Copula-based bivariate statistical characteristics for post-fire heavy rain in Kamaishi in 2019

Tohoku University Student Member ○ DONG HAOYU
Kyoto University Member Yoshiya TOUGE
Tohoku University Student Member KE SHI

1. INTRODUCTION

Located in the monsoon region, Japan is very wet and receives heavy rains almost every year which may cause much damage. On the other hand, although the wet weather in Japan prevents the severity of the wildfire disaster in Japan from being particularly high, it is necessary to assume that heavy rain will follow after the wildfire occurs.

Heavy rains and wildfires are considered the main types of natural disasters, and much research has been done on these extreme events. At the same time, people are also focusing on compound disasters, which are two types of disasters independently occur at the same place, causing enhanced damage severe than a single disaster.

A preconditioned event is one classification of compound disaster, which is one disaster can lead to an amplified impact, only because of a pre-existing condition. As an example, the disaster that occurred in Kamaishi city is a preconditioned event, caused by the 2017 wildfire and the 2019 typhoon that brought heavy rain. The aim of this research is (i) to investigate bivariate statistical characteristics of a post-fire heavy rain event in Kamaishi area, and (ii) to find the relationship between the frequency and the severity of the post-fire heavy rain event.

2. STUDY AREA

The target area is in Kamaishi city, located in northeastern Japan, where the average annual rainfall is 1,693 mm. The city is prone to wildfire in the dry spring.

2.1. Wildfire in Ozaki Peninsula

In May 2017, the wildfire on the Ozaki Peninsula in Kamaishi City, which burned 413 ha, was the largest wildfire in Japan since 1995, regarded as the extreme wildfire in Japan. **Fig 1** shows the burnt area in Kamaishi area.

Fig.1. Burnt area by the Ozaki Peninsula wildfire

2.2. Typhoon Hagibis in 2019

In 2019, Typhoon Hagibis hit Kamaishi city, causing heavy rains. **Fig 2** shows the rainfall recorded at Kamaishi meteorological station during Typhoon Hagibis, which is about 5 to 6 km from the burnt area. The 3-hour precipitation of 147.5 mm and the 6-hour precipitation of 230.0 mm were the highest on record at the station since the observation started in 1976.

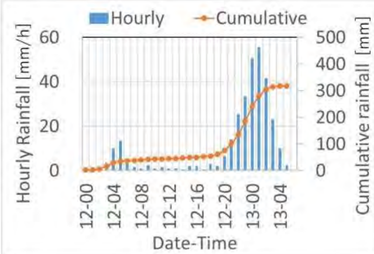

Fig. 2. Rainfall during Typhoon Hagibis at Kamaishi station

3. METHODOLOGY

3.1. Data Collection

In this study, I will obtain the information of the burned area of the Fire through the Fire and Disaster Management Agency, and the Japan Meteorological Agency to obtain the information of rainfall.

As for the rainfall data, I will select the hourly rainfall in Kamaishi area, select the maximum rainfall in 24 hours every day, and sum it up to the maximum rainfall in 24 hours every month. For wildfire research, I will log all burnt area data in Iwate prefecture as input data.

3.2. Copula based analysis

For the analysis of Copula, the cumulative distribution function (CDF) of rainfall and wildfire is required first.

I used the L-moment program package of R Studio to calculate, respectively fitting the input data, and selected the function with the highest fitting degree from 8 functions (GEV, GUM, LN3, GLO, NOR, WEI, PE3, EXP) as the output data.

For the calculation of Copula fitting, I used the Copula program package of R Studio to calculate, fitting the CDF of wildfire and heavy rain, and selected the function with the highest fitting degree from 5 functions (CLA, FRA, GUM, AMH, JOE) as the output data and then output the figure to do the analysis.

