Landslides and Landscape Change Induced by Heavy Rainfall and Intensive Earthquake in Mid-Niigata, Japan: GIS Analyses and Interpretation of Aerial Photographs

Hiromitsu Yamagishi,[1)] Toko Takayama[2)] and Junko Iwahashi[3)]
1) Niigata University, Japan, 8050 Ikarashi-2-no-cho, Niigata 950-2181, Japan (hiroy@env.sc.niigata-u.ac.jp)
2) Asia Air Survey, Co. Ltd., Japan, Manpukuji 1-2-2, Asao-ku, Kawasaki 215-0004 Japan (tk.takayama@ajiko.co.jp)
3) Geographical Survey Institute, Japan, Kitasato-1-ban, Tsukuba 305-0811 Japan e-mail (iwahashi@gsi.go.jp)

Abstract

In 2004, two big triggering mechanisms (heavy rainfall on July 13 and intensive earthquake on October 23) brought about numberless landslides and remarkable geomorphic changes in hilly terrains composed of considerably folded and faulted Neogene sedimentary rocks. Using GIS, we have analyzed the distribution characteristic of the two landslides and compared between the two landslides. As the results, we have revealed the relationship and the comparison between the two landslides distribution and the topography and geology.

Most of the gentle slopes of the Mid-Niigata terrains have been mostly used for paddy fields and ponds. In order to reveal the relationship between the two events and such landuse, we are analyzing the change in landscape, the damage on paddy fields, the pattern of destruction of ponds and occurrence of landslides in GIS using various techniques and inputs. The use of high resolution aerial photographs and LiDAR data are especially useful to classify paddy fields and ponds.

Keywords: Landslides, landscape change, heavy rainfalls, intensive earthquakes, DMC image, GIS

Introduction

In 2004, ten typhoons attacked throughout Japan and extensive damages were incurred because of subsequent rainfalls. At the same time, Mid-Niigata region (Fig. 1a) was affected by heavy precipitation and earthquakes (Fig. 1b) on July 13 and October 23, 2004, respectively.

The heavy rainfalls and the subsequent floods in Kariyatagawa and Ikarashigawa rivers claimed the lives of 13 people. Kariyatagawa and Ikarashigawa are major tributaries of Shinanogawa. The latter is the longest river in Japan. More than 3600 landslides triggered by the rainfalls killed 2 people. Three months later, high magnitude intensive earthquakes occurred in the southern part of Mid-Niigata and around 60 persons were killed directly or indirectly until now. The area affected by the earthquakes is typically characterized by a hilly terrain where there are beautiful landscapes consisting of paddy fields and ponds for feeding carps and irrigation. The destruction includes roads and houses too. Landslides triggered by the heavy rainfalls and the intensive earthquakes occurred in areas with similar geologic and geomorphologic conditions. In this study, we are analyzing the two landslides and landscape change using GIS, associating with aerial photographs.

1. The July 13, 2004 heavy rainfalls

According to Ushiyama (2004), the rainfall began in the evening of July 12, 2004. High amount of rainfall, however, was documented in the early morning of July 13 in the lowlands and mountainous areas. Fig. 1b presents the rainfall distribution on July 13, 2004 in the areas where flooding and landsliding occurred. In the roughly 1250 km^2 area considered, the Tochio and Kariyatagawa localities got the maximum rainfalls of one day. The 24 hour rainfall data of AMEDAS station in Tochio City for example showed a daily precipitation of 421mm.

2. Landslides triggered by the July 13, 2004 heavy rainfalls

Many landslides were inventoried through aerial photographs. We have been done field researching using research cards (Yamagishi and Ayalew, 2005). In Izumozaki and Tochio areas about 3600 landslides are recorded. Particularly the Yoita area is characterized by more than 500 landslides. Some of the landslides are associated with mudflows.

