

Chapter 2

Spatial Comparison of Two High-resolution Landslide Inventory Maps Using GIS—A Case Study of the August 1961 and July 2004 Landslides Caused by Heavy Rainfalls in the Izumozaki Area, Niigata Prefecture, Japan

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Abstract The spatial distribution of shallow landslides in the Izumozaki area, Niigata, caused by the heavy rainfalls in August 1961 and July 2004 was investigated using high-resolution ortho-photoimagery and a 2-m DEM. We found that the number of the August 1961 landslides is more than twice the July 2004 landslides. More than half of the July 2004 landslides (about 70% as the number ratio and 54% as the area ratio) were primary landslides. These primary landslides seem to occur randomly regardless of the geological structure of the stratum. The large landslides which occurred in July 2004 were often expanded landslides immediately higher than the August 1961 landslides. These expanded landslides often occurred on daylighting dip slopes. Among the July 2004 landslides, the ratio of landslides along roads is very high compared to 1961 (1961: 4.2%; 2004: 16.4%).

Keywords Landslide · Ortho-photoimagery · LiDAR

2.1 Introduction

In this section, research of GIS analyses for shallow landslides caused by heavy rainfalls in Izumozaki Town, Niigata Prefecture in Japan is introduced. The authors investigated spatial distribution of shallow landslides in the Izumozaki area caused

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by heavy rainfalls in August 1961 and July 2004 using high-resolution ortho-photoimagery and a 2-m DEM from ground-based LiDAR data (Iwahashi and Yamagishi 2010).

We utilized commonly used GIS software, spreadsheet software, and statistical software. The applied skills were very simple: digitizing, overlaying, and creating graphs and tables. However, without recent advances in technology of spatial data creation such as ortho-photoimagery and high-resolution DEMs by LiDAR, the research would have not been carried out because the innovation of data creation and GIS brought enough positional accuracy of landslide inventory data. In addition, without past continuous studies of local research such as field geological surveys, referred to in the Reference, the research also would not have been carried out.

We mainly used landslide distribution data directly digitized from 50-cm digital ortho-photoimagery. Moreover, a 2-m DEM of LiDAR surveyed in November 3, 2007, was overlaid. Although the LiDAR DEM was surveyed after the July 2004 heavy rainfalls, Saito (2007) revealed that majority of landslides in the study area occurred in shallow surfaces whose thicknesses were less than 3 m. Therefore, we suppose that there is no major problem for surveying terrain attributes by the DEM. Two-meter resolution makes it possible to compare landslide polygons and topographical features of individual slopes.

2.2 Study Area

Figure 2.1 shows the location and a lithological map of the study area. The study area lies on fold mountains of sedimentary rocks and is dominated by steep slopes.

The study area lies on four sheets of 1:50,000 geological maps. We compiled four geological map sheets (Kobayashi et al. 1993; Kobayashi et al. 1995; Kobayashi et al. 2001; Takeuchi et al. 2004) referring to descriptions of the geological maps before producing GIS data of the lithology (Iwahashi and Yamagishi 2010).

The dominant lithology in the study area is sedimentary rocks of Miocene to Pleistocene: interbedded sandstone and mudstone with thick sandstone of Shiiya formation [hereinafter referred to as the Shiiya formation (interbedded sandstone and mudstone)], massive mudstone with interbedded sandstone and mudstone of Nishiyama formation [the Nishiyama formation (massive mudstone)], sandy siltstone with interbedded sandstone and mudstone of Haizume formation [the Haizume formation (sandy siltstone)], and gravel, sand, silt, and mud of Uonuma formation [the Uonuma formation (sand dominated)]. Those four groups are distributed over one km² and occupy a large portion of the mountains.

Nozaki (1994) and Nozaki (1995) reported that the Shiiya formation was of lesser intensity than the Nishiyama, Haizume, and Uonuma formations, despite the fact that the Shiiya formation is older than other formations. In the study area, many landslides are distributed in the slopes of the Shiiya formation.

