of points having similar probabilities.

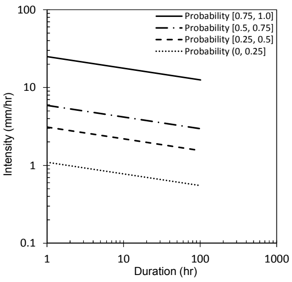
3 RA`INFALL THRESHOLDS FOR LANDSLIDES IN SOUTH KOREA

Rainfall intensity and duration data were established from 231 landslide histories and their rainfall data. Rainfall intensity-duration thresholds were proposed for the landslide probabilities (0, 0.25], [0.25, 0.5], [0.5, 0.75] and [0.75, 1.0] based on the Bayesian approach, and the IETD was changed from 6 to 96 hours as in the previous rainfall data analysis. From the results of the probabilities of landslide occurrences for each intensity-duration location, probabilistic ID curves were proposed as shown in Figure 2. The functions of each proposed ID curves were summarized in Table 2, and the range of rainfall duration was increased with increasing the IETD.

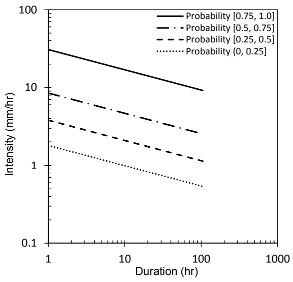
The probability of each ID curve indicates the possibility of landslide when rainfall of about the ID curve occurs. As shown in Figure 2, the probability of occurrence of landslides was higher in the case of higher rainfall intensity, and each probabilistic ID curves was estimated by regression analysis as a function of the basic equation of ID curves ($\mathrm{I} = \alpha D^{-\beta}$), representing the points included in the probability of the range. In addition, as the IETD increased, the data points are distributed over a wider range of rainfall durations.

In Figure 3, the coefficients α and β of the basic equation of ID curves ($\mathrm{I} = \alpha D^{-\beta}$) were increased with increasing the IETD and converged to each constant value. These results indicate that the slope of the ID curve and the y-intercept increased with increasing the IETD and then remain above a certain level. In order to confirm these tendencies, we plotted the ID curves corresponding to the probability of landslide occurrence 0.75 ~ 1.0 in Figure 4. As shown in Figure 4, for shorter duration such as ≤10 h, rainfall intensities for landslide occurrences were increased with increasing the IETD, while that for longer duration were decreased. As stated earlier, these results were considered to be due to the IETD reflects the effects of antecedent rainfall. Applying the longer IETD implies that the effect of antecedent rainfall lasts longer, and it can be predicted that landslides may occur even at lower rainfall intensity for long duration rainfall.

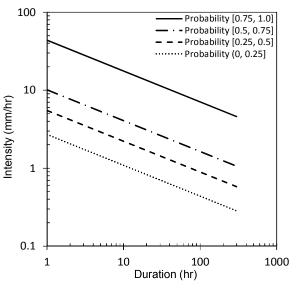
For metropolitan area, the effect of geological characteristics on rainfall thresholds was also investigated. As a result, it is shown that the slope of rainfall threshold for metamorphic rock is slightly higher than that of igneous rock (Figure 5).



