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The continuous snake-line method as a potential indicator of warning levels for landslides and lahar disasters

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Abstract. A combination of long-term rainfall index (LRI) and short-term rainfall index (SRI) is commonly used as an indicator for estimating whether a series of rainfalls is likely or unlikely to cause landslides or lahar flows. The LRI represents the condition of soil structure instability. The SRI represents the condition of soil surface instability. A critical line can be drawn separating zones of occurring and non-occurring landslides or lahar floods. An occurrence of series of rainfalls can be monitored by drawing a snake line representing the progression of LRI-SRI values. By selecting an appropriate definition of LRI and SRI indices, a continuous snake-line can be developed for monitoring warning conditions of progressing rainfall events. Several existing definitions of LRI vs. SRI such as cumulative rainfall vs. hourly rainfall, working rainfall vs. hourly rainfall, and working rainfall with long half-life vs. working rainfall with short half-life were reviewed in terms of their effectiveness in delivering warning and practicability in drawing and reading the snake-line. A procedure for accommodating snake-line drawings of several definitions was established. The procedure was tested by several serial rainfall events and has shown good capability in facilitating monitoring activities for landslides or flood warnings.

Keywords: landslide, lahar flood, warning, snake-line method

1. Introduction

A combination of long-term rainfall index (LRI) and short-term rainfall index (SRI) is commonly used as an indicator for estimating whether a series of rainfalls is likely or unlikely to cause landslides or lahar flows [1, 2, 3, 4, 5], and [6]. The LRI, which can be replaced by the soil moisture index, represents the condition of soil structure instability. Meanwhile, the SRI represents the condition of soil surface instability. A critical line can be drawn on the LRI-SRI chart to separate zones of occurring and non-occurring landslides or lahar floods based on empirical data. At the occurrence of a series of rainfalls, the progression of LRI-SRI values (points on the chart) can be monitored, and the lines that connect the points are called a snake-line.

When the moving end of a snake-line approaches the critical line, warning information can be issued. Therefore, a warning line and an evacuation line can be also drawn on the LRI-SRI chart for determining the issuance of warning information.



Selecting a working rainfall that considers the antecedent rainfall and cumulative rainfall as LRI has many alternative combination schemes. This can also apply to the SRI. Therefore, evaluating such combinations would be very beneficial for improving the reliability of a warning system. This paper shares the experience in developing tools for monitoring rainfall as well as evaluating several LRI and SRI definitions.

2. Materials and Methods

2.1. Rainfall Indices

Methods of warning criteria for probable landslide and lahar or debris flood occurrences have been developed based on rainfall parameters. This approach does not consider geologic, morphologic, and vegetation coverage (land use). However, its simplicity has attracted many researchers and institutions for its application and development. The condition and process of landslide or lahar/debris flow initiation can be understood as a function of instability of soil structures, whether that of deeper parts or shallow parts. The change in the stability condition is caused by the change of water content in soil pores and impact pressure from rain drops or erosion process from the overland runoff on the ground surface.

The LRI represents the first factor. LRI is most popularly taken to be the working rainfall, R_W (in mm), that is defined as the cumulative rainfall of a certain period, R_C (in mm), and the decaying effect of the previous rainfall or the antecedent rainfall, R_A (in mm). The cumulative rainfall and antecedent rainfall are calculated with the following formulas [1]:

$$R_W = R_C + R_A \quad (1)$$

$$R_C = \sum_{i=1}^n R_i \quad (2)$$

$$R_A = \sum_{i=1}^m \alpha_i R_i, \quad \alpha_i = 0.5^{\left(\frac{t_i}{T}\right)} \quad (3)$$

where R_i is the recorded rainfall depth within the i^{th} recording time interval, α_i is the decaying coefficient of R_i , t_i is the time interval between time of R_i and current time, T is the time needed for the decaying effect of R_i to become half of its original value (the half-life), n is the number of rainfall data records for the cumulative rainfall, and m is the number of rainfall data records for the antecedent rainfall. As for the SRI, the rainfall intensity of a selected time interval R_I (in mm/hr) or R_W of different half-lives can be used.