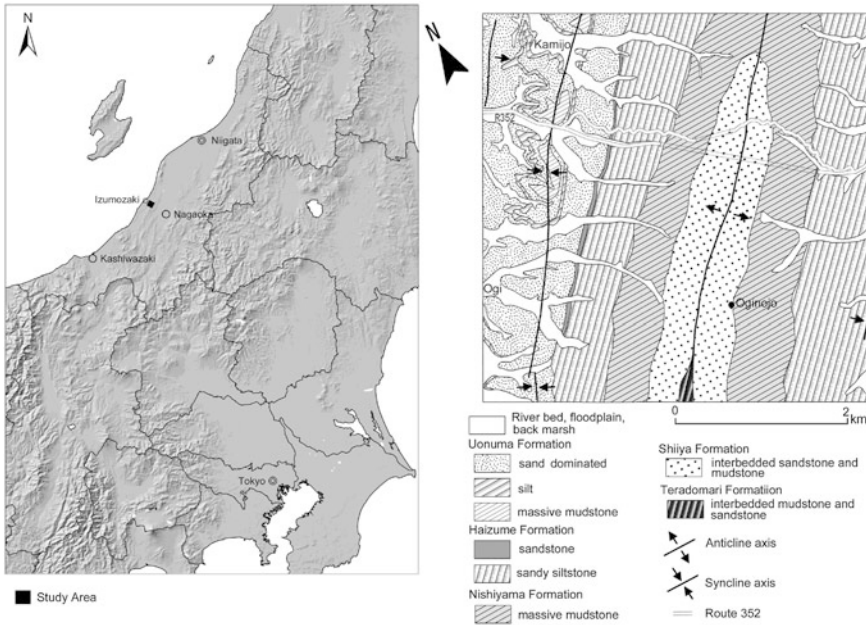


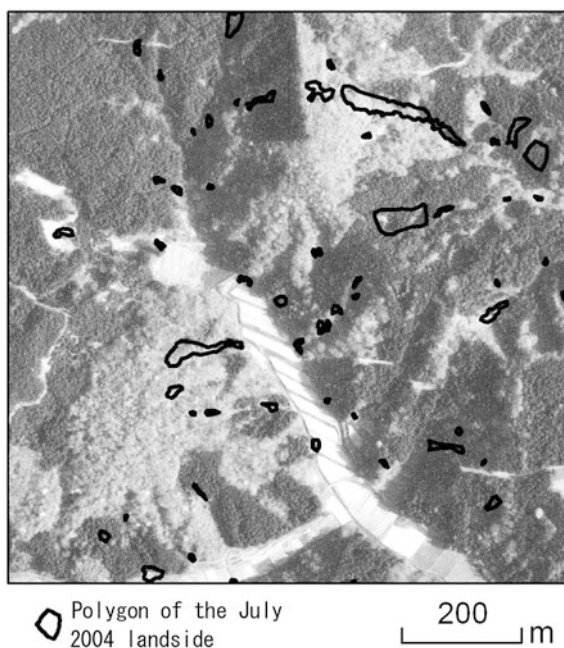
Fig. 2.1 Study area and its lithological map. The lithological map is compiled from 1:50,000 geological maps of Kobayashi et al. (1993), Kobayashi et al. (1995, 2001), Takeuchi et al. (2004)

In the study area, cedar plantations and broad-leaved deciduous forests are widely distributed. Vegetation of the study area is well controlled by humans. According to the observation of air-photographs, a considerable portion of the study area was logged in the 1940s. After the 1960s, the study area is covered by forest and there has been no bare land (Fig. 2.2). The distribution of cedar plantation has been changed widely every 10–20 years due to logging. There is no concrete evidence that vegetation influences the development of landslides. Therefore, the vegetation was not considered as a predisposition in this study area.

2.3 Details of the August 1961 and July 2004 Heavy Rainfalls in the Study Area

The Izumozaki area has suffered several disasters caused by heavy rainfalls in the last several decades. Many landslides occurred in the study area, in particular due to the 5 and 20 August 1961 heavy rainfalls caused by a typhoon and the 13 June 2004 heavy rainfalls caused by a rainy season front (Yamagishi et al. 2008). This study focuses on landslides caused by the two events.

Fig. 2.2 Landslides induced by the July 2004 rainstorms plotted on the monochrome air-photograph taken in 2001 by GSI. *Dark parts* correspond to artificial forests of cedars, and *gray parts* to broad-leaved deciduous forests



According to reports of the meteorological observatory, daily precipitation of the 5 August 1961 heavy rainfall in the study area was estimated as 250 mm. Maximum hourly precipitation in the study area was unknown; however, it was 40 mm in Nagaoka which is located 10 km east of Izumozaki. Half of the residential buildings in the Izumozaki area suffered damage and 14 people were lost because of landslides (Tokyo District Meteorological Observatory 1961). Two weeks later, heavy rainfalls came again. On August 20, 1961, middle of Niigata Prefecture suffered concentrated heavy rains. Daily precipitation of the study area was 126 mm (Society of Agricultural Meteorology of Niigata Prefecture 1961). According to Tokyo District Meteorological Observatory (1961), most of the damage of Izumozaki was caused by the 5th August heavy rainfall, however, Saito (2007) reported that many landslides occurred in the eastern slopes of Oginojo on 20th August.

The 13 July 2004 heavy rainfalls were caused by a rainy season front. The greatest damage came from an overflow of the Kariyata River on the plains. In the Izumozaki area, many landslides occurred and one person was lost. Kawashima et al. (2005) reported detailed data of precipitation. In the town office of Izumozaki and Mishima, which are close to the study area, the daily precipitation was approximately 350–370 mm. The maximum hourly precipitation in the Izumozaki area was approximately 50 mm (Yamagishi et al. 2008).