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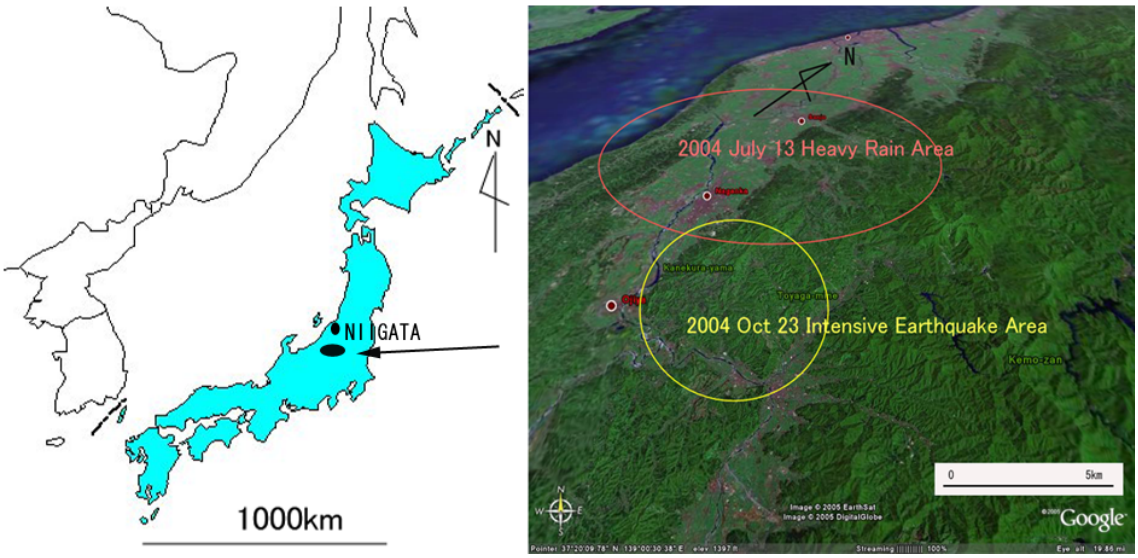

Fig. 1. a: Location map of the Mid Niigata, Japan. b: Circle area is affected by the 2004 July 13 heavy rainfalls, and the elliptical area is affected by the 2004 Oct 23 intensive earthquakes.

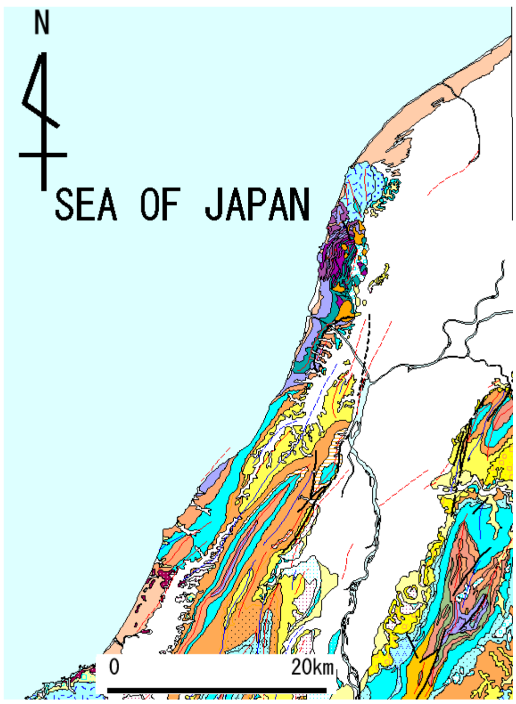

Fig. 2. Geologic map of Nagaoka area (Geological Survey of Japan, 2004a)

3. GIS analyses of the rainfall-induced landslides

Vector data models were prepared from the inventory maps of landslides and mudflows. As the base map, we used a 10m grid DEM prepared by GISMAP (Hokkaido Chizu Co. Ltd.). Geologic maps of Izumozaki and Sanjo areas at a scale of 1: 50,000, and Niigata and Nagaoka (1: 200,000 in scale) were provided by Geological Survey of Japan (Fig. 2, 20004a) and digitized. Moreover, as an additional data, we used the landslide distribution maps (1:50,000) of Nagaoka and Takada prepared by the National Research Institute for Earth Science and Disaster Prevention (NIED, 2006).

