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# The Determination of Rainfall Threshold Triggering Landslides Using Remote Sensing

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**Abstract.** Landslide is one of the natural disasters that can cause a lot of loss, both material and fatalities. Banjarnegara Regency is one of Central Java Province regencies where landslides often occur due to the region's topography and high intensity rainfall.. Therefore, it is necessary to determine the threshold of rainfall that can trigger landslides to be used as an early warning for landslides. The rainfall data used for the threshold is daily and hourly rainfall intensity from remote sensing data that provides complete data but relatively rough resolution. So that remote sensing data need to be re-sampled. The remote sensing data used is CMORPH satellite data that has been re-sampled for detailing existing information of rainfall data. The resampling method used is the bilinear method and nearest neighbor by choosing between the two based on the highest correlation. Threshold calculation using Cumulative Threshold (CT) method resulted equation  $P_3 = 7.0354 - 1.0195P_{15}$  and Intensity Duration (ID) method resulted equation  $I = 1.785D^{-0.305}$ . The peak rainfall intensity occurs at the threshold of 97-120 hours before a landslide occur.

Keywords : landslide, threshold, rainfall, CMORPH

## 1. Introduction

Some areas in Indonesia consist of mountains and hills with gradual to steep slopes. This condition results in the potential for landslides that can cause a lot of loss, material, fatalities, and environmental damage. Landslide is a local disaster but is widely spread throughout Indonesia. One of the districts in Indonesia that have experienced many landslides is Banjaregara Regency. Based on data from the Banjarnegara Regional Disaster Management Agency (BPBD) listed in the Statistics Indonesia (BPS) publication [1], it was noted that Banjarnegara Regency had experienced 253 landslides in 5 years from 2013 through 2017. Most of the Banjarnegara Regency areas are threatened by landslides of medium to high scale [2]. Due to the number of landslides and the number of losses caused by this disaster, it is essential to study the Pagentan Sub-district threshold, one of the sub-districts in Banjarnegara Regency, which also experiences many landslides. Based on the research results of



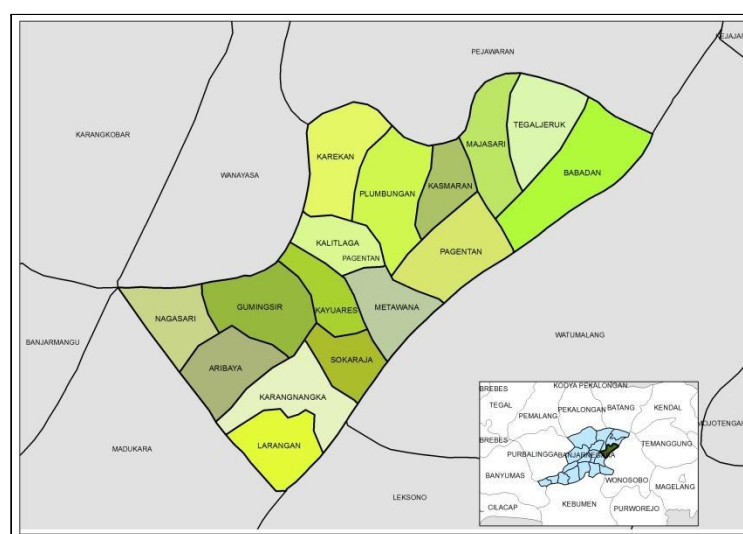
Raditya and Setiawan [3], there are areas in Pagentan Sub-district with high vulnerabilities of landslides, so that it needs to get attention related to disaster mitigation.

Most of the slope collapse or landslides are triggered by extreme rainfall and several researchers have tried to establish a threshold for rainfall intensity in predicting slope collapse or landslides accurately [4]. A global survey shows that the occurrence of landslides in the last 12 months to the end of September 2013 states that more than 90% of the 210 landslide events that damage the world are triggered by heavy rains [5]. The minimum amount of rainfall that can trigger landslides needs to be defined. An empirical approach is needed to calculate the threshold for landslides triggered by rainfall. Landslide threshold can be defined by two approaches, namely a physical approach based on a process and conceptual basis and an empirical approach that uses statistical calculations using historical data as used in the research of Caine [6], Chleborad [7], and Guzzetti [8, 9]. Rain that occurs in an area can cause landslides, and the intensity and duration of rain also affect it. Therefore, it is necessary to conduct a study on the threshold for rainfall that can trigger landslides. A threshold is a minimum or maximum level of some quantity required for a process to occur or a country to change [10].

