Preliminary study on mountain slope partitioning addressing the hierarchy of slope unit using DEMs with different spatial resolution

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Abstract—**This study proposed a procedure of mountain slope partitioning for landslide hazard assessments that addresses a slope unit hierarchy. This study was undertaken to validate the procedure of slope partitioning using DEMs with different spatial resolution by comparing the relation between the average slope angle and relative height of each slope unit in the Akaishi Mountains and the Shikoku Mountains, Japan. We used DEMs of three types with spatial resolutions of ca. 50 m, 30 m, and 10 m grid cells. In general, individual slope units are partitioned by drainage and divide lines. We therefore newly defined an order of divide lines and partitioned slope units. Divide lines were regarded as catchment boundaries. The order of divide lines was defined according to frequency of divide lines that were extracted as catchment boundaries from DEMs, with changing area conditions of catchment identifications. By partitioning slope units with these divide and drainage lines, slope units therefore showed a relative hierarchy corresponding to the order of divide lines. These procedures were validated and cross-checked using both different spatial resolution DEMs and the different study areas, considering the relation between slope angle and relative height of each unit. Partitioned slope unit maps revealed inclusive relations among the hierarchies: a slope unit consisted of units with a low-order hierarchy, and was included in a high-order hierarchy. A scatter diagram of slope angle and relative height of each slope unit revealed a concentrated distribution that corresponds well to previous studies. This distribution was confirmed in both different DEMs and the study areas. These results demonstrate that the procedure of slope partition is useful to identify the same slope unit using DEMs of different kinds, and in different areas.**

I. INTRODUCTION

Many studies have analyzed landslide susceptibility using GIS [e.g., 1, 2]. In these studies, it is worth discussing the criteria for selecting the terrain-unit (or mapping unit). By definition, the terrain-unit must be mappable at effective cost over the entire region through criteria, as objectively as possible. When this is accomplished, all subsequent analyses will refer to and treat each terrain unit as a spatially homogeneous domain in terms of both the instability factor and the landslide hazard degree [3].

Terrain units of various types have been used: geomorphologic units, grid cells, unique condition units, sub-basins, and slope units. Among these, a slope unit is appropriate for landslide hazard assessment because a clear physical relation exists between landslides and the fundamental morphological elements of hilly or mountainous regions. The individual slope units are also partitioned by drainage and divide lines [3]. However, some limitations are associated with the difficulties in manually identifying slope unit boundaries, namely drainage and divide lines, and in selecting the spatial scale of the slope unit (slope unit area). It is necessary to find the most appropriate spatial scale of slope units for studying landslides.

Recently, DEMs of various kinds have become available with different spatial resolutions. It is also meaningful to propose a method that can identify the same slope units using DEMs of different kinds. The objectives of this study were to partition slope units automatically using DEMs with different spatial resolutions and to compare these results obtained for the Akaishi Mountains and the Shikoku Mountains, Japan. This study also proposed a procedure of mountain slope partition for landslide hazard assessments, addressing a hierarchy of slope units. We then validated the results by comparing the relation between the average slope angle and the relative height of each slope unit in both different DEMs and study areas.

II. Study area and Data

This study investigated the Ohi River Basin (1,280 km^2) in the Akaishi Mountains, and the Niyodo River Basin (1,560 km^2) in the Shikoku Mountains, Japan (Fig. 1). The Ohi River Basin is ranges from 0 to 3,189 m (Fig. 1a). The Niyodo River Basin ranges from 0 to 1,982 m (Fig. 1b).

This study used ca. 50 m and ca. 10 m grid-cell DEMs provided by the Geographical Survey Institute of Japan. We also used ASTER G-DEM, with ground resolution of ca. 30 m, distributed by Earth Remote Sensing Data Analysis Center, Japan.