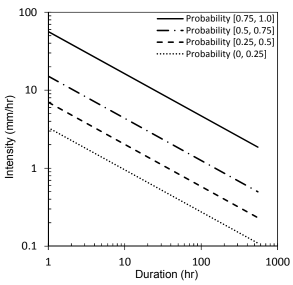
(a) IETD = 6 hour



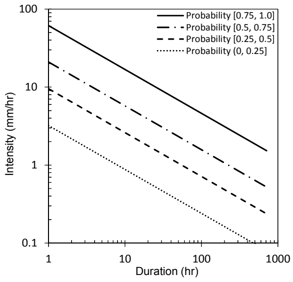
(b) IETD = 12 hour



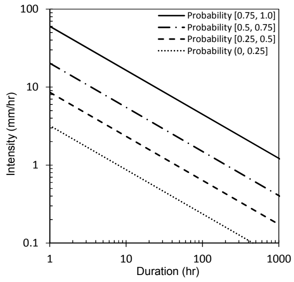
(c) IETD = 36 hour



(d) IETD = 60 hour



(e) IETD = 84 hour



(f) IETD = 96 hour

Figure 2. Proposed probabilistic ID curves with various IETDs

Table 2 Summary of the functions of each ID curves

IETD (h)	Probability	ID curves	Duration range (h)
6	$0 < P \leq 0.25$ $0.25 \leq P \leq 0.5$ $0.5 \leq P \leq 0.75$ $0.75 \leq P \leq 1.0$	$\mathrm{I} = 1.1 \times D^{-0.15}$ $\mathrm{I} = 3.1 \times D^{-0.15}$ $\mathrm{I} = 5.9 \times D^{-0.15}$ $\mathrm{I} = 25 \times D^{-0.15}$	$1 \leq D \leq 101$
12	$0 < P \leq 0.25$ $0.25 \leq P \leq 0.5$ $0.5 \leq P \leq 0.75$ $0.75 \leq P \leq 1.0$	$\mathrm{I} = 1.8 \times D^{-0.26}$ $\mathrm{I} = 3.8 \times D^{-0.26}$ $\mathrm{I} = 8.5 \times D^{-0.26}$ $\mathrm{I} = 30.8 \times D^{-0.26}$	$1 \leq D \leq 105$
36	$0 < P \leq 0.25$ $0.25 \leq P \leq 0.5$ $0.5 \leq P \leq 0.75$ $0.75 \leq P \leq 1.0$	$\mathrm{I} = 2.7 \times D^{-0.395}$ $\mathrm{I} = 5.5 \times D^{-0.395}$ $\mathrm{I} = 10.1 \times D^{-0.395}$ $\mathrm{I} = 43.7 \times D^{-0.395}$	$1 \leq D \leq 299$
60	$0 < P \leq 0.25$ $0.25 \leq P \leq 0.5$ $0.5 \leq P \leq 0.75$ $0.75 \leq P \leq 1.0$	$\mathrm{I} = 3.3 \times D^{-0.54}$ $\mathrm{I} = 7.0 \times D^{-0.54}$ $\mathrm{I} = 15.1 \times D^{-0.54}$ $\mathrm{I} = 56.3 \times D^{-0.54}$	$1 \leq D \leq 551$
84	$0 < P \leq 0.25$ $0.25 \leq P \leq 0.5$ $0.5 \leq P \leq 0.75$ $0.75 \leq P \leq 1.0$	$\mathrm{I} = 3.2 \times D^{-0.562}$ $\mathrm{I} = 9.5 \times D^{-0.562}$ $\mathrm{I} = 21.0 \times D^{-0.562}$ $\mathrm{I} = 61.4 \times D^{-0.562}$	$1 \leq D \leq 713$
96	$0 < P \leq 0.25$ $0.25 \leq P \leq 0.5$ $0.5 \leq P \leq 0.75$ $0.75 \leq P \leq 1.0$	$\mathrm{I} = 3.2 \times D^{-0.565}$ $\mathrm{I} = 8.6 \times D^{-0.565}$ $\mathrm{I} = 20.2 \times D^{-0.565}$ $\mathrm{I} = 60.4 \times D^{-0.565}$	$1 \leq D \leq 1044$