The importance of determining the threshold value for the intensity of rainfall that can trigger landslides encourages the author to conduct this study in Pagentan Sub-district, Banjarnegara Regency. This study was conducted by developing two empirically calculated threshold methods, including the CT Threshold and ID Threshold methods. Furthermore, the use of remote sensing data can be used for areas that are not covered by rain observation points. Besides, Indonesia, with a wide and varied area, still experiences limited rainfall data, both from the uneven distribution of rain posts and discontinuous data conditions [11].

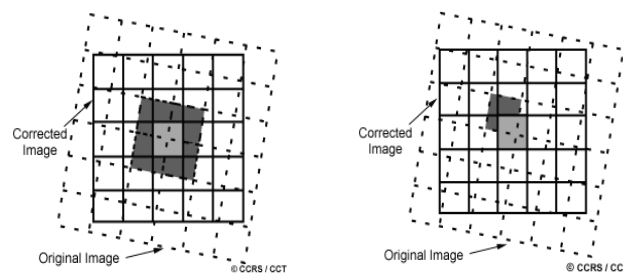
## 2. Data and Method

The location of this research is in Pagentan Sub-district, Banjarnegara Regency, Central Java, displayed in Figure 1. Rainfall data used in this study is rainfall data from NOAA CPC Morphing Technique (CMORPH) [12] with a resolution of  $0.25^\circ \times 0.25^\circ$  and is downloaded from the IRI / LDEO Climate Data Library website [13]. Landslide events data in Banjarnegara Regency was obtained from BPBD Banjarnegara Regency. The length of the landslide events data in this study is 2011 - 2017. This data is a recap of landslide natural disasters which contains the date of the event and the location of the landslide event at the village level.



**Figure 1.** Location of Pagentan sub-district, Banjarnegara regency, Central Java

The daily rainfall data from the satellite before being used in determining the threshold for landslide-triggering rainfall is first resampled to obtain more detailed results due to the large enough resolution of the CMORPH. The method to be used is the bilinear interpolation method and the nearest neighbor (the closest point). Re-sample was performed by reducing the resolution from 0.25 to 0.20, 0.15, 0.10, 0.05 and 0.01. Re-sample was reworked using R-Statistics. Both resample methods are in the raster package [14]. Meanwhile, the data used is downloaded in the net-CDF format (extension .nc), opened with R-Statistics using the ncdf4 package [15]. The resample results will be correlated with the observed rainfall to determine the method and the best resolution. The method and resolution that has the highest correlation will be used in determining the threshold. The nearest neighbor scheme uses the one closest control point where the interpolation value is required, while the bilinear interpolation uses the four closest points [16]. Illustrations of both re-sample schemes are shown in Figure 2.



**Figure 2.** Re-sample schemes; (a) bilinear (b) nearest neighbour.

Determination of the rainfall threshold that triggers landslides uses two methods: Cumulative Threshold (CT) method and Intensity-Duration (ID). The CT method was calculated using a cumulative rainfall of 3 days and 15 days. This is based on Chleborad [17] who assumes that three daily rainfall has played a significant role in developing or triggering landslides. Meanwhile, the 15-day rainfall was chosen after a scatter plot carried out at 5 to 30-day intervals, which revealed that the 15-day plot produced a relatively better lower threshold for landslide initiation. Data on the amount of rainfall for 3 days ( $P_3$ ) and 15 days ( $P_{15}$ ) before the landslide event were collected and then a scatter plot was made to obtain an empirical equation of the rainfall threshold that triggered landslides.  $P_3$  as the X-axis (ordinate) and  $P_{15}$  as the Y-axis (abscissa). A threshold line is drawn from the scatter plot obtained from taking the lower limit between  $P_3$  and  $P_{15}$ , which can be used as a threshold for landslide triggering rainfall. The formula that will be used is as follows:

$$P_0 = P_3 - aP_{15} - b \quad (1)$$

$P_0$  is the potential for landslides to occur,  $P_3$  is the 3-day cumulative rainfall,  $P_{15}$  is the 15-day cumulative rainfall,  $a$  is the slope (slope) of the rainfall threshold and  $b$  is the intercept. If  $P_0$  is positive, it means that the area concerned has the potential for landslides to occur. Meanwhile, if  $P_0$  is negative, it does not have the potential for landslides to occur.