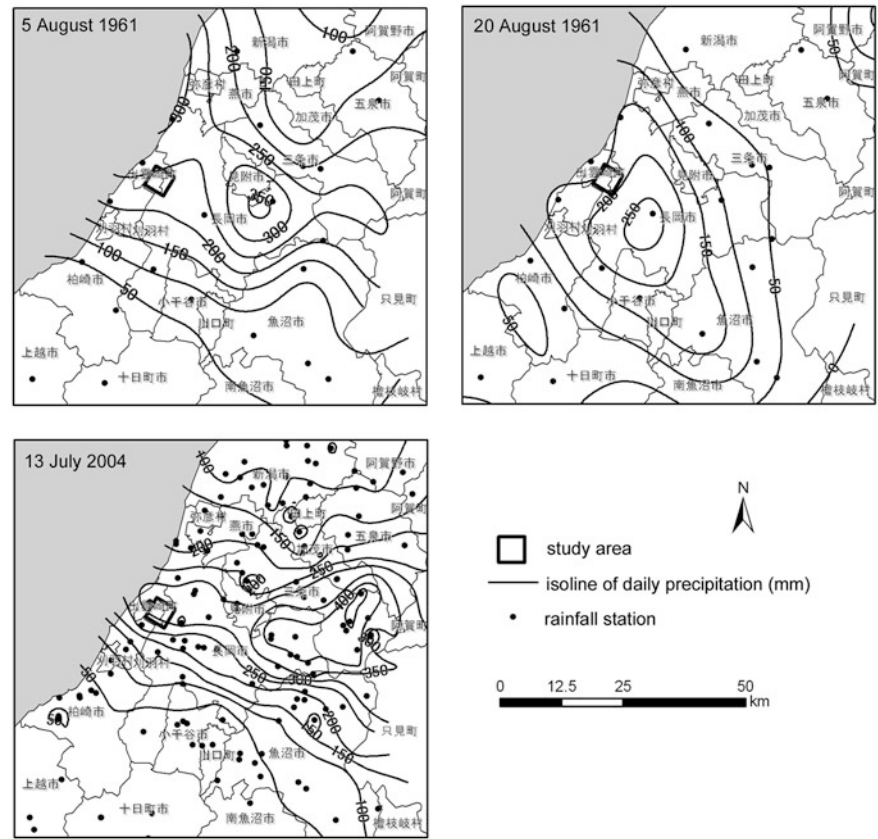


Fig. 2.3 Distribution maps of daily precipitation of the August 1961 heavy rainfalls (*upper-right and upper-left*) and July 2004 heavy rainfalls (*lower-left*). Precipitation data are from Society of Agricultural Meteorology of Niigata Prefecture (1961), Kawashima et al. (2005). Isolines of daily precipitations were interpolated by spline interpolation from the data of rainfall stations

As described above, the two events were different in their rainfall processes. The August 1961 heavy rainfalls occurred twice in two weeks. The June 2004 heavy rainfalls were all at once, however, it rained harder than the August 1961 heavy rainfalls (Fig. 2.3).

2.4 Preparation of GIS Data

2.4.1 Preparation of Landslide Inventory Data

Positional accuracy of landslide distributions is the key for this study. We made an effort to digitize accurate landslide polygons. At first, photographic papers of aerial photographs of 1961 and 2004 were used to grasp rough locations of landslides by a three-dimensional view. 1:20,000 scaled monochrome aerial photographs taken by GSI on May 20, 1962, were used for the landslides caused by the August 1961 heavy rainfalls (hereinafter referred to as the August 1961 landslides). These photographs were taken nine months after the heavy rainfalls; however, disaster-relief work had not been done and locations of the landslides were easily identified. 1:25,000 scaled color aerial photographs taken by GSI on the July 24, 2004, were used for the landslides caused by the 13 July 2004 heavy rainfalls (hereinafter referred to as the July 2004 landslides). In this study, we digitized landslide polygons on 50-cm resolution ortho-photoimagery. The ortho-photoimagery was created by ERDAS Imagine (Hexagon Geospatial) using 1200 dpi scanned films of aerial photographs. We digitized landslide polygons using ArcGIS (ESRI). By enlarging the ortho-photoimagery on a PC monitor, small landslides with a width of several meters were identified and accurate polygons were digitized.

For terrain data, we used a 2-m DEM derived from LiDAR data surveyed on the November 3, 2007. The study area experienced the 2004 Niigata Prefecture Chuetsu Earthquake (M 6.8) on the October 23, 2004. However, the earthquake brought on a few landslides in the study area (Iwahashi et al. 2008). Compared with the 24 July 2004 aerial photographs, we found almost no new landslides on the digital aerial photographs taken at the same time with LiDAR.

Lithology, positional relationships with roads, positional relationships with the 1961 landslides (for the July 2004 landslides only) were inputs as attributes of landslide polygons. Areas of landslides were calculated using the GIS software.

We used a compiled and simplified 1:50,000 geological map (Fig. 2.1) as the basis for lithological data. A 1:50,000 map scale is too small compared with the resolution of the DEM. Therefore, we modified the attributes of landslide polygons manually, especially in the case that the location of alluvium (inferred from the shaded relief image of LiDAR DEM) was overlaid in the polygons of mountainous rocks in the GIS data of lithology.

We have classified positional relationships between the landslides and the roads, as landslides in natural slopes and landslides in road slopes. Road slopes were certified using the shaded relief image created by the 2-m DEM. We also defined the new or widened roads that were not shown in the 20 May 1962 aerial photographs, as newly constructed roads after 1962.

