2018 年北海道胆振東部地震により発生した斜面崩壊と土砂堆積の関係性
Linkage between landslides and sediment accumulations caused by 2018 Hokkaido Eastern Iburi earthquake

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1. INTRODUCTION

Sediment accumulations within channels by earthquake-induced landslides alter both short- and long-term sediment dynamics in watersheds (Hovius et al. 2011). By investigating > 1000 debris flows after the 2015 Gorkha earthquake in the Nepal Himalaya, Dahlquist and West (2019) identified that 501 debris from landslides in steep channels were flushed out to lower basins during the first monsoon after the earthquake. Koi et al. (2008) found that sediments associated with landslides by 1923 Kanto earthquake remained within channels over 80 yr and affected contemporary sediment discharge.

Sediments produced in headwater catchments are not only flushed out to downstream, but also deposited within channels (Kasai et al. 2004) depending on the sediment dynamics. Sediment budget in headwater catchments depends on the episodic sediment supply by landslides and debris flow and in-channel accumulation (Dietrich and Dunne, 1978). By investigating sediment yields in watersheds from 10^{-1} to 10^{1} km^2 in Sarugawa watershed, Shimizu (1998) suggested that sediments in larger watersheds tended to be retained for a long time to evacuate compared to smaller watershed, because of increasing in locations for retentions from up to downstream.

Despite importance of landslides in sediment storages (Fan et al., 2019), linkages between landslides occurrences and associated in-channel sediment accumulations in terms of locations and amounts are poorly understood. Spatial variability of landslide occurrence and sediment accumulation is key information for predicting long term sediment dynamics after the episodic sediment recruitment (De Vente et al., 2013). Thus, we examined (1) the spatial variability of earthquake-induced landslides and in-channel sediment accumulations, and (2) linkage between landslides and sediment accumulations.

2. METHODOLOGY

This study was conducted in 40.2 km^2 Habiugawa watershed located in south central Hokkaido, Japan. The area was affected by landslides induced during the Hokkaido Eastern Iburi earthquake in 2018. The watershed is located 13 km north of the epicenter with 0.12 km^2/km^2 of landslide area density. Mean annual precipitation and temperature are 1028 mm and 7℃, respectively (AMeDAS Atsuma, 1991-2020). The land is mostly covered by secondary conifer and deciduous forest, and partially by golf park. The topography is hilly associated with long-term landform development by paleo-glacial erosions and fallout volcanic ash. Altitude ranges from 30 to 440 m; mean hillslope and channel gradients are 30º and 10º, respectively. Several active fault lines are crossed through the watershed. Landslides mostly occurred at depths from 1 to 2 m below pumice layers formed by the Mt. Tarumae eruption 9000 yr ago (Ta-d), with total soil depths from 2 to 3 m.

Sub-watersheds were defined as upstream area at each tributary confluence along the Habiugawa river. Based on field observation and DEM, we defined drainage area < 0.01 km^2 as zero-order basin (Tsukamoto, 1998). For each sub-watershed units, we calculated landslide area density (LAD: landslide area divided by watershed area) to examine intensity of landslide using the 0.5 m LiDAR-based DEM and the 0.2 m orthophotos of post-earthquake. To examine in-channel sediment accumulations by landslides, we used deposit length ratio (DLR: total length of channel impacted by sediment deposits divided by total channel length within watersheds). In-channel sediment accumulations were assessed as distinctive rough surface topography based visual delineation on 0.5 m DEM.

3. RESULTS

We identified 2941 landslides with 1620 m^2 mean (20 to 34710 m^2). Sub-watersheds < 0.1 km^2 (n = 67) had wide ranges in landslide area density (LAD: 0.00 to 0.80 km^2/km^2) with 0.22 km^2/km^2 of mean and 0.20 of standard deviation (SD). For sub-watersheds from 0.1 to 0.5 km^2 (n