In Mid-Niigata, there are high relief hills with elevations in the range of 200 to 600 m.

Many straight ridges (for instances, Nishiyama hills in the west, Shimoda hills in the north and

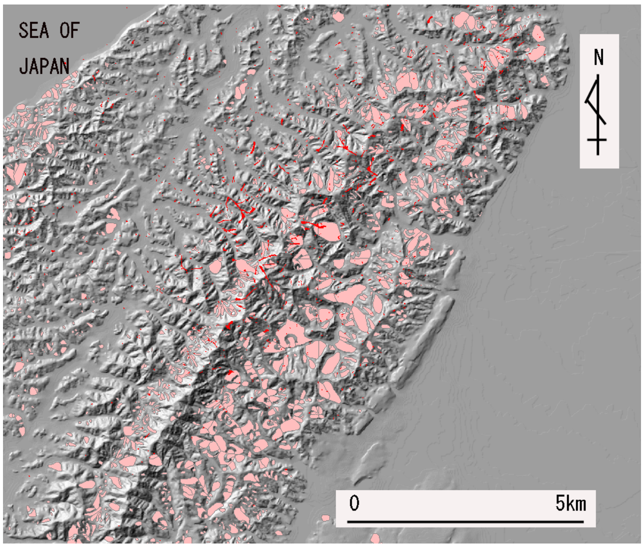

Fig. 3. Map showing the distribution of the 7.13 landslides and old deep-seated slides (NIED, 2006) in the Nishiyma Hill.

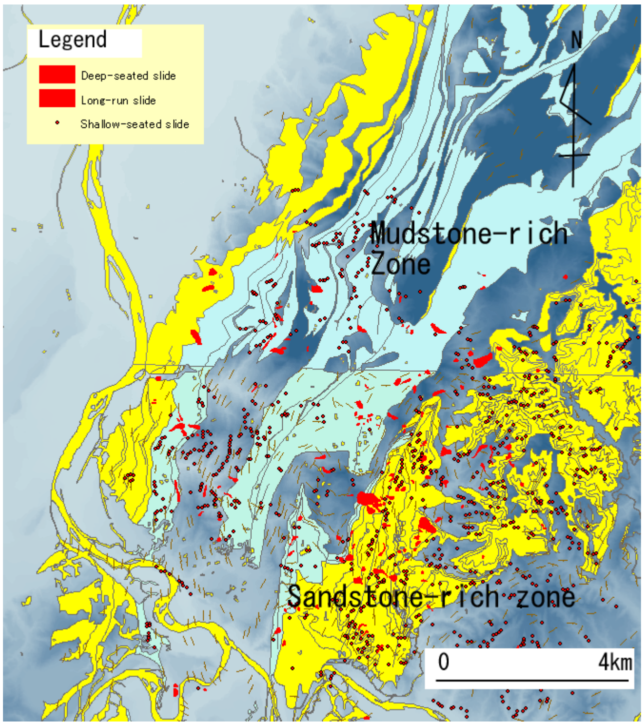

Fig. 4. Map showing the distribution of landslides triggered by the October 23, 2004 earthquakes and the aftershocks. Notice that yellow colored areas indicate the sandstone-rich zone and blue color areas the mudstone-rich zone.

Higashiyama hills in the east) are trending in the directions of NNE-SSW (Fig. 2). Folding structures with axes in directions of NNE-SSW are common most likely following the trend of the ridges. The geology of these ridges is dominated by mudstones and sandstones both of which make up the relatively hard Teradomari Formation. Landslide deposits formed by old deep-seated slope failures are abundantly distributed in the gentle dipping stratum (Fig. 3). Relationship between the recent landslides and the topography has revealed that