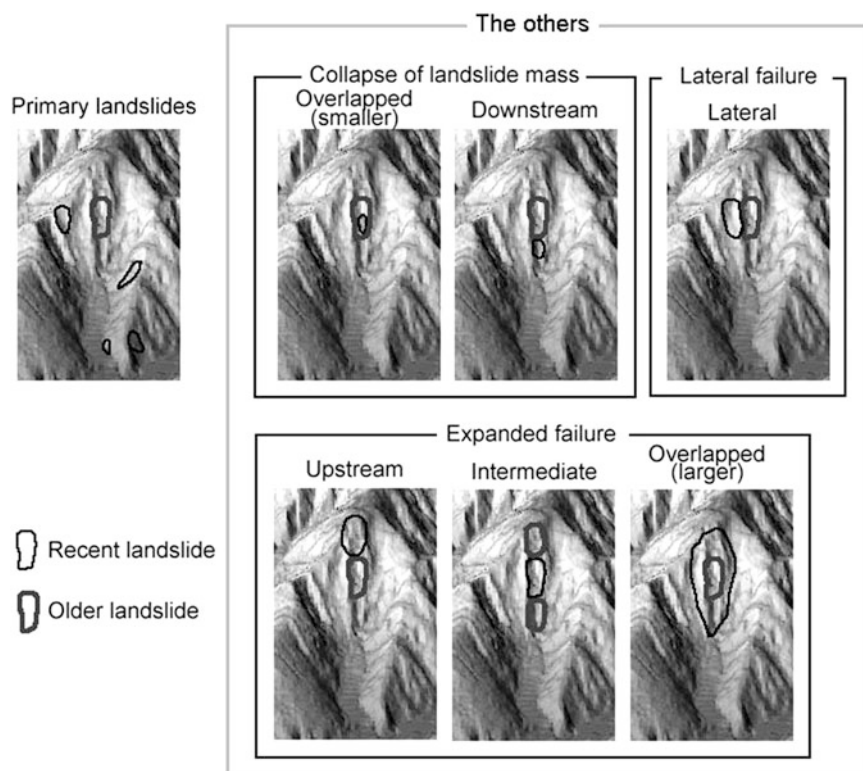


Fig. 2.4 Images showing frame formats of positional relations between new and old landslides. In this figure, gray polygons and black ones indicate 1961 landslides and 2004 landslides, respectively

The July 2004 landslides can be classified into primary landslides, meaning those without any relationship to the August 1961 landslides in the same valley side slope, and other landslides with the August 1961 landslides in the same valley side slope. Moreover, we re-classified the other landslides as follows. Figure 2.4 shows schematic images of the descriptions.

Overlapped (smaller): small landslide occurred on the 1961 landslide

Downstream: landslide occurred in a downstream valley of the 1961 landslide

Lateral: landslide occurred in a close lateral valley of the 1961 landslide

Upstream: landslide occurred in an upstream valley of the 1961 landslide

Intermediate: landslide occurred between the two 1961 landslides

Overlapped (larger): large landslide occurred on and around the small 1961 landslide







					
horizontal dip	daylighting dip	parallel dip	hangnail dip	vertical dip	infacing dip
outfacing dip					
$\gamma = 0^\circ$	$0^\circ < \gamma < \theta$	$\gamma = \theta$	$\theta < \gamma < 90^\circ$	$\gamma = 90^\circ$	$90^\circ < \gamma < 180^\circ$
stable	extremely unstable	stable to unstable	stable	stable to rather unstable	stable

Fig. 2.5 Classification of the structure of stratum defined by relational inclination between surface slope gradient (θ) and slope gradient of geological discontinuity planes (γ) such as planes of stratification or joint face (Suzuki 2000)

2.4.2 Preparation of the Data for Structure of Stratum

We created the data for the inner structure of stratum for each geological formation using the slope gradient and the slope orientation calculated from the 2-m DEM, and strike and dip data digitized from the 1:50,000 geological maps (Kobayashi et al. 1993; Kobayashi et al. 1995, 2001) adding 13 point data measured at the foot of mountains from Yamagishi et al. (2005). The data show the area of classified groups for the structure of stratum according to Suzuki (2000) (Fig. 2.5).

Since the data of dip and strike are based on descriptions in the 1:50,000 geological maps, positional accuracy of the data is not commensurate with the 2-m DEM. However, since the orientations of strata are broadly constant between fold axes, we thought the problem would not have a significant effect on the results. Meanwhile, the resolution of DEM will cause a significant problem for preparing the data of the structure of stratum. A high-resolution DEM was needed to prepare surface slope orientation data which express the real situation of slopes. The method of preparation of the data is described in Fig. 2.6.

In the classification, we omitted the slopes where the geological surface was in a direction perpendicular to the ground surface (approximately 26% in the mountain slope), because we cannot determine if those slopes are infacing or outfacing. We classified infacing dips into two categories: those in which the dip is greater or less than 40°. In the case of outfacing dips, the dip degrees were already taken into account when classifying daylighting dip, parallel dip, and hangnail dip (Fig. 2.5). There are no vertical dip slopes in the study area.

2.4.2.1 Slope Angles of Mountains for Each Geological Structure of Stratum

The average slope angles for each geological structure type of stratum calculated by the 2-m DEM are shown in Table 2.1. The average slope gradients in Table 2.1 are the values for the all mountain slopes including landslides.

