

EVALUATION OF DRIFTWOOD GENERATION IN THE NORTHERN KYUSHU HEAVY RAIN IN 2017 BY LOGISTIC REGRESSION

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ABSTRACT

We tried to develop a model to calculate the amount of driftwood generation from a given watershed area in a specific heavy rain event. In this research, slope failure dataset in the Northern Kyushu Heavy Rain in 2017 was used for the logistic regression model to estimate the possibility of slope failure generation. In this model, C-X band radar precipitation, geographical data, geological data, and land use data were adapted. As a result of the present research, it is found that the best model can express the slope failure in the heavy rain with very high accuracy. In addition, the model can estimate the driftwood generation from 10 rivers with 20% of accuracy the model.

Keywords: driftwood, logistic regression analysis, slope failure, Northern Kyushu Heavy Rain in 2017

1. INTRODUCTION

Recently, historical recorded heavy rain disasters have occurred in Japan, such as, the West Japan Heavy Rain in 2018, the Typhoon *Hagibis* in 2019, and the Northern Kyushu Heavy Rain in 2017. These heavy rains may be caused by the progress of global warming. In these flood events, not only inundation, but also deposition of sediments and driftwoods were widely seen in the devastated area. Thus, river manager requires to evaluate the risk of floods with sediments and driftwoods influence in the heavy rain event.

In this research, we tried to develop a new model to estimate a possibility of slope failure as a source of driftwood generation in a given watershed area. The dataset of slope failure area in the Northern Kyushu Heavy Rain in 2018 was used for the development, because a lot of the simultaneous generation were seen in the event. The Logistic Regression model was applied as a multivariable statistical way to express the possibility of slope failure generation under a given precipitation condition.

2. THE NORTHERN KYUSHU HEAVY RAIN IN 2017

The Northern Kyushu Heavy Rain in 2017 occurred in Asakura City, Toho Village (Fukuoka Prefecture), and Hita City (Oita Prefecture) on July 5, 2017. The heavy rain was caused by the *linear precipitation zone* due to the Baiu front and the high sea surface temperature (SST) in the East China Sea. The maximum total accumulative precipitation was recorded as 894mm at the rain gauge of *Kitashoji Kominkan* by Fukuoka prefectural government. Also, 586 mm and 402.5 mm of the total precipitation were recorded at the rain gauges of *Asakura* and *Hita* by JMA, in which the normal values of monthly total precipitation in July were 354.1 mm and 333.4 mm, respectively.

In the heavy rain, the historical recorded driftwood generation was occurred as 20,000 m³/km² as an amount of driftwoods per area from a single mountain stream area. It broke the previous record as 1,000m³/km² for a coniferous tree. According to the report for the policy to restore the devastated area [MILT and Fukuoka Prefecture, 2018], many slope failures significantly occurred in areas mainly composed of plutonic rock (granodiorite) and metamorphic rock. It was known that the failure area ratio, which was defined as a ratio of collapse area to basin area, was high in the Sozu River and Shirakitani River composed of the kinds of rock. In

addition, the increase of the failure area was seen under the condition that each accumulative precipitation exceeded 100mm/1h, 250mm/3h, 350mm/6h, 400mm/12h, and 450mm/24h.

Yano *et al.* (2018) reported a result of a multivariate analysis to show a relationship between the rate of slope failure of each mountain stream and a few factors. They showed that the maximum 3 hours or 6 hours accumulative precipitation and slope inclination indicated the significant correlation to slope failure, that is, driftwoods generation in the rainfall event.

3. METHODOLOGY

3.1 The survey targets

As shown in Figure 1, survey targets of the analysis are several river basins of the Ihome River, the Katsura River, the Myoken River, the Kita River, the Naragaya River, the Sozu River, the Shirakitani River, the Akatani River, the Ohi River, and the Kuro River. Those rivers are tributaries on the right side bank of the middle Chikugo River, which is the largest river in Kyushu region. Generation of driftwoods due to slope failure occurred in these river basins during the flood. Each of the basins can be divided into mountain stream areas.

