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Impacts of climate change on shallow landslide and sediment runoff in Kyushu district, western Japan

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1. Objective
In mountainous forest areas, roads or railroads and local inhabitants often suffer from shallow landslides and debris flows along torrents, while rainfall in the area obviously increase supposedly due to climate change. On this point of view, we are intrigued to elucidate the response of landslide and sediment runoff to climate change. Therefore, time series analysis of shallow landslide distribution in a sample area, monitoring of the sediment runoff including debris flow from shallow landslides, analysis of its response to rain, and long term rainfall fluctuation analysis were conducted, in order to evaluate the impact of rain increment induced by climate change on shallow landslides and sediment discharge.

2. Method and target areas
Rain observation by pluviometer for 30 years and sediment discharge (periodical observation) monitoring over 3 years with sediment trap facilities were conducted in Fukuoka (Northern Kyushu). On the other hand, shallow landslide analysis using aerial photographs for typical 3 years, rain and sediment discharge monitoring were conducted in Miyazaki (Southern Kyushu) for 30 years at hydroelectric power dams. Both of these areas are located in Kyushu district, western Japan where they often have severe landslide disasters. The geology in research areas consists of Paleozoic and Mesozoic rocks (mainly schist, Phyllite, sand stone) and the vegetation consists of mainly Japanese cypress and cedar. Theoretical analysis with physical equation and statistic analysis with Kendall's rank correlation are conducted with the data obtained in these areas.

3. Result and consideration
1) Increase of heavy rainfalls and their frequency observed
They are obviously increasing in every point for 30 years. In particular, extremes of daily and hourly rain often have clear tendency confirmed by Kendall's rank correlation analysis with statistic test. Their increasing rate is almost up to 20mm/hr or 40mm/day in 30 years, and frequency of extreme rain "Ri" heavier than 40mm/hr is found to be 1.5 multiplied.
2) Impact on shallow landslide density N/A
Shallow landslide density N/A is theoretically evaluated with following equation derived from the analogy with thermodynamics.
C/A = (ai•N)/A = Re•C1•(R-Ro)Exp(C2)
Here, "Exp" designates exponent.
N: landslide frequency, ai: average scale of each landslide, A: watershed area, C1,C2: Constants related to precipitation pattern, Re: Relief energy of the basin, Ro: Rainfall loss. The observed results clearly fit to the equation and for sample area we obtained next values; C0•Re•C1/ai = 9Exp(-22), Ro=0.0 and C2=7.58.
Also, theoretically, sediment runoff discharge from landslides Qsl is proposal to N in way of next semi-empirical formula.
Qsl = f•vi•N, f = (I)Exp(0.4)/(A)Exp(0.2 or 0.3)
vi: sediment volume of each landslide, f: runoff ratio, I: slope of the stream bed.
In our study, sediment runoff Qs includes debris flows originated from stream bed sediment. Therefore, Qs is in direct proportion to Ri•R, not to R.
3) Impact on sediment runoff discharge Qs

Sediment runoff discharge is expressed by next equation derived from hydraulic principle.

$Qs/A = M \bullet Ri(t) \int (Ra \bullet \cos)dt$

here, Qs: sediment runoff discharge, A: watershed area, M: function concerning with sediment deposit features on the upstream torrent (porosity, torrent bed slope gradient, sediment accumulation length and depth, cohesion), t: time, : torrent bed slope gradient, Ri, Ra: instant precipitation. If the time integral is made over the rainfall duration, then $\int (Ra \bullet \cos)dt = R \bullet \cos$; R: total rainfall, Ri: rain intensity over 1 hour. Therefore, $Qs = C \bullet Ri \bullet R$, ($C= A \bullet M \bullet \cos$). Hence, theoretically Qs can increase with increment of Ri and R.

This relationship is substantiated with observed data in our research areas and they sufficiently fit the equation with the constant C ranged from 4.8 to 20.5.

4) Increase of observed sediment runoff

It increased definitely with the rate of approximately 200,000m3 in 30 years in accordance with the rainfall increment. This tendency is credited by Kendall's rank correlation analysis as a purposive increase.

3. Conclusion

Since the shallow landslide density in our sample area is in direct proportion to R and the sediment runoff in torrents is in direct proportion to Ri•R, the increase of rainfall Ri, R due to climate change with the increasing rate such as 20mm/hr or 40mm/day in 30 years surely has strong impact on shallow landslide occurrence rate and sediment discharge.