Comparison of the occurrences of landslides between orange groves and forests on landslides induced by the heavy rainfall 2018 in Uwajima City, Japan

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1. Introduction

Landslide is a frightful and destructive natural disaster; the number of landslides tend to increase over the time. Comprehending the landslide susceptibility of the targeted area is an initial and important processes when developing disaster mitigation plans. The type of ground cover is a key factor in the susceptibility of landslides induced by rainfall.

The fruit groves such as orange groves or apple orchards are composed of trees which are same as forests. However, several practical land managements are conducted in fruit groves which possibly alter the landslide susceptibility. Few studies evaluated landslide susceptibility in fruit groves. The evaluation would be essential for policy makers to develop a plan of land use in regions here fruit groves will be developed.

The objective of this study was to evaluate the susceptibility of landslides in fruit groves in a part of Uwajima city, Ehime prefecture, Japan. In this area, tangerine orange plantations have been widely distributed in mountainous areas and heavy rainfall caused many landslides in July, 2018.

2. Material and methods

2.1 Study site

The study was conducted in the northern part of Uwajima city, Ehime prefecture, Japan (Fig.1). The total area is 30.28 km^2, occupying 6.5% of Uwajima city. There was a heavy rainfall event from July 1 to July 8, 2018. At the Uwajima station (4.4 km from the southern of the study site), the total rainfall was 578.0 mm; the maximum hourly rainfall, observed from 06.00 to 07.00 on July 7, was 49.0 mm. The rainfall event induced huge numbers of landslides in several cities of Ehime prefecture, particularly in Uwajima city. We found 162 points of landslide with 0.16 km^2 of total landslide area.

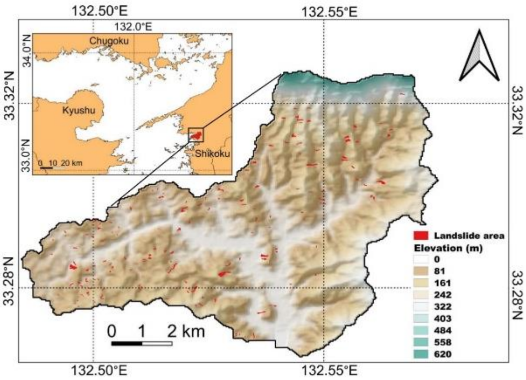

Fig. 1 Location of the study and landslide distribution in July 2018

2.2 Data preparation

We used the landslide inventory map (LIM) developed through 1:25000 aerial photography. We also used map of slope gradient, slope aspect, Normalized Different Vegetation Index (NDVI), land use, geology. Slope gradient and aspect were calculated from a Digital Elevation Model. Land use map in 2016 originally consist of 6 categories (i.e., forest, paddy field, other agriculture, barren land, building and transportation areas). We used the original classification for examining the landslide density, afterwards we reclassified them as forest, other agriculture (mainly orange groves), and the others. Geological classification consists of sandy turbidite, muddy turbidite, turbidite, limestone block and chert block. MLIT XRAIN rainfall dataset were used for developing rainfall distributions. We downloaded rainfall data for each 10 minutes during July 1 – 8, 2018, and calculated the 1-h, 3-h, 12-h, 24-h maximum rainfall, and total rainfall.

2.3 Data analysis

First, we evaluated the differences in the possibility of landslides among categories using landslide area density (LAD). Second, we develop the logistic regression models to determine the effect significancy of each conditioning factor. We set landslide points at the point with the highest elevation for each landslide, whereas the non-landslide points were selected randomly in areas without landslides. We used training sets (80% of data) and testing sets (20% of data). Five models (i.e., the models 1-5) with different rainfall indices (i.e., 1-h, 3-h, 12-h, and 24-h maximum and total rainfall). Akaike's Information Criterion (AIC) was used for selection of experimental variables, subsequently the models were evaluated by Area Under Curve (AUC).

3. Results

Most of landslide area was distributed on gentle terrain. 78.5% of total landslide areas located on the slope gradient of 0° to 24° (Fig. 2a). LAD in southern-east and southern facing slopes tended to be larger than that in western and northern facing slopes (Fig. 2b). According to Fig. 2c, LAD in small NDVI was lower than that in large NDVI. Subsequently, the highest LAD was found on other agriculture among the types of land use (Fig. 2d). LAD for the sandy turbidite was more than twice as large as the muddy turbidite and turbidite (Fig. 2e).

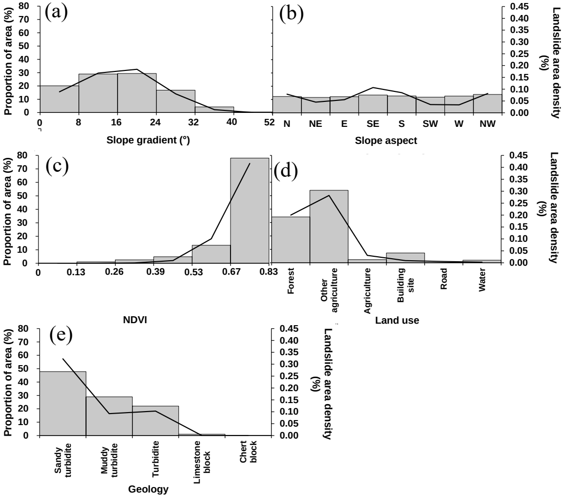

Fig. 2 The proportion of area (bars) and landslide area density (line) on each category of causative factors; (a) slope gradient (°), (b) slope aspect, (c) NDVI, (d) land use, and (e) geological types