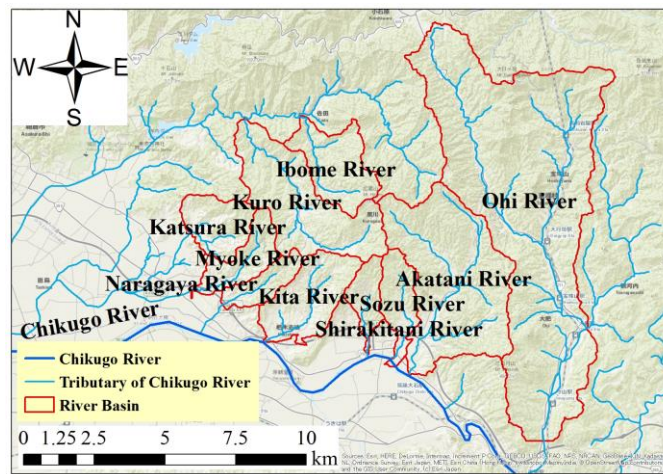


Figure 1. The river basins as a survey target

3.2 Evaluation of the possibility of slope failure

We try to develop a slope failure probability evaluation model using the logistic regression analysis. All factors related to generation of slope failure which can be treated as a spatial distribution dataset are introduced to the developed model. Generally, the logistic regression model can be expressed as Eq.(1).

$$P(z) = \frac{1}{1 + \exp(-z)} = \frac{\exp(z)}{1 + \exp(z)}, \quad z = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n \quad (1)$$

where, $P(z)$: possibility of the objective variable z , β_i : regression coefficient, and X_i : explanatory variables.

Table 1. Examples of the combination of X_i

		case20	case21	case22	case23	case24	case20	case21	case22	case23	case24	
coefficient of determination							0.3997	0.3968	0.307	0.3107	0.4089	
intercept							-13.4719	-11.7139	-7.38794	-8.12986	-17.4159	
inherent factor	an angle of inclination	○	○	○	○	○	0.043606	0.052081	0.034386	0.034238	0.053126	
	sectional curvature	○	○	○	○	○	-15.683	4.81206	-18.6578	-19.1047	3.477268	
	geology	volcanic rock	○	○	○	○	○	0.053588	-0.61927	-0.95539	-0.98608	-0.3442
		plutonic rock	○	○	○	○	○	0.355472	0.251173	0.721172	0.711803	0.088236
		metamorphic rocks	○	○	○	○	○	0.437201	0.555266	0.391972	0.400206	0.515042
	cumulative flow						0	0	0	0	0	
	land cover	① grassland	○	○	○	○	○	1.236709	1.379762	1.339182	1.320539	1.364957
		② deciduous hardwood	○	○	○	○	○	1.03072	0.938538	0.828437	0.832068	0.951718
		③ evergreen hardwood	○	○	○	○	○	0.286283	0.143633	0.23272	0.238543	0.163669
		④ evergreen conifer	○	○	○	○	○	0.363511	0.086872	0.076015	0.089207	0.150757
⑤ bare ground		○	○	○	○	○	-11.997	-11.7202	-11.5315	-11.5447	-11.6938	
	①+⑤						0	0	0	0		
trigger	precipitation	1 hour				○	0	0	0	0	0.066495	
		3 hours	○				○	0.047909	0	0	-0.02188	
		6 hours		○			○	0	0.025578	0	0	0.035618
		12 hours			○		○	0	0	0.011907	0	-0.01997
		24 hours				○	○	0	0	0	0.011927	0.019078

In the present research, the logistic regression model is used to estimate the possibility of slope failure $P(z)$ in each square grid of 30 m mesh in the target river basins. from the division of mountain stream. We introduced the spatial distribution dataset for the geographical data such as the slope inclination angle from 10 m DEM data [Geospatial Information Authority (GSI) of Japan], the geological map [MLIT], the land cover map [JAXA-EORC], and the maximum accumulative precipitation for 1, 3, 6, 12 and 24 hours from the C-X band radar precipitation [MLIT]. We choose 38 combinations for the explanatory variables as shown in Table 1 as an example.