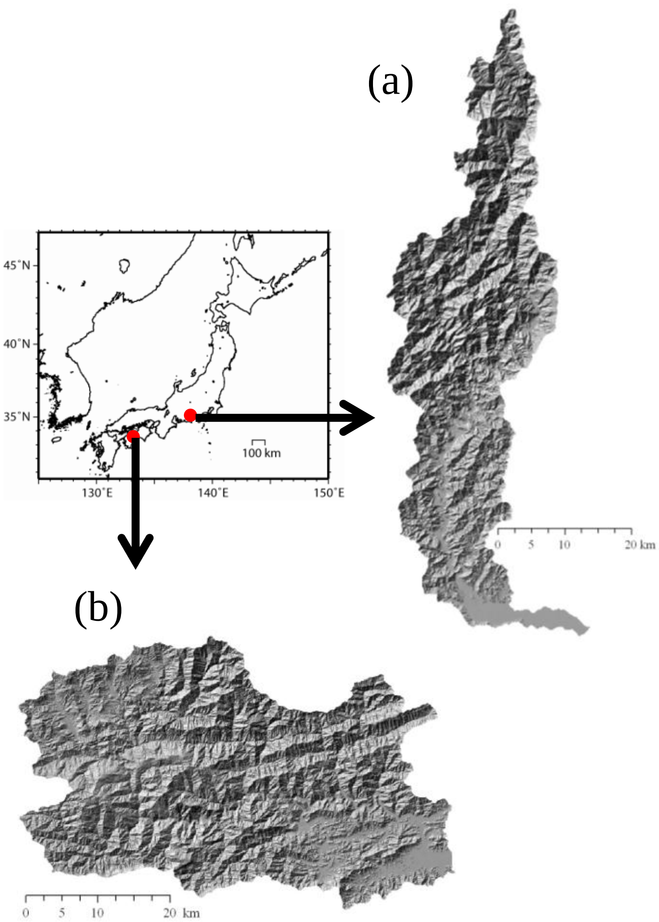

Figure 1 Study areas (a, Ohi River Basin; b, Niyodo River Basin).

III. Method

Slope units were partitioned by the drainage and divide lines (Fig. 2): each slope unit was characterized by hydrologic and morphometric parameters. Drainage and divide networks were defined automatically from DEMs using ArcGIS (ESRI) and our original C language programs [2]. Namely, the direction of surface water flow and the drainage networks were obtained from DEMs using a flooding type algorithm [4] that identified the down-slope direction for each cell. Catchments were then derived from these drainage networks. Divide lines were regarded as the catchment (or sub-basin) boundaries. We also extracted main drainage lines, which have the largest flow length in a catchment. By overlaying the drainage and divide lines, we partitioned the study area into slope units (Fig. 2).

To partition slope units, the area (spatial scale) of the slope unit should be considered. We therefore newly defined a relative order of divide lines and partitioned slope units using these boundaries. The order of divide lines was defined according to the frequency of divide lines that were extracted as catchment boundaries from DEMs, with changing area conditions of catchment. To derive catchment in this study, we defined the catchment area using five conditions: 0.1–1 km^2, 1–10 km^2, 10–100 km^2, 100–1,000 km^2, and 1,000–10,000 km^2. Therefore, the divide lines which were identified as catchment boundaries five times were defined as the fifth-order divide lines, whereas the divide lines identified as catchment boundaries only one time were defined as the first order divide lines, the latter corresponding to small mountainous watersheds.

By partitioning slope units with these divide and drainage lines, slope units had relative hierarchy (1st–5th) corresponding to the relative order of divide lines (1st–5th). These procedures were validated and cross-checked using both DEMs with different spatial resolutions (50 m, 30 m, and 10 m grid cell) and the different study areas (Ohi River and Niyodo River basins), considering the relation between the average slope angle and the relative height of each slope unit.

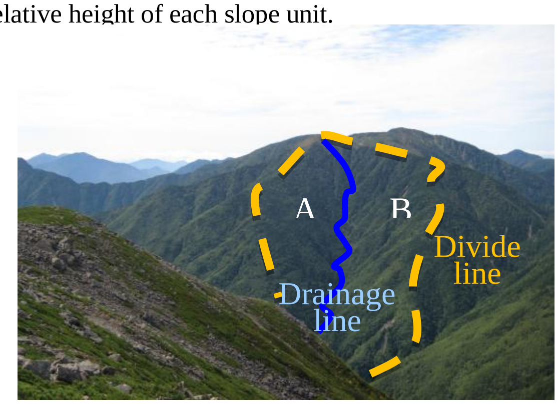

Figure 2. Example of slope units partitioned (A and B units) by drainage and divide lines (Ohi River Basin).