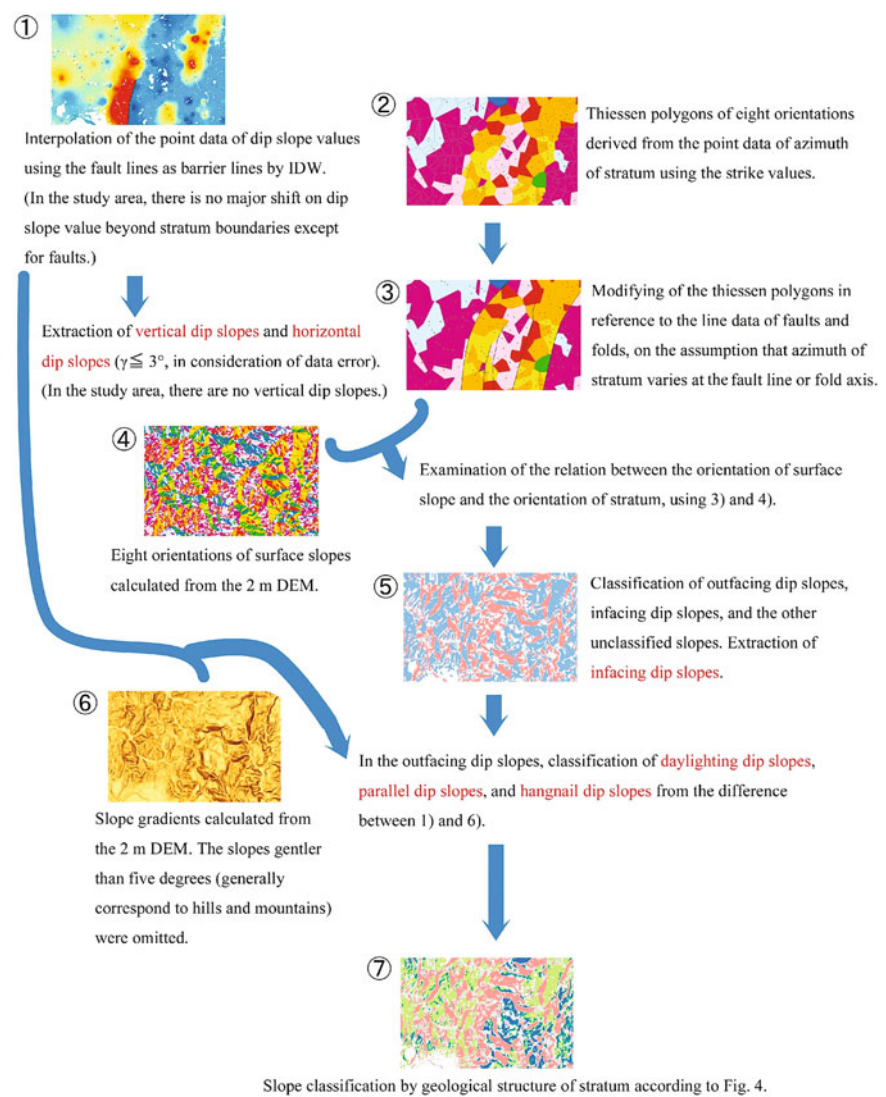







Fig. 2.6 Method of preparation of the data for structure of stratum using GIS

It is estimated that steep slopes are mainly distributed in hangnail dips in the Uonuma formation (sand dominated) and the Haizume formation (sandy siltstone), and parallel and hangnail dips in the Nishiyama formation (massive mudstone) and the Shiiya formation (sandstone dominated). Around the study area, especially hangnail dip slopes are stable (Suzuki 2000), and it is known there were few occurrences of slope failure in the Chuetsu Earthquake (Sasaki et al. 2006). The presence of many steep slopes does not always mean the area is unstable in high-resolution observation.

Table 2.1 Geological structures for stratum and the average slope gradient (°) according to the formations

	Uonuma formation (sand dominated)	Haizume formation (sandy siltstone)	Nishiyama formation (massive mudstone)	Shiia formation (interbedded sandstone and mudstone)
Daylighting dip 	18.4	23.9	29.0	27.8
Parallel dip 	18.9	27.7	38.8	42.1
Hangnail dip 	29.2	36.2	39.0	43.2
Infacing dip (dip < 40) 	23.0	28.2	27.4	33.8
Infacing dip (dip > 40) 	22.5	31.1	32.9	29.6

To determine average slope gradients, the slopes less than 5° calculated in 5 by 5 cell windows, which coincided with valley bottoms or plains, were omitted

In the Uonuma formation (sand dominated), the Haizume formation (sandy siltstone), and the Shiia formation (interbedded sandstone and mudstone), infacing dip slopes are steeper than daylighting dip slopes or parallel dip slopes. On the contrary, the Nishiyama formation (massive mudstone) shows no concrete tendency.

2.5 Results

2.5.1 Comparison of the Densities of the August 1961 and July 2004 Landslides

Table 2.2 shows the number of landslides for each lithological unit. Landslide numbers and areas for the July 2004 landslides were 1/2–1/3 of those in the August 1961 landslides. In both disasters, landslides occurred most frequently on the slopes

Table 2.2 Number of landslides for each lithological unit

	August 1961	July 2004	A/B	Average value of slope gradient (°)
	Number of landslides/km ² (A)	Number of landslides/km ² (B)		
Uonuma formation (sand dominated)	134.4	47.8	2.8	21.4
Haizume formation (sandy siltstone)	152.1	56.2	2.7	26.5
Nishiyama formation (massive mudstone)	184.3	74.2	2.5	29.9
Shiia formation (interbedded sandstone and mudstone)	88.6	43.3	2.0	28.4

Table 2.3 Number of landslides for each category of geological structure of stratum

	August 1961		July 2004	
	Number of landslides	%	Number of landslides	%
Daylighting dip	776	29.7	375	36.5
Parallel dip	21	0.8	7	0.7
Hangnail dip	206	7.9	95	9.3
Infacing dip (dip < 40°)	218	8.3	109	10.6
Infacing dip (dip > 40°)	680	26.0	173	16.8
Not categorized	710	27.2	268	26.1

of the Nishiyama formation (massive mudstone) and less frequently on the slopes of the Shiya formation (interbedded sandstone and mudstone), although average slope angle is the largest in the Shiya formation.