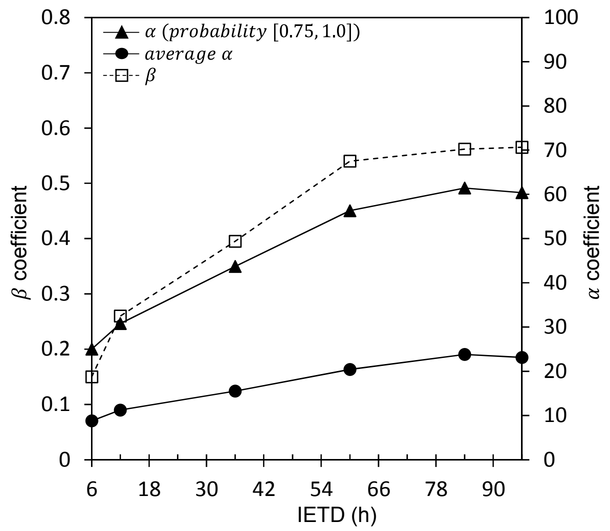


Figure 3. Changes in coefficients α and β with various IETDs

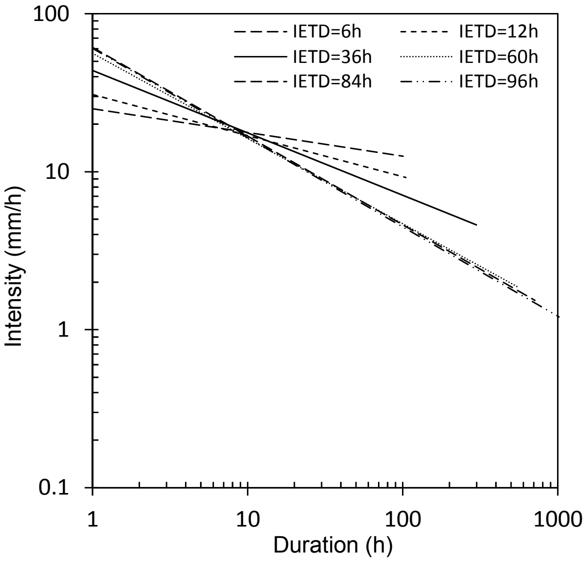
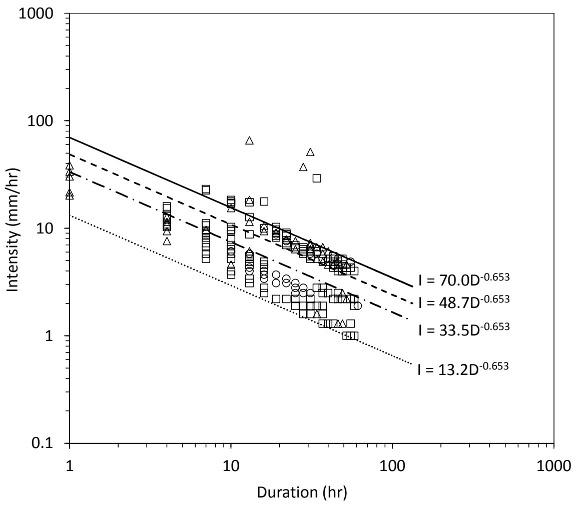
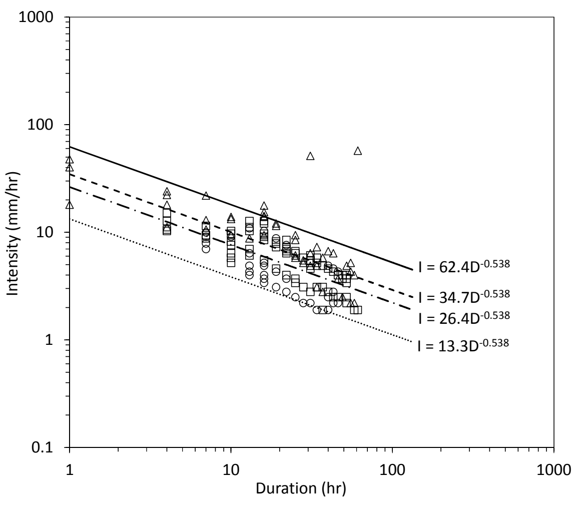


Figure 4. ID curves corresponding to the probability of landslide occurrence 0.75 ~ 1.0



(a) Metamorphic rock



(b) Igneous rock

Figure 5. Comparison between two metropolitan ID curves for metamorphic rock and igneous rock

4 CONCLUSIONS

The primary objective of this study is to propose rainfall thresholds for landslide predictions. In South Korea, landslides caused by rainfall concentrated in the summer have occurred continuously, and all rainfall thresholds for landslide predictions suggested in this study were based on 231 landslide histories in South Korea. Rainfall thresholds were suggested in the form of ID curve (intensity-duration threshold) by an empirical method. Two focus of this study were to propose probabilistic ID curves empirically to reflect the influence of other factors except rainfall and to compare ID curves for various IETDs to analyze the variation of ID curves according to the effects of antecedent rainfall. For metropolitan area, the effect of geological characteristics on rainfall thresholds was also investigated. The following conclusions can be drawn from the findings of this study:

(1) To reflect the influence of other factors except rainfall, probabilistic ID curves were proposed by using Bayesian approach, and the probability of landslide increased with increasing rainfall intensity.

(2) For shorter duration such as ≤10 h, rainfall intensities for landslide occurrences were increased with increasing the IETD, while that for longer duration were decreased. These results were considered to be due to the IETD reflects the effects of antecedent rainfall.

(3) For metropolitan area, it is shown that the slope of rainfall threshold for metamorphic rock is slightly higher than that of igneous rock.

5 ACKNOWLEDGEMENTS

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