The half-life is influenced by the rate of soil moisture decay. Therefore, sandy soil will have a smaller half-life than clay soil. The values of the half-life, n , and m are determined empirically. Whenever the antecedent rainfall term has decayed to be very small, it can be neglected; therefore, this determines the value of m .

2.2. Plotting Non-Occurring and Occurring Rainfall Points

The state of a series of rainfalls, whether as a disaster event of a landslide or lahar/debris flooding that occurs within the period of the rainfalls, is of two conditions. Occurring rainfall represents a series of rainfalls that causes at least one disaster event, and non-occurring rainfall represents a rainfall series that causes no disaster events. In the LRI-SRI chart, non-occurring rainfall is plotted based on the values of R_W and R_I that are calculated at the maximum rainfall intensity of the rainfall series data. As for occurring rainfall, both indices are calculated at the time of the disaster event [1].

2.3. Critical Line

Based on occurring and non-occurring rainfall point plots, an averaged border line for a zone of non-occurring rainfall and a zone of occurring rainfall can be found. This border may be approximated as a

line as in Method A by [1] or a curve as in [7] and [8]. The critical line needs to be updated every couple of years since a temporal shift phenomenon occurs [8].

2.4. Snake-Line

The monitoring of progressing rainfall using a snake-line requires the evaluation of LRI and SRI values for every incoming data from rainfall sensors. This is because as a warning tool, the information of a warning state needs to be known and forwarded as soon as possible. As a new point in the LRI-SRI chart becomes available, the line connecting that new point and the previous point is drawn. What becomes very important is to estimate whether the last point and line are showing that the progressing rainfall is approaching the critical line and already at a distance for issuing a warning, as shown in Figure 1.

The simplest way to evaluate this condition is by calculating the distance of the last point to the critical line or curve. For a straight critical line, the evaluation of such a distance is not difficult; however, the distance of the point to a curved critical line is not simple to evaluate.

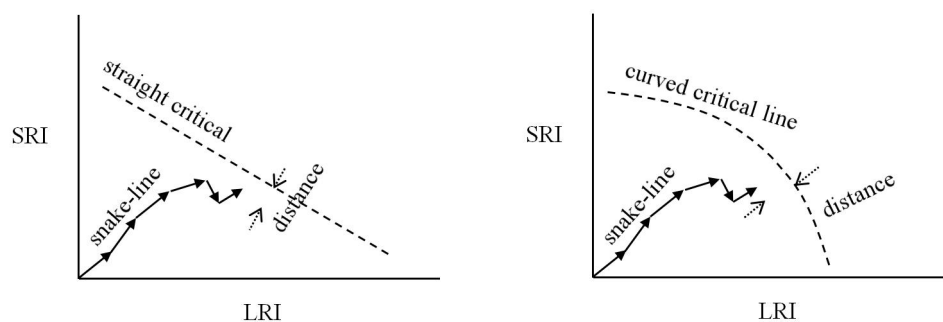


Figure 1. The snake-line approaching the critical line, with the distance to a straight critical line (left), to a curved critical line (right)

3. Results and Discussion

Based on the LRI-SRI chart, a software application for monitoring rainfall was developed. The development of the application was performed firstly with Microsoft Excel using VBA, before migration to a web-based rainfall monitoring software application. Figure 2 shows two charts. In the left chart, based on an empirical study, a critical line is drawn first. The snake-line is drawn segment by segment as the rainfall progresses. The distance to the critical line of a progressing point is calculated and evaluated to determine the state of warning.