IV. RESULTS AND DISCUSSION

By overlain drainage lines and divide lines that showed the relative hierarchies, the study area was partitioned into slope units, which also had relative hierarchies according to those of divide lines (Fig. 3).

Partitioned slope unit maps showed inclusive relations among hierarchies: a slope unit consisted of units with a low-order hierarchy, and was also included in a high-order hierarchy (Fig. 3). These results were confirmed both in DEMs with different spatial resolutions (50 m, 30 m, and 10 m grid-cell) and different study areas (Ohi River and Niyodo River basins).

Figs. 4 and 5 showed scatter diagrams of the average slope angle and the relative height of each slope unit in the Ohi River Basin using 50 m, 30 m, and 10 m grid-cell DEMs. For this study, we defined the relative height as the difference between maximum height and minimum height of a slope unit. A specific distribution was found in the relation between the average slope angle and relative height: with increasing average slope angle, the relative height of slope unit increases. However, the maximum average slope angle was about 35 deg. The same relation is confirmed in other hierarchies (Fig. 4). We also confirmed the relation both in the results obtained using DEMs of different kinds (Fig. 5), and in the Niyodo River Basin. These results show that the procedure of slope partition is useful to identify the same slope unit using DEMs of different kinds, and in different study areas.

In Figs. 4 and 5, relations among the average slope angle, relative height and landslide occurrence of each slope unit indicated that landslides occurred in slope units where an average slope angle is around 35 deg and the relative height is larger.

These results agree well with those of previous studies [e.g., 5, 6], which analyzed the relation between slope angle and height. Especially, Katsube and Oguchi (1999) [6] reported that the modal slope angle in the Akaishi Mountains (Ohi River Basin) tends to be around 35 deg. The angle of mountain slopes under rapid uplift tends to increase with progressing valley erosion. However, if hillslopes exceed 35 deg, more hillslopes become extremely unstable and are easily eroded by both shallow failure and bedrock erosion [2, 6].

The results in this study therefore indicate that landslides occurred in the specific slope where the average slope angle is around 35 deg, and for which the relative height is around its upper limits. These characteristics, which should be verified using other topographic and lithological parameters, will be useful for landslide hazard assessment.

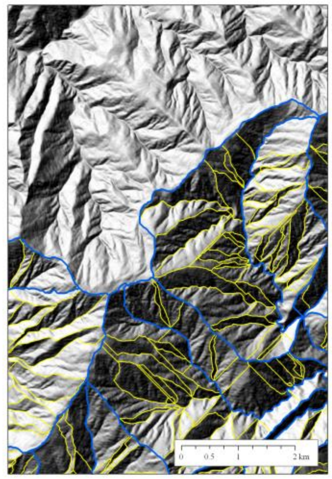

Figure 3. Enlarged map of partitioned slope units and those hierarchies around Fig. 2 (Ohi River Basin). Two hierarchies are displayed: yellow and blue polygons respectively show first and second units.