Table 2.3 shows landslide densities for each geological structure type of stratum. In the infacing dip slopes whose dip is steeper than 40°, number densities of landslides in the August 1961 landslides are 10% larger than those in the July 2004 landslides. In the daylighting dip slopes, the number is 5% less than those in the July 2004 landslides. Differences of other values are less than a few percentage points; the overall trends observed in Table 2.3 are similar in the two disasters.

However, different characteristics were observed in the frequency of the structure of stratum of the two categories of the July 2004 landslides: isolated landslides which occurred in the different slopes of the August 1961 landslides (primary landslides) and landslides which occurred in the same side slope of the August 1961 landslides. We describe this in the next section.

2.5.2 Position of the July 2004 Landslides in Relation to the August 1961 Landslides

Among the July 2004 landslides, 70% of landslides in number and 54% of landslides in area are regarded as primary landslides, and the other landslides occurred in the same valley side slopes (Table 2.4).

As can be inferred from the median values of the area of landslides, *Upstream*, *Intermediate*, and *Overlapped (larger)* types are mainly large landslides and indicated to be expanded failures of older ones. Most of these expanded type landslides are the *Upstream* type.

The sum of the numbers of *Overlapped (smaller)* and *Downstream* types is approximately half of the July 2004 landslides which occurred in the same valley side slope of the August 1961 landslides. Among these, especially the *Overlapped (smaller)* type is dominant. *Overlapped (smaller)* and *Downstream* types are inferred to be collapses of landslide masses of the August 1961 landslides. *Lateral* type landslides are also small. The median values of the area of those small landslides are close to the value of primary landslides (83 m²).

Table 2.4 Position of the July 2004 landslides in relation to the August 1961 landslides

Type of the July 2004 landslides	Number of landslides	%	Total area of landslides (ha)	%	Median area of landslides (m ²)
Primary	724	70.5	13.54	54.0	83
Overlapped (smaller)	125	9.8	1.78	7.1	60
Downstream	31	2.4	0.76	3.0	92
Lateral	59	5.7	1.27	5.1	93
Upstream	69	5.4	4.28	17.1	307
Intermediate	5	0.4	0.22	0.9	525
Overlapped (larger)	14	1.1	3.21	12.8	1874

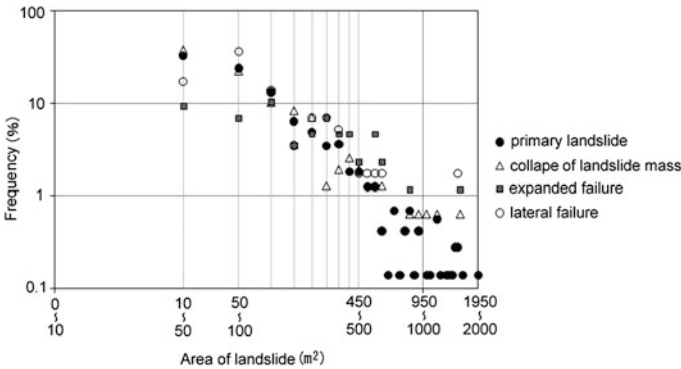


Fig. 2.7 Frequency distribution of landslides. Landslides larger than 2000 m² are not included in this figure. Axes of the graph are in logarithmic scale

Figure 2.7 shows the size-frequency distribution of the July 2004 landslides, for the primary landslides and the other landslides. The sizes were calculated by GIS using landslide polygons. The size distribution of the primary landslides is close to a power-law distribution. There are many *Lateral* type landslides in a range between 50 and 100 m². The slope of the graph of the expanded failures is significantly different from that of the primary landslides.

Figure 2.8 shows pie charts of the geological structure of stratum in relation to the types of the July 2004 landslides. The pie charts of “all mountain slope” indicate a standard of ratio of geological structure for each lithological unit. All charts of the primary landslides are similar to the charts of all mountain slopes. This fact indicates that the influence of geological structure on the occurrence of primary landslides is small. In contrast, except for the Nishiyama formation (massive mudstone), expanded type landslides include a larger ratio of daylighting dip slopes than the original percentage shown in the pie charts of “all mountain slope.” In the case of sandstone slopes, it can be estimated from the pie charts that collapse of landslide masses and lateral landslides mainly occurred in the infacing dip slopes.