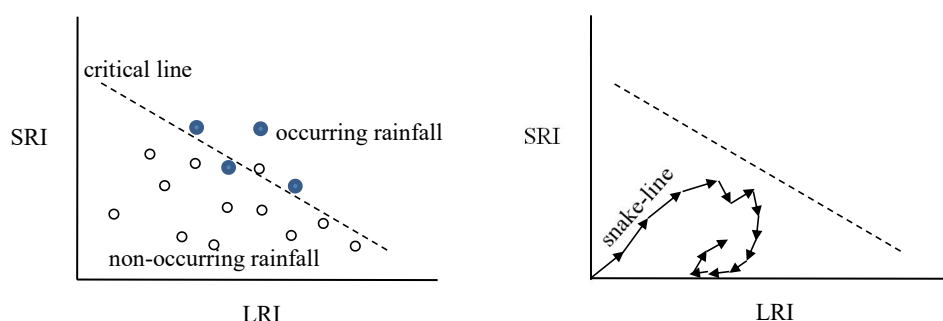


Figure 2. Development of the critical line (left), and monitoring of the progressing snake-line (right)

It can be seen that when a rainfall series is in recession, the snake-line moves down or even curves back to the origin of the chart. When rainfall stops, the snake-line is on the LRI axis and moves to the origin. The snake-line will move up again should a series of rainfall data be received from the rainfall sensor. Therefore, the rainfall progress monitoring can be conducted continuously on the LRI-SRI chart.

A study of half-life sensitivity to the averaged snake-line slope and to the working rainfall value (LRI) at maximum rainfall intensity (SRI) was conducted using this software application. The study used the five-minute interval rainfall data records of ARR Station BO-CO UGM-Lembah during the Cempaka Cyclone from November 27 to 29, 2017 (Figure 3). The half-life values were 60, 120, 180, 240, and 300 minutes. The plots of the snake-lines with 180-minute and 300-minute half-lives are shown in Figure 4 and Figure 5.