The basis for determining the threshold using ID method refers to the research of Caine [6], who conducted research on determining the intensity and duration of rainfall that can cause landslides. The ID method is the most widely used type of threshold in the literature. The general formula of the ID method is as follows [8]:

$$I = c + \alpha \times D^\beta \quad (2)$$

Where  $I$  is rainfall intensity,  $D$  is rainfall duration,  $c \geq 0$ ,  $\alpha$  and  $\beta$  are parameters. Data on the intensity and duration of rainfall when landslides occurred in Pagentan Sub-district are illustrated in a graph. Then the threshold equation is defined.

### 3. Results

#### 3.1 Re-sample of Satellite Observation Rainfall Data

The data used to calculate the threshold is remote sensing data from CMORPH that has a large resolution for one sub-district study area. Therefore it is necessary to re-sample to reduce the resolution. This step is carried out to detail the current information and aim to be more in accordance with the observed data. The method used is nearest neighbor and bilinear. The correlation table between the two methods, the nearest neighbor and bilinear with the observed rainfall data from the rain station in Pagentan Sub-District, is shown in Table 1.

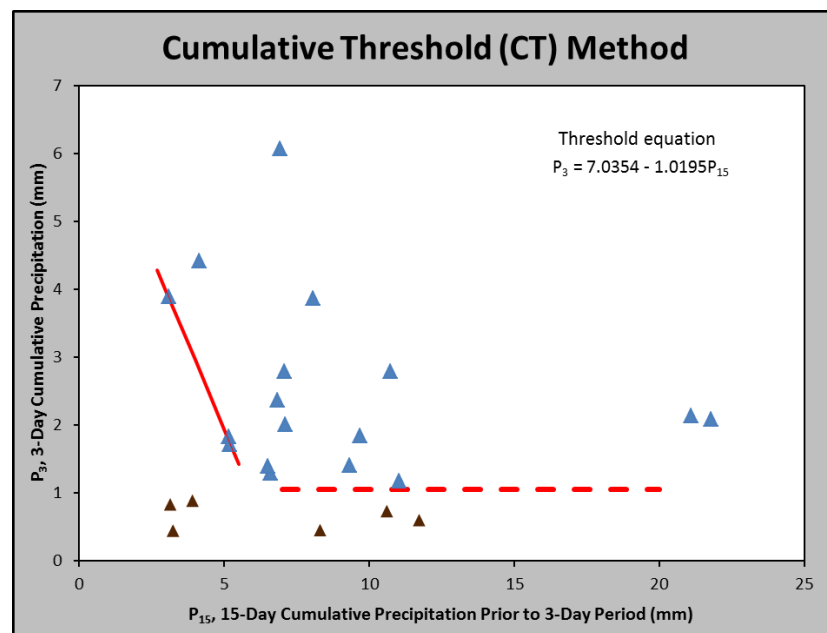
**Table 1.** Correlation of re-sample results and observation data from rain post.

Scale	Nearest Neighbour	Bilinear
<b>0.01</b>	0.326	0.345
<b>0.05</b>	0.326	0.342
<b>0.10</b>	0.326	0.336
<b>0.15</b>	0.326	0.342
<b>0.20</b>	0.326	0.331
<b>0.25</b>	0.326	0.326

The bilinear method shows a more significant and more varied correlation from the table above's correlation results. This is followed by what was stated by Bovik (2009) that the approach with the bilinear interpolation method is smoother than using the nearest neighbor interpolation method. The nearest neighbor method does not show any variation in the correlation value. The correlation value is the same at all resolutions. Meanwhile, the bilinear method shows a more significant correlation value with decreasing resolution. The highest correlation is shown by the bilinear method with a resolution scale of 0.01, namely 0.345. This correlation shows an increase from the original resolution of CMORPH, which shows a correlation value of 0.326. This bilinear interpolation method will then be used to extract rainfall data from CMORPH in calculating daily and diurnal thresholds.

#### 3.2 Cumulative Threshold Method

The CT method uses 3 days and 15 days of cumulative rainfall to identify rainfall thresholds. The threshold graph of the CT method is shown in Figure 3. Of the 23 landslide events in Pagentan Sub-district, rainfall was collected for 3 days and 15 days before the landslide event. The threshold in Figure 3 is a distribution plot of the  $P_3$  and  $P_{15}$  values corresponding to each landslide event. From the distribution plot, the threshold is determined by the equation  $P_3 = 7.0354 - 1.0195P_{15}$ .