Generally, Fig.3 compared LADs among forests, orange groves, and the others for each category (or level) of the slope gradient, slope aspect, NDVI, and geology. For slope aspect (Fig. 3b), NDVI (Fig. 3c), and geology (Fig. 3d), LAD for orange groves was larger than LAD for all categories or levels. For the slope gradient (Fig. 3a), LAD for orange groves was larger than LAD for forests on gentle slopes (< 24°); inversely smaller on steep slopes (>25°).

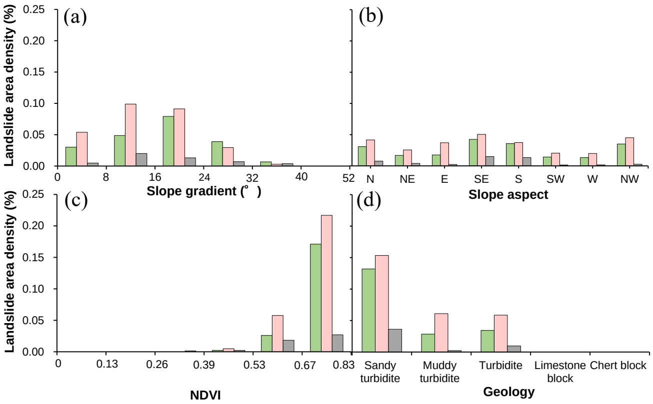

Fig. 3 Landslide area density of different land use types (forest, other agriculture, the others) on classes of slope gradient (a), slope aspects (b), NDVI (c), and geology (d)

Table 1 Coefficients of explanatory variables selected in the model 1 and the models 2-5.

Variable	LR Coefficient	
	Model 1	Models 2 - 5
Slope gradient	-	-
Slope aspect	-	-
NDVI	-3.32^{***}	-3.79^{***}
Forest	-	-
Other agriculture	0.11	0.14
Sandy Turbidite	-0.12	-0.13
Muddy Turbidite	-	-
Rainfall	0.01^{*}	-
AIC	313.7	318.5

Note:
(-) : eliminated variables by stepwise regression process
***: p-value < 0.001
** : p value < 0.01
* : p value < 0.05

Simulation by logistic regressions (Table 1) showed rainfall was selected as a significant factor only on the model 1, and NDVI was selected as a significant factor in all models. In addition, other agriculture and sandy turbidite were selected for all models. The AIC value of the model 1 was lower than that the models 2-5. AUC value of the model 1 and the others were 85.0%, 79.8%, respectively (Fig. 4).

4. Discussion

We found that this area has a highest LAD, even though there was inconsiderable difference between orange groves and forests (Fig. 2c). The LAD on orange groves was obviously larger than forests for most levels or categories of slope gradient (Fig. 3a), NDVI (Fig. 3c) and geology (Fig. 3d). In addition, the orange groves of an explanatory variable in landslide susceptibility models. These results are consist with previous studies reporting the mass displacement mainly occurred on the orange groves and conversion from forests to orange groves increased landslide area [1][2].

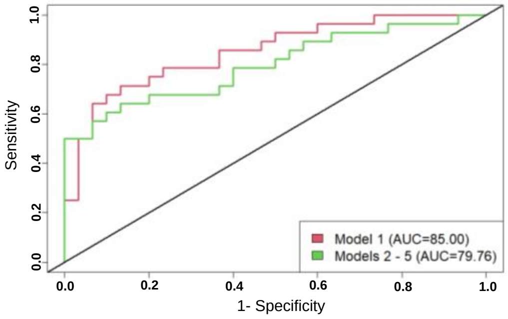

Fig. 4 Receiver operating curves (ROC) with the value of Area Under Curve (AUC) for the model 1 and the models 2-5

Considering the implemented land management of the orange groves, the following treatments may be the reason for higher landslide susceptibility in orange groves than in forests. First, soil compaction by mechanized tillage may increase the pressure of pores and the gravity force, and the effective normal stress which controls the soil shear strengths will gradually decrease [3]. Second, orange groves are often developed on cut or fill slopes. In general, man-made slopes are more susceptible than natural slopes. Third, irrigation may be conducted, which keeps soil water content high. Fourth, orange groves are composed of a species which have a weak root network system in terms of soil binding capacity [4]. Based on our results, we suggest that it is better not to develop orange groves in slopes along houses or public facilities.

NDVI and 1-h maximum rainfall were selected as the most causative factors (Table 1), and the model with 1-h maximum rainfall has higher accuracy than the others (Fig.4). According to Fig.2c, the significant difference of LAD on each NDVI's group was found that included NDVI as a significant factor. 1-h maximum rainfall was selected because it has a positive relationship with LAD than others. In addition, the highest rainfall indices on this period tended to be on the western site where orange groves areas have been dominantly distributed. Thus, it was reasonable if 1-h maximum rainfall was selected as the best real-time rainfall to be inserted in the landslide model.

References

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