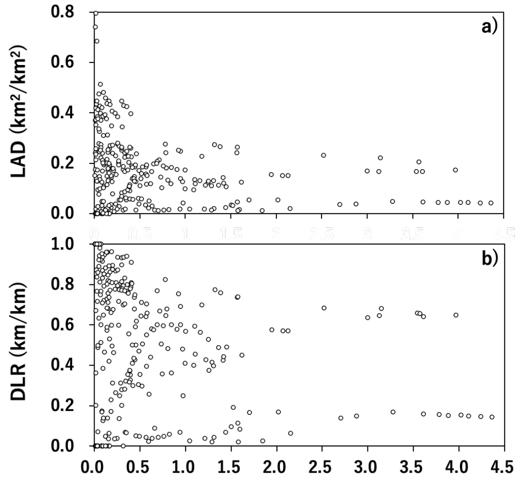

Figure 1. LADs and DLRs in different watersheds

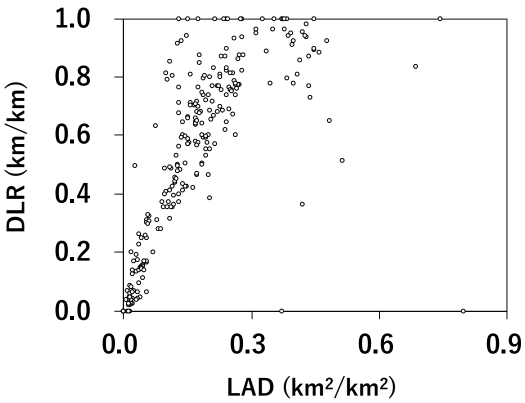

Figure 2. Relationship between LAD and DLR

= 115), mean and SD of LAD were 0.18 and 0.12 km^2/km^2, ranging from 0.00 to 0.46 km^2/km^2 (Fig. 1a). Once sub-watersheds were greater than 0.5 km^2 (n = 95), ranges of LADs were small from 0.01 to 0.28 km^2/km^2 with 0.12 and 0.08 of mean and SD.

Deposit length ratios (DLRs) in sub-watersheds < 0.1 km^2 were varied from 0.0 to 1.0 km/km (mean = 0.59, SD = 0.41), similar to ranges in sub-watersheds from 0.1 to 0.5 km^2 (0.00 to 0.96 km/km: mean = 0.57; SD = 0.30) (Fig. 1b). Ranges of DLRs in sub-watersheds from 0.5 to 2.0 km^2 (n = 73) were slightly small, ranging from 0.02 to 0.82 km/km with 0.42 and 0.25 of mean and SD. Relatively constant DLRs with ≈ 0.6 or 0.1 km/km occurred in sub-watersheds > 2.0 km^2 (n = 22).

LADs tended to increase with increases in DLRs at given sub-watersheds with LADs up to 0.3 km^2/km^2 (Fig. 2). Once LADs were greater than 0.3 km^2/km^2, DLRs appeared to be highly varied.

4. DISCUSSION

Although landslide area density (LAD) in the entire Habiugawa watershed (0.12 km^2/km^2) was higher than that in other earthquakes (e.g., Wenchuan earthquake: 0.03, Dai et al., 2011), LADs differed depending on sub-watersheds with < 0.1 km^2. Such variabilities were possibly associated with susceptibility for landslides by earthquakes. For instance, Kasai and Yamada (2019) confirmed that landslides spread north-northeast directions from the epicenter, compatible with fault lines. Indeed, a 0.10 km^2 sub-watershed with high LAD (0.48 km^2/km^2) in the study site were located at near faults (50 m), compared to a 0.12 km^2 sub-watershed with low LAD (0.01 km^2/km^2) located far from faults (2000 m).

A relationship between LADs and deposit length ratios (DLRs) indicated contribution of landslide materials to in-channel sediment accumulations. Positive correlation between LADs and DLRs suggested that increases in landslide materials from hillslope elevated sediment accumulations within channels, particularly in small sub-watersheds (≤ 0.5 km^2). Because earthquake-induced landslides are generally less mobile compared to rainfall-induced landslides (Saito et al. 1995), most of recruited sediment from hillslope could be accumulated within channels adjacent to the hillslopes due to limited transports. The findings that LADs > 0.3 km^2/km^2 did not correspond to DLRs implied that sediment accumulations were associated with not only landslides, but also other fluvial processes. Because of high landslide density and steep channels, most of the sediments were possibly evacuated form the channels and mobilized toward further downstream, resulting in low DLRs despite high LADs. The other possibility was related to longer total channel lengths in larger watersheds, increasing channels without accumulations despite high intensity of landslides. Such differences in landslide occurrences and their accumulations within channels depending on sub-watersheds may alter sediment propagation from headwaters to downstream. These findings provided important insights into development of methods for predicting subsequent sediment transports and their long-term monitoring in earthquake-affected areas (Wasowski et al., 2011).

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