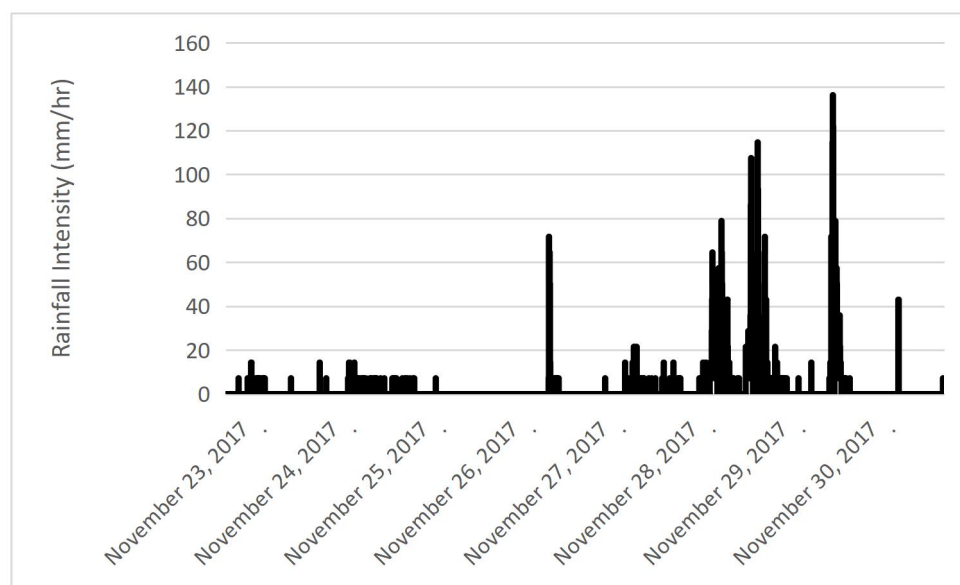


Figure 3. ARR data records from November 23 to 30, 2017

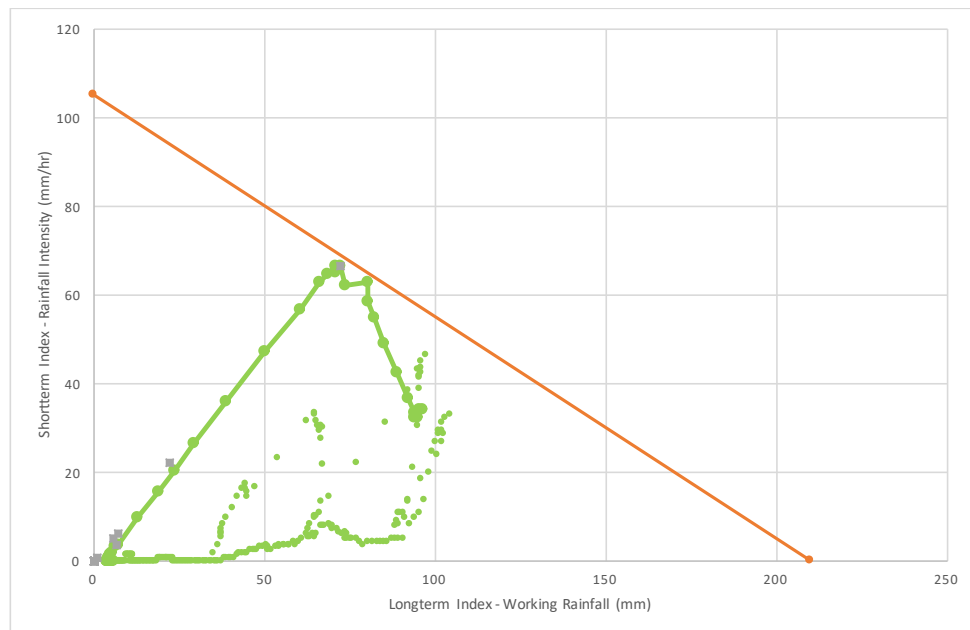


Figure 4. Snake-line track of ARR data records from November 23 to 30, 2017, with a 180-minute half-life value

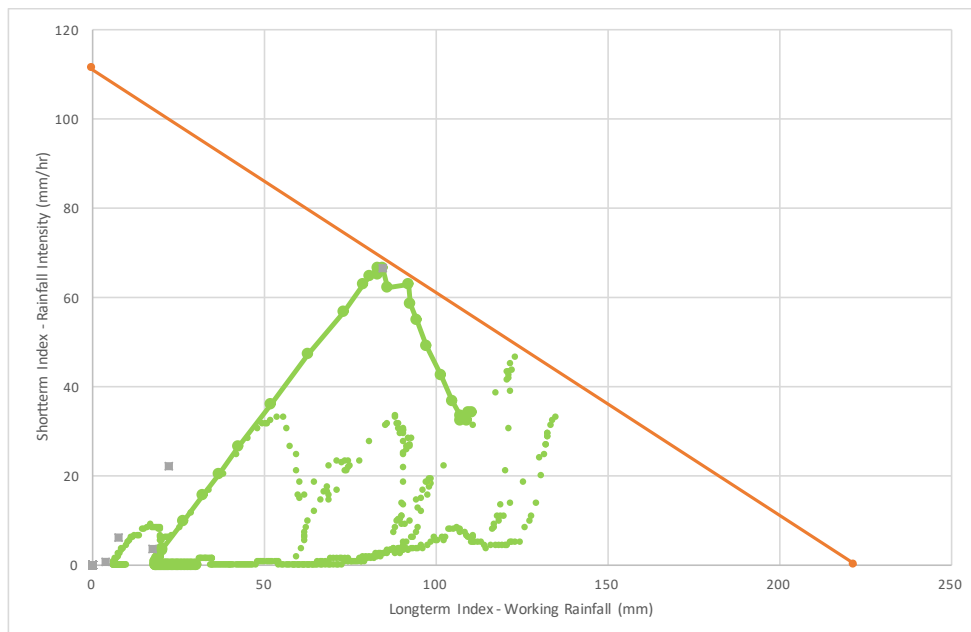


Figure 5. Snake-line track of ARR data records from November 23 to 30, 2017, with a 300-minute half-life value

Two parameters were used to examine the effect of different half-life values on R_W at the maximum R_I value and the average of increasing snake-line slope values. The results are shown in Table 1 and Figure 6.