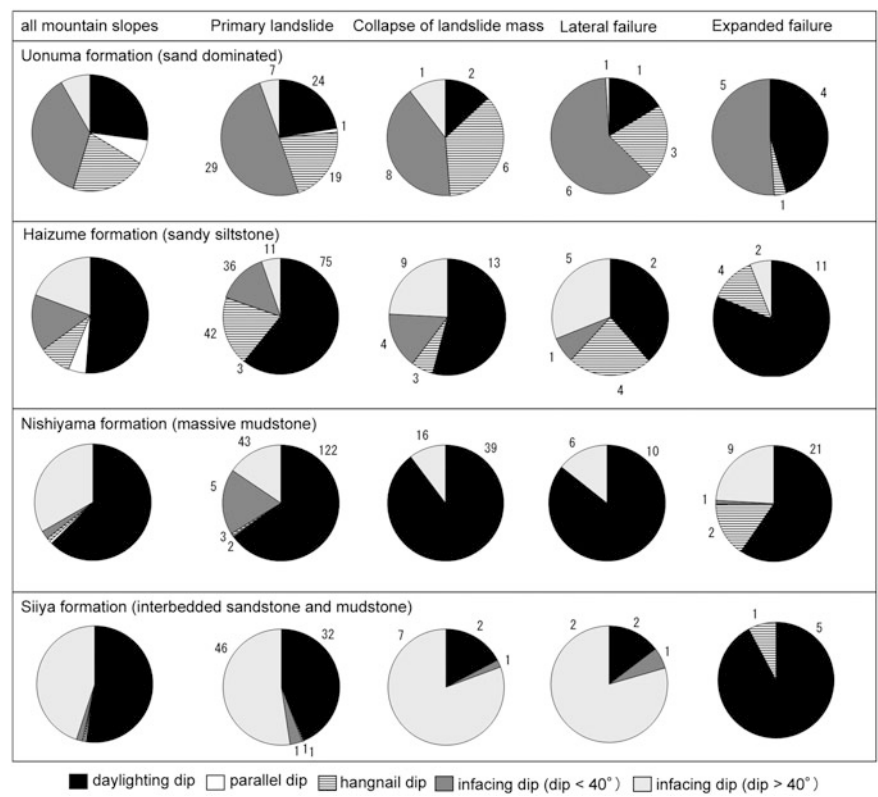


Fig. 2.8 Pie charts showing positional relations between geological structures in the July 2004 landslides and the August 1961 landslides. Angles of pie charts indicate the area ratio. *Subscripts* are numbers of landslides. The *leftmost pie* chart shows the area ratio in all mountain slopes

2.5.3 Landslides Along the Roads

Observing the landslide distributions (Fig. 2.9), there is a significant difference between the spatial distributions of the August 1961 and July 2004 landslides separate from geology. Though the July 2004 landslides were considerably less than the August 1961 landslides, the July 2004 landslides are prominent in that there were many landslides in artificial slopes around roads. Before 1961, the only road which had been constructed by cutting the hillside slopes was Route 352; most roads were constructed along the lines of the feet or ridges of mountains. In 1962–2004, many forest roads were constructed by cutting or filling. In the study area, most of the artificial slopes of the new roads are covered by wire mesh and grass seed spraying; shotcrete or mold blocks are seldom used for slope protection.

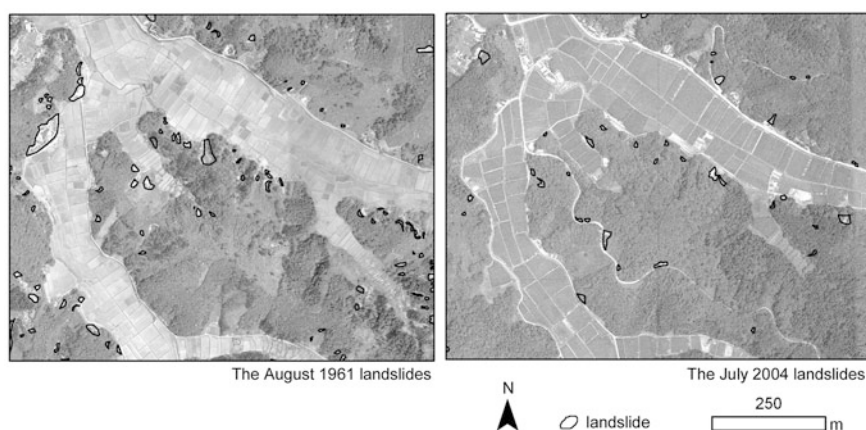


Fig. 2.9 August 1961 landslides (*left* the background air-photograph was shot by GSI in 1962) and the June 2004 landslides (*right* the background air-photograph was shot by GSI at shortly after the heavy rainfalls) around Kamijo in Izumozaki town

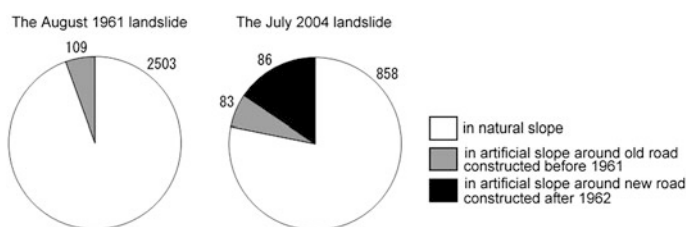


Fig. 2.10 Pie charts showing the comparison between the August 1961 landslides and the July 2004 landslides along roads. Angles of pie charts indicate the area ratio. *Subscripts* are numbers of landslides

Figure 2.10 shows the pie charts which show the areas of landslides in natural slopes, in artificial slopes around old roads constructed before 1961, and in artificial slopes around new roads constructed after 1962. Landslides that occurred in artificial slopes around roads are only 4.2% (109 per 2612 in number) of the August 1961 landslides, however, are 16.4% (169 per 1028 in number) of the July 2004 landslides. It is clear from the charts that the increase of landslides occurring in artificial slopes comes from the landslides around new roads.