In the present heavy rain event, MLIT made slope failure map. But, the map includes disappearance of data for slope failure generation. Thus, we modified it by using other information [GSI] of the slope failure and deposition of the sediments form them. Using GIS (ArcGIS), the total number of meshes including slope failure areas was clarified as 3,659 meshes, and the number of meshes not including them was 209,257. In application of the logistic regression model Eq.(1), both numbers of the meshes should be equal. Therefore, 3,659 non-collapsed meshes were selected by random sampling. 20 trials of the random selection were performed to reduce a bias for them. It was confirmed that there was no bias in the random sampling.

The regression coefficients β_i for each cases with different X_i combinations were evaluated. Then, the best model was chosen from a few statistical ways for reproduction of the slope failures.

4. RESULT AND DISSCUSSION

As a result of the analysis adapting the logistic regression model, case 24 was selected as the best model in the present research. Table 2 shows the list of the values of β_i for the case 24. The case includes almost all explanatory variables.

Table 2. Regression coefficient β_i of case24

		case24	
coefficient of determination		0.4089	
intercept		-17.41595	
inherent factor	an angle of inclination	0.0531261	
	sectional curvature	3.4772678	
	geology	volcanic rock	-0.344199
		plutonic rock	0.0882362
		metamorphic rocks	0.5150422
	cumulative flow	0	
	land cover	①glassland	1.3649568
		②deciduous hardwood	0.9517178
		③evergreen hardwood	0.1636693
		④evergreen conifer	0.1507565
⑤bare ground		-11.69381	
①+⑤	0		
trigger	precipitation	1 hour	0.0664949
		3 hours	-0.021877
		6 hours	0.0356183
		12 hours	-0.019965
		24 hours	0.0190775

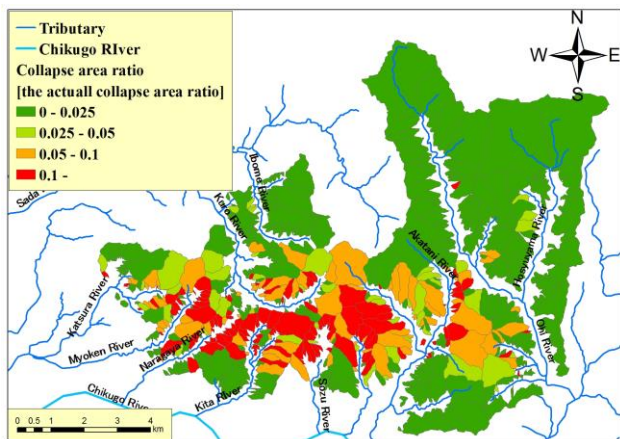


Figure 2. Map of actual slope failure area ratio

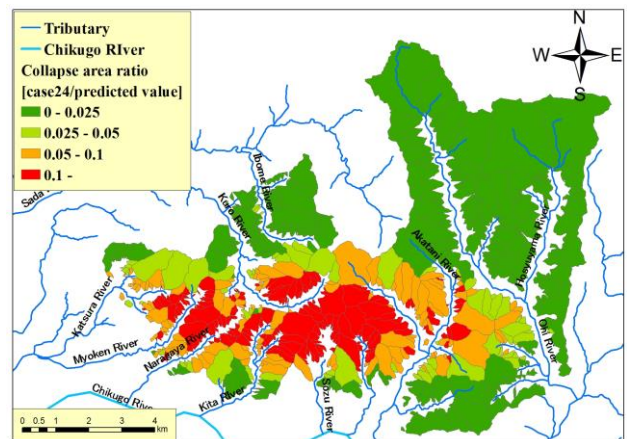


Figure 3. Map of estimated slope failure area ratio in the optimal case (case24)

