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Developing methods for evaluating spatial distribution of soil depth for Slope Stability Analysis

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1. INTRODUCTION

Soil depth is considered one of key factors for affecting the occurrence of landslides and resultant debris flow (Wu and Sidle, 1995; Dietrich *et al*., 1995). Because soil indicates availability and storage of water in soil matrix as well as runoff and groundwater flow, deflagration of sediment disasters directly depends hydrological conditions and processes in soil matrix in a given hillslopes and watersheds. Hence, soil depth extremely varies extensively depending on where it forms. On flattened terrains, they are shallower while on slopes where material is redistributed due to gravity, deeper layers may form. Slope gradient, length, direction and curvature moreover vegetation play an important role in variation of the soil depth. For instance, Roering *et al.* (2010) analyzed the variation of soil depth and demonstrated the influence of vegetation not only on topographic features but also on subsurface characteristics, since the depth varied according to the density and reach the roots.

Various methods had been developed for estimating soil depth various location with a given watershed. Existing methods can be classified into (1) field methods and (2) mathematical and statistical approaches. For instance, using Knocking Pole test method, Kim *et al.* (2016) showed that soil depth can be assessed through the of penetrometers, especially when applied to shallow soils with 0,3 to 2 m. Moore *et al.* (1993) used quantitative relationships between soil properties and the environment are based mainly on linear regression and artificial neural networks in Colorado at Sterling in Logan County. Both field and mathematical methods have advantages and disadvantages for identifying the spatial patterns of soil depth. Indeed, the field methods provide point information and thus require the mathematical methods to generate more comprehensive information about the whole area of study. Mathematical methods, in turn, require field data to calibration and validation.

Despite the difficulty for estimating soil depth, soil depth is an important input parameter in slope stability analysis. In a physically-based analysis, an infinite-slope concept is usually adopted with the defined physical parameters of the study area, and information of the spatial distribution of soil thickness in the valley is required to perform the slope–instability analysis (Michel and Kobiyama, 2015). For overcome the problems of investigating soil depth, characteristics of spatial patterns of soil depth need to be investigated. Therefore the primal objective of this study is to estimate the soil depth based on field investigations (knocking pole test) and using morphometric analysis. Based on the findings of this study, we will propose the method for including the patterns of soil depth for improving the slope stability analysis.

2. STUDY AREA AND METHODOLOGY

This study was conducted in a 9.5 ha catchment area in Hofu City, south of Yamaguchi Prefecture. Geology of catchment is consisted by fine-grained biotite granite and granodiorite. Mean annual precipitation and temperature was 1802mm and 15.3 °C, respectively. Vegetation of these areas is mainly Japanese red pine (Daimaru *et al.*, 2011). On 21 July, 2009, the heavy rainfall induced a 241 landslides and debris flow with 330mm with 48hours (hourly rainfall of 63.5mm and daily rainfall of 275mm), consequently fourteen casualty in Hofu City by the debris flow (Wakatsuki *et al.*, 2010).

Digital evaluation model (DEM) with contour lines with 1-m intervals was developed by the air-born LiDAR investigation in 2014. The interpolation method used was: TOPOGRID in ArcGIS 10.4.1. From the DEM-derived catchment analysis obtained, several parameters were calculated, such as the Slope angle, Elevation and Wetness index. We also obtained Topographic Wetness Index (TWI) through the TOPMODEL method proposed by Beven and Kirkby (1979) in SAGA GIS. The morphometric factors that control the distribution of landslides in the study area were analyzed from the Frequency (F), Scar Concentration (SC) and Landslide Potential (LP) indices (Gao, 1993). Frequency (F) is the ratio between the number of cells of each class and the total number of cells in the basin. The Scar Concentration (SC), ratio of the number of cells of each class affected by the slides and the total number of cells of the basin that were reached; Landslides Potential (PE), ratio between the number of cells affected by landslides and the total number of cells in that class. We also delimited the erosion zone and deposition zone of the landslides was done using an aerial photograph (obtained in 2010).