Positional relationship between the type of landslide based on Fig. 2.4 and roads are shown in Fig. 2.11. Figure 2.11 reveals the following. In the sandstone slopes, most of the landslides around the new roads constructed after 1962 were primary landslides. In contrast, large expanded landslides significantly occurred around the new roads in massive mudstone slopes.

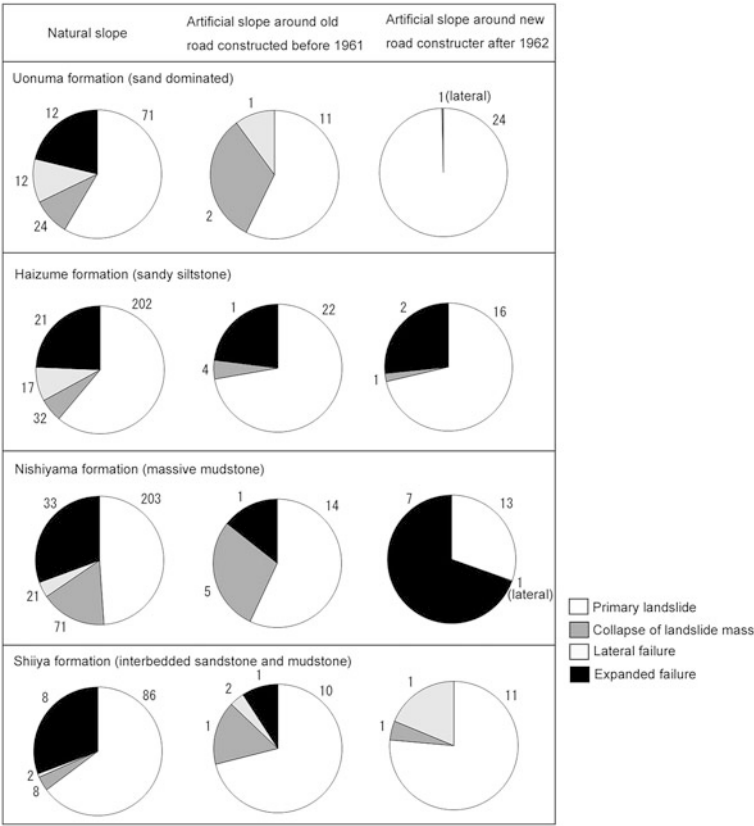


Fig. 2.11 Pie charts showing classifications of the July 2004 landslides on the basis of Fig. 2.4 for each lithological unit, and positional relation with roads. Angles of pie charts indicate the area ratio. *Subscripts* are numbers of landslides

2.6 Discussion and Conclusion

The August 1961 heavy rainfalls were twice in two weeks. The June 2004 heavy rainfalls were all at once, however, in 2004 it rained harder than the August 1961 heavy rainfalls according to the daily precipitation in the study area (Fig. 2.3). Those different rainfall processes are probably related to the landslide densities per lithological unit (Table 2.2).

Seventy percent (in number) of the July 2004 landslides were small primary landslides which occurred in valley side slopes not affected by the August 1961 landslides. On any lithological unit, the pie charts of the types of geological structure for primary landslides (Fig. 2.7) are similar to those of all mountain slopes. This indicates that primary landslides occurred randomly. Therefore, even a

simple method using topographical attributes such as slope gradient and convexity will be able to bring a valuable hazard evaluation for primary shallow landslides in the slopes without old landslides.

The other landslides which occurred in the same valley side slopes of the August 1961 landslides can be classified into (1) collapse of landslide mass of the August 1961 landslide, (2) expanded failure of the August 1961 landslide, and (3) landslide occurred in a close lateral valley of the August 1961 landslide. Though Type 1 is the largest in the number of landslides, Type 2 should be noticed, because Type 2 landslides are the largest in scale and they significantly affect human society. After our analyses using GIS, most of the expanded failures (Type 2) are slope failures of upstream slopes of the August 1961 landslides. Except for the slopes of the Nishiyama formation (massive mudstone), expanded failures (Type 2) often occurred in daylighting dip slopes (Fig. 2.5). Therefore, daylighting dip slopes of sedimentary rocks, which have a clear layered structure and an old landslide in their downstream, should be noted. For the slopes which have a history of slope movement in the last several decades, extensive mapping of landslide distribution and information of the geological structure of stratum are more important than topography.

Artificial steep slopes cut along new forest roads cannot be disregarded because they are outstanding origins of recent landslides. In the July 2004 landslides, differences of landslide type (Fig. 2.4) are observed according to the geological structure of stratum (Fig. 2.11). In the sandstone slopes (the Uonuma and Shiiya formation), most of the landslides around the new roads constructed after 1962 were primary landslides. In contrast, large expanded failures significantly occurred around the new roads in massive mudstone slopes (the Nishiyama formation).

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