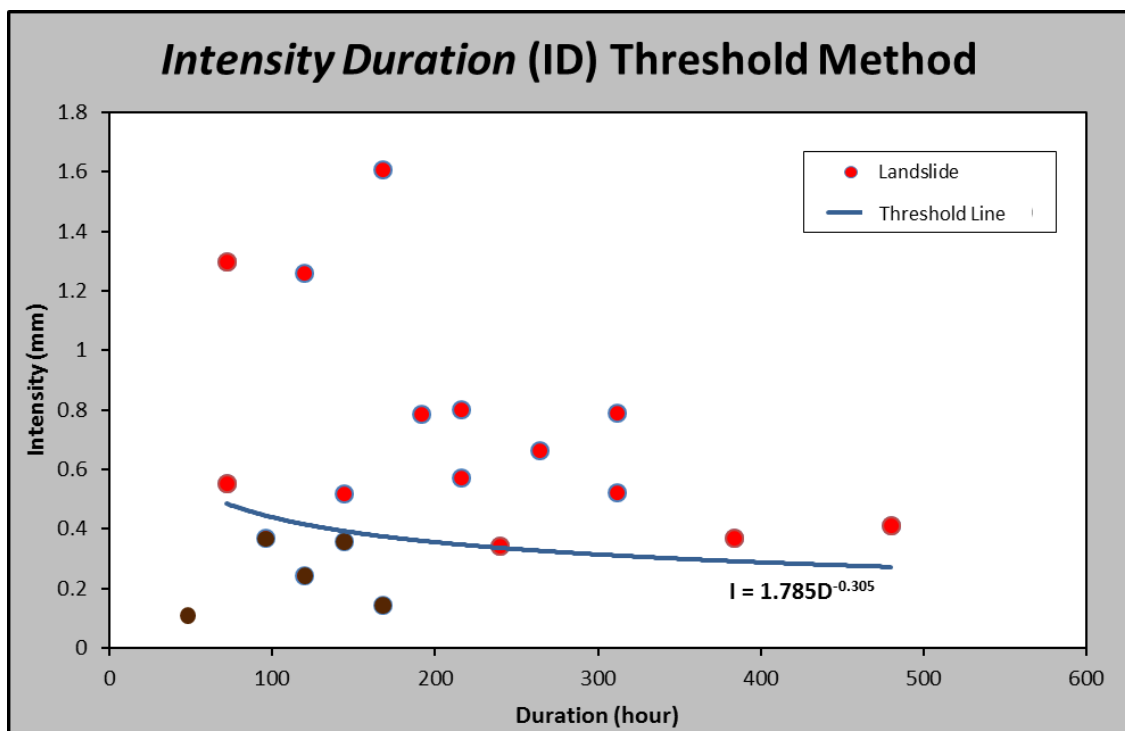
**Figure 3.** Cumulative Threshold for Pagentan Sub-District.

The solid red line is the equation for the threshold and for landslide initiation when the cumulative rainfall of 15 days is 200mm or less. The dashed red line is for 15 days of cumulative rainfall over 200 mm. A blue triangle is a landslide event above the threshold line that has been made, while a brown triangle is a landslide event below the threshold line. The ideal rain threshold will always differentiate between conditions that have the potential for landslides and those that are not. However, several points are outside the rainfall threshold that has been made. Those can happen because of other factors besides rainfall that trigger the landslide to occur. According to Warnadi (2014), events that are below the threshold are estimated to be due to human activity and are supported by the condition of the area itself, which has a very steep slope. Topographic conditions in Pagentan Sub-district do have a steep to very steep slope with medium to large scale soil movements. There are six events that fall below the CT method's threshold line with CMORPH satellite input data. The CT method threshold error was 26.1% (6 events were below the threshold for a total of 23 events). The error in the threshold of the CT method with CMORPH data is greater because this data is much smaller (underestimates) than the observed rainfall from the main post.

### 3.3 Intensity Duration Method

The Intensity Duration method calculates the threshold for landslide-triggering rainfall that uses hourly rainfall intensity and duration data. The data used is 3-hour CMORPH data extracted by the bilinear interpolation method with a resolution of 0.01 using the R Studio application. The 3-hour data is down-scaled to hourly rainfall data by dividing it into three equal parts. The calculation of the duration used in determining the threshold starts when there is rain (rainfall > 0 mm) to the occurrence of landslides. This method is used to determine the intensity and duration of rain that can trigger landslides.