To measure soil depth, was used a knocking pole test which consists of several 0.5 m flights of a 15 mm diameter stainless steel rod, with a cone diameter of 25 mm and a weight of 5 kg with etched graduations every 10 cm (Kim *et al.*, 2016). The penetration resistance value, Nd (drop/10 cm), was computed as the number of blows required to penetrate 10 cm. The soil depth in the study site was measured in the vertical gravitational direction with measurements made at 151 points (15m intervals) along the slope (the inside and outside of the landslide area). The position and elevation of each soil sample were georeferenced using a global positioning system.

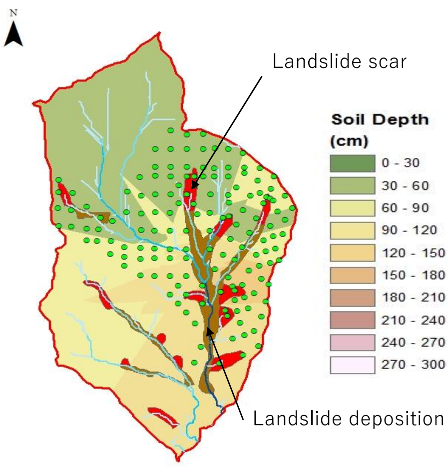

Fig.1 Soil depth distribution in 9.5 ha catchment in Hofu

3. RESULTS AND DISCUSSION

3.1) Geomorphic pattern of landslide occurrence

Topographic analysis showed that elevation ranging from 208 - 225m was the high and affected to the location of landslide scar. With respect to the slope gradient, 59% of landslide scars are concentrated between the 30º - 45º angles, although highest Landslide potential (LP) occurred above 45º with 12 % . These pattern of our findings agree to the findings by Guimarães (2000). For the TWI, the most frequent class occurred 15.9m²/º-16.5m²/º (28.3%). Hence, the high value of LP was found in 19.6m²/º - 21.8m²/º (13.8%). The highest values of scar concentration were not corresponding to TWE. Based on the study in the northern region of Turke with 50 cm to 2–3m soil depth, Yilmaz (2009) found that TWI for the most frequent landslide was 3.3m²/º and 3.8m²/º which was lower than our studies sites.

3.2) Soil depth distribution and characteristics

The soil depth based on Nd value 20 ranged from 0.3 m to 3 m with mean value of 89cm, in which thin soil was found on the narrow ridges and thick colluvium accumulated at the bottom of the valley (Fig 1). Uchida *et al.* (2009) compared the vertical Nd distributions between locations outside and inside shallow landslides and found that soil layers with Nd values ranging from 5 to 20 were not detected at locations inside landslides at their study site. They suggested that soil depths with Nd $\leq$ 20 be defined as soil layers with the potential to rupture and soil depths with Nd $\geq$ 20 be defined as bedrock layers. Yamakawa *et al.* (2010) suggested that the bedrock was defined as the layer with Nc exceeding 100 in granitic regions. Based on these previous studies, we further conducted analysis for identified the weathered soil layer and the bedrock (granite). We assumed that the Nd40 to Nd100 values was highly weather bedrock which is possibly the formation low permeable layers (potential landslide surface), Fig 2. After the calculate 15 points, mean depth of Nd100-Nd40 was 1m with 0,75 of standard deviation. In general, it can be observed that in the depth of weathered bedrock changed depending on the depth, being able to be related to the rock property changes (granite).

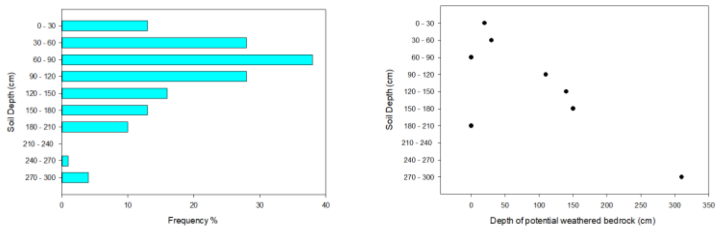

Fig. 2 Soil depth and depth of potential weathered bedrock

4. CONCLUSIONS

Although various studies showed the total soil depth of soil by using a knocking pole method, our approach proposed the method for estimating the depth of weather bedrock layers which is a key for landslide occurrences. Our findings and method is further confirmed by the field for the presence of weathered bedrock layers. We will conduct both field and laboratory analysis for testing the applicability for improving the slope stability model.

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