Table 1. Working rainfall at maximum rainfall intensity and increasing snake-line slope values with different half-life values

Half-life (minutes)	60	120	180	240	300
Max R_I (mm/hr)	66.3	66.3	66.3	66.3	66.3
R_W (mm)	69.3	69.9	72.4	77.4	84.6
Slope (1/hr)	0.96	0.95	0.92	0.86	0.78

Half Life (minutes)	60	120	180	240	300
Max R_I (mm/hr)	66.3	66.3	66.3	66.3	66.3
R_W (mm)	69.3	69.9	72.4	77.4	84.6
Slope (1/hr)	0.96	0.95	0.92	0.86	0.78

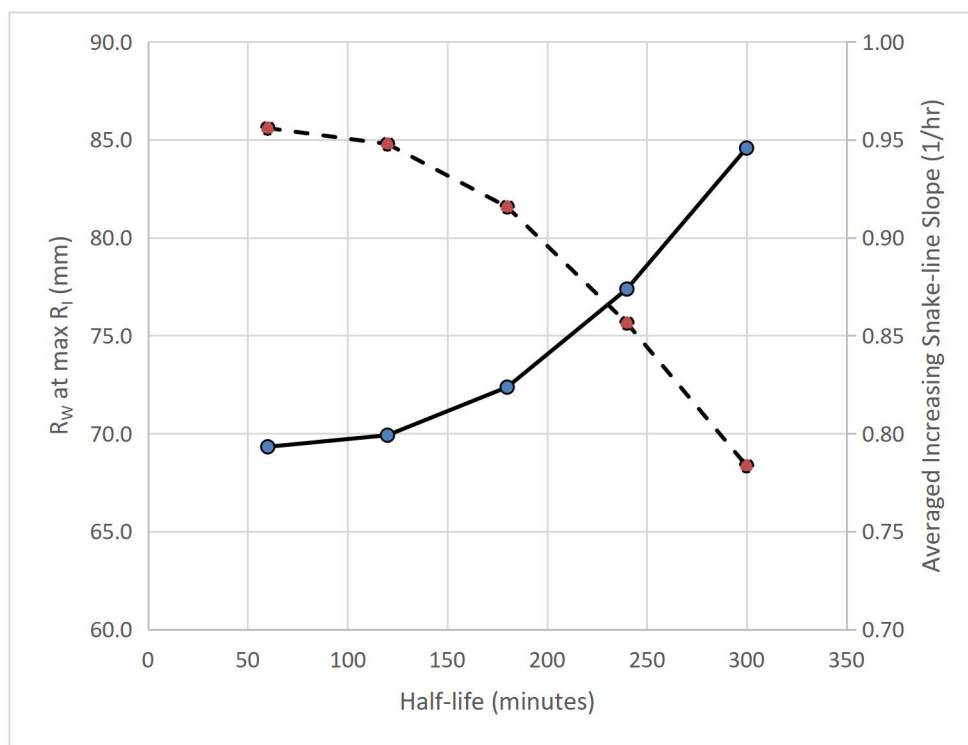


Figure 6. Sensitivity of half-life values to the R_W and the average of increasing snake-line slope values

The results of the study showed that the R_W with the maximum R_I increases as the half-life value increases. As the critical line is fixed, a higher half-life value causes the maximum points to become closer to the critical line, as shown in Figures 4 and 5. In the case of the Cempaka Cyclone event, there was no report of landslide or debris flow occurrence, but there was flooding, since heavy rainfall was in the lower area (Bantul and Gunung Kidul). The important points here are that the developed tool has demonstrated that monitoring and evaluation of progressing rainfall become easier and calibration of half-life value needs to be conducted for certain areas to provide more reliable warning criteria.

4. Conclusion

The software application for monitoring progress of rainfall has been developed and preliminary testing in providing information for issuing warning of landslides and lahar/debris flow occurrences has been carried out. The monitoring method implements the Long-term Rainfall Index (LRI) – Short-term Rainfall Index (SRI) chart. The LRI and SRI are able to be defined in a flexible manner so that evaluation and calibration of some relevant parameters can be conducted.

Sensitivity analysis of half-life values to the Working Rainfall at Maximum Rainfall Intensity has shown the importance of calibrating the half-life value for the warning system. The calibration process needs data of rainfall occurrences that are also needed in adjusting the critical line. Therefore, calibration of half-life values and adjustment of the critical line need to be conducted concurrently.

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