The high intensity of rainfall that occurs and the long duration of the rain can affect soil moisture which can then cause landslides to occur. The relationship between the intensity and duration of rain (duration) before a landslide can interpret the threshold for landslides, which can then be used as a reference for landslide warnings in Pagentan Sub-district. The curves of rainfall intensity and the duration of 23 landslide events in the Pagentan Sub-district are shown in Figure 4.



**Figure 4.** Intensity-Duration Threshold for Pagentan Sub-District.

From the threshold curve of the ID method below, the equation  $I = 1.785D^{-0.305}$  is obtained, where  $I$  is the intensity that can trigger landslides and  $D$  is the duration of rain needed to trigger the landslides. The blue line is the threshold line and the red dot is the landslide event that is above the threshold, while the brown dot is the landslide event that occurred and is below the threshold. The intensity of rainfall that causes landslides in the Pagentan Sub-district ranges from 0.11 to 1.61 mm/hour. Meanwhile, the duration of the rain is between 48 and 480 hours. If only seen from the landslide events above the threshold line, the intensity that causes landslides to occur ranges from 0.34 to 1.61 mm/hour with a duration of 72 to 480 hours.

There are five events that fall below the threshold. Those are because it is suspected that other factors can trigger landslides besides rainfall. These things have been discussed in the previous threshold determination method, namely human activities and the topographical conditions of the area. The five landslides outside the threshold occurred in Kalitlaga Village (3 incidents), Sokaraja and Gumingsir once each. The error of the ID method threshold with the CMORPH satellite rainfall data input is 21.7% (5 events out of a total of 23 events).

The time of peak rainfall before landslides needs to be analyzed. Therefore, hourly rainfall data before landslides were collected. Rainfall intensity data collected is 200 hours before landslides occur. Data are obtained from CMORPH data per 3 hours. The data is then graphed in Figure 5 and grouped into nine-time sections to see the peak rainfall intensity occurring in the hours before landslides occur, as in Table 2.





**Figure 5.** Graph of Rainfall Intensity in 200 Hours Before Landslide Events.

In Table 2, the period is the time (hours) before the landslide where the highest rainfall intensity (peak) occurred in 23 landslides in Pagentan Sub-district. The rainfall intensity graph 200 hours before the landslide event for each event can be seen in Figure 5. The highest frequency of peak rainfall intensity (peak hour) occurs in 97 to 120 hours before the landslide event. There are six events with peak rainfall intensity that occur at that time.

Meanwhile, if one looks at each graph, the peak rainfall intensity generally occurs at the 66th and 114th hours before landslides occur. There were three landslides with peak rainfall intensity at both times. From the graph, it can also be seen that the peak rainfall intensity ranges from 3.4 mm/hour to 21.7 mm/hour. This peak rainfall intensity can be used as a reference for creating landslide warnings. If the intensity of rainfall increases or reaches the average value of 23 historical events, then in a few hours, landslides will occur. This warning can be used to prepare for landslides that may occur.

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**Table 2.** Peak hour intensity of rainfall before landslides occur.

No	Period (hours)	Frequency
1	0-24	3
2	25-48	3
3	49-72	4
4	73-96	1
5	97-120	6
6	121-144	2
7	145-168	4
8	167-192	0
9	192-200	0

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#### 4. Conclusion

The landslide threshold in Pagentan sub-district, Banjarnegara Regency, Central Java has been analyzed using remote sensing data from CMORPH with the Cumulative Threshold and Intensity Duration methods. CMORPH data were extracted and re-sampled using the bilinear interpolation method with a resolution from 0.25 to 0.01. The re-sample results successfully increased the correlation between the CMORPH rainfall data and the observation rain post data from 0.326 to 0.345. Based on 23 landslide events during 2011 - 2017 in Pagentan Sub-district, the threshold for landslide-triggering rainfall was calculated using the Cumulative Threshold method with CMORPH rainfall data obtained the equation  $P3 = 7.0354 - 1.0195P15$ . From this method, the error of the threshold is 26.1%. More than 70% of 23 landslide events are above the threshold line. Calculation of the threshold using the Intensity-Duration method obtained the threshold equation  $I = 1.785D - 0.305$ . From this method, the error of the threshold is 21.7%. The error of the Intensity-Duration method is lower than the Cumulative Threshold method. The peak hour of the highest rainfall intensity occurs in the period of 97 to 120 hours before the landslide event. For further studies, it is necessary to conduct research that combines empirical and physical bases to understand better the factors that influence landslides in the Pagentan sub-district.

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