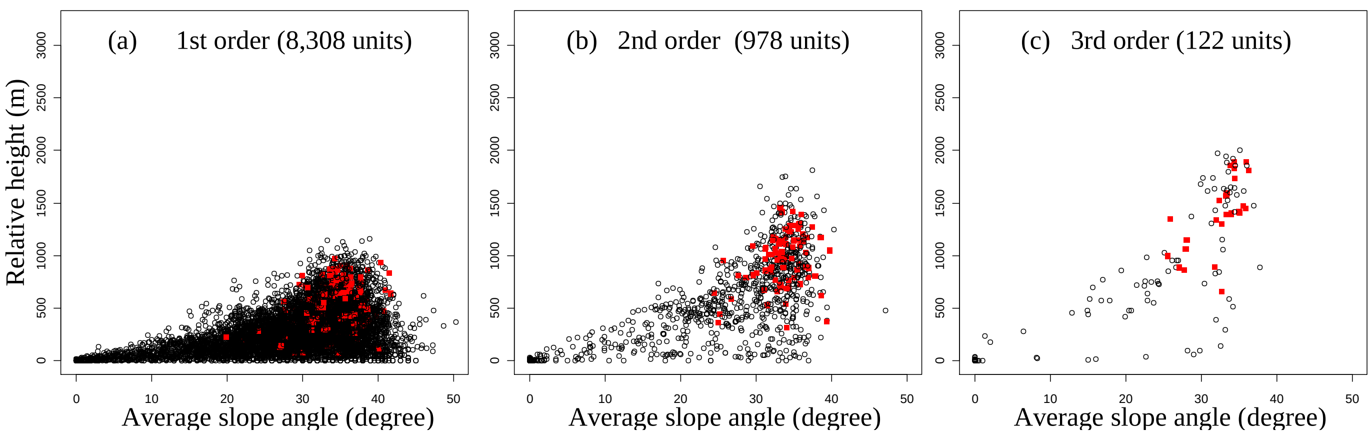

Figure 4. Relation between the average slope angle and the relative height of first (a), second (b), and third (c) order slope units using 50 m grid-cell DEMs in the Ohi River Basin. Red circles show slope units with landslides during 1992–2002 [2].

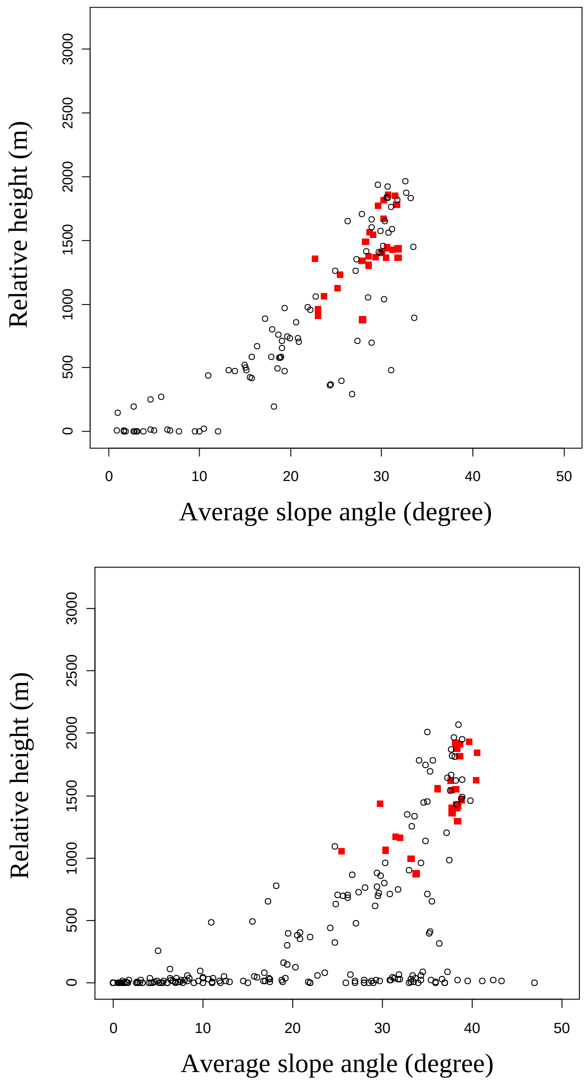

Figure 5. Same as Fig. 4(c), but using 30 m (a), and 10 m (b) grid-cell DEMs.

V. CONCLUSION

By partitioning slope units with drainage and divide lines, the study area was partitioned into slope units where relative hierarchies (1st to 5th) were also identified according to those of divide lines. The partitioned slope unit revealed inclusive relations among hierarchies. These results were confirmed in both DEMs with different spatial resolutions (50 m, 30 m and 10 m grid cells) and the different study areas (Ohi River and Niyodo River basins). In the Ohi River Basin, relations among the average slope angle, relative height and landslide occurrence of each slope unit indicated that landslides occurred in the specific slope unit where the average slope angle (35 deg) and relative height were around their respective upper limits.

We can therefore conclude that the slope unit partition proposed in this study was reasonable for landslide hazard assessments. Further studies should examine the hierarchies of slope units from a geomorphologic perspective and assess landslide hazards using each spatial scale of a slope unit.

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