Figure 2 shows the spatial distribution of the actual slope failure area ratio in each mountain stream. Figure 3 shows the estimated spatial distribution from the optimal case (case 24). The case 24 can reproduce the actual results. In addition, other good cases with high reproducibility were chosen. These cases also included the

maximum accumulative precipitation for 3 hours or/and 6 hours. 3 hours and 6 hours can be considered as the most significant precipitation to generate a slope failure in the present heavy rain event.

Finally, the amount of driftwood generation V in each river was calculated from the estimated slope failure in the case 24. It is calculated by Eq.(2).

$$V = \beta_w A_{sf} \quad (2)$$

where, β_w : volume of standing trees per unit area, and A_{sf} : surface area of slope failure. In the present research, $\beta_w = 54,900 \text{ m}^3/\text{km}^2$ is adapted. The value was also introduced to the estimation of the driftwood amount by MLIT as a constant, because the value in an artificial forest was able to be calculated using the system by Fukuoka Prefectural Government.

Figure 4 shows a comparison between the estimation of driftwood generation in each river by the model and the actual its generation by MLIT. These estimation shows result with accuracy of 20%.

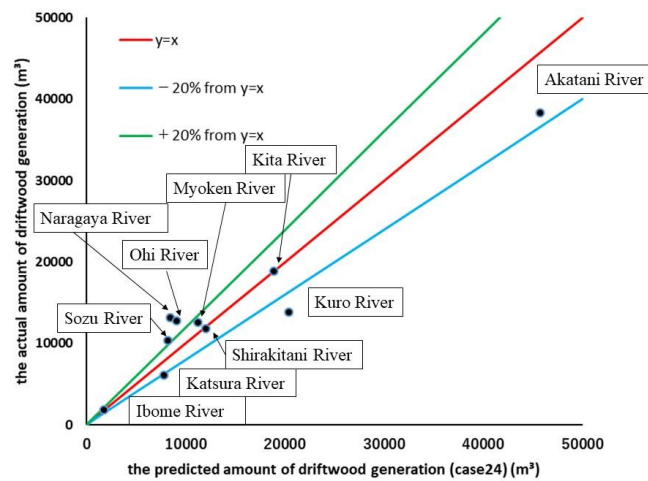


Figure 4. Comparison between estimation and actual record for driftwood generation for each river

However, in the case including multi precipitation variables like the case 24, some regression coefficient for accumulative precipitation shows negative value such as 3 hours and 12 hours accumulative precipitation in the case 24 (Table 2). It may be caused by the multicollinearity among accumulative precipitation. Therefore, improvement of the model is necessary in the further research.

5. CONCLUSIONS

We attempted to evaluate the possibility of slope failure occurrence by logistic regression analysis in the Northern Kyushu Heavy Rain in 2017 to estimate the driftwood generation in a given river. As a result, it was succeeded to reproduce the slope failure in each mountainous stream and driftwood generation from each river. The effectiveness of the model was confirmed as a new estimation of driftwood disaster risk in a heavy rain event. In the present research, all rivers data were used to develop the Logistic model. In further research, we will attempt to confirm the proposed model applicability by adapting it to other big flood events, e.g., Western Japan Heavy Rain in 2018, and heavy rain by the Typhoon 1919.

ACKNOWLEDGMENTS

This research was supported by JSPS KAKENHI, Grant-in-Aid for Scientific Research (A) (19H00812), the River Fund of the River Foundation, Japan in 2018 and 2019, the Research Fund of the Foundation of River & basin Integrated Communications (FRICS) in 2018, and the Social Implementation Program on Climate Change Adaptation Technology (SI-CAT) of MEXT, Japan.

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