The goodness of fit will be calculated separately by plot correlation coefficient (PPCC) for L-moment and root mean square error (RMSE) and Akaike information criterion (AIC) for Copula. The functions are written as follows:

$$PPCC = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(M_i - \overline{M})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2 (M_i - \bar{M})^2}} \quad 1)$$

$$RMSE = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(P_e - P_t)^2} \quad 2)$$

$$AIC = 2D - 2l \quad 3)$$

where, X_i and M_i are the ordered observations and the order statistic medians, P_e and P_t are empirical cumulative probability and theoretical cumulative probability, D is the

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Tohoku University, 6-6-20 Aoba Aramaki, Aoba-Ku, Sendai 980-8579, Japan. Tel & Fax: +81-22-795-7455

number of parameters of the statistical model, l is the log-likelihood value of the best parameter set.

4. RESULTS AND DISCUSSION

4.1. Result of the CDF of single disaster

With the help of R- studio, the result can be plot easily. The goodness of fit are shown in **Fig 3**.

Type	Function	Goodness of fit indices ppcc	Type	Function	Goodness of fit indices ppcc
Monthly 24h max Rainfall	GEV	0.99371	Burnt area	GEV	0.99541
	GUM	0.98885		GUM	0.98998
	LN3	0.92944		LN3	0.97797
	GLO	0.98247		GLO	0.98892
	NOR	0.92649		NOR	0.98438
	WEI	0.99774		WEI	0.99655
	PE3	0.99824		PE3	0.99563
	EXP	0.99688		EXP	0.95372

Fig. 3. The goodness of fit of CDF

After input the data, the monthly 24h max rainfall is best fitted by function PE3, and the burnt area data of Iwate is best fitted by Weibull function.

4.2. Result of the fitting of Copula

Also using R-studio, after input the result of CDF, the result can be plot easily. In these 5 functions, the goodness of fit is shown in **Fig 4**.

Function	Parameters θ	Goodness of fit indices RMSE	AIC
CLA	34.6	0.0183	-1499.388
FRA	36.9	0.0172	-1523.702
GUM	-18.4	0.0239	-1400.006
AMH	46.2	0.0406	-1200.614
JOE	56.7	0.0239	-1400.006

Fig. 4. The goodness of fit of Copula

And the Copula figure is shown in **Fig 5**.

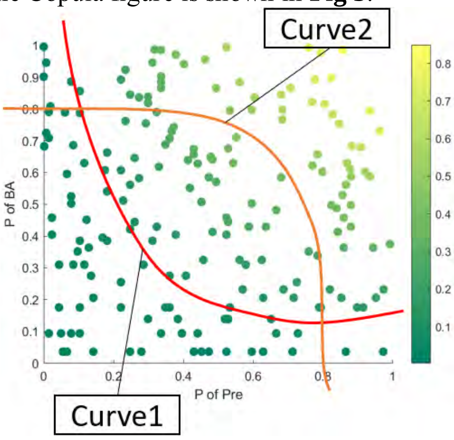

Fig. 5. Copula joint probability

The two curve have different meaning. In the top half of curve 2, the destruction caused by these events is relatively large. It includes the extreme single disaster of heavy rain and wildfire and also the compound disaster of large wildfire heavy rain. The events below curve 1 are more likely to occur. It can be easily found that the probability of the compound disaster is very high (dark green on the chart). By this chart we can find that for the compound disaster the rarity is not physical severity.

As the Copula analysis need the months of two kind of data correspond. The time gap problem is still hard to solve. Also, one important point which cause the damage of the heavy rain being enhanced is the change of soil hydraulic properties. The water repellency will create a discrete layer of variable thickness and spatial continuity which is hard for water to get through. The existence of water repellency may be one of the main reason of the landslide caused by post-fire heavy rain event.

5. CONCLUSIONS

From the above explanation, we can conclude as follows:

The Copula fitting joint distribution function is focusing on the probability of compound disasters rather than the probability of single extreme disasters.

A single extreme disaster is less extreme than a joint of two moderate disasters (Less destructive than single extreme disaster) in Copula analysis.

Rainfall and wildfires in the fitting Copula are month corresponding but actually there was a two-year gap between heavy rain and wildfire in the Kamaishi event. Time gap need to be taken into account. We are still thinking how to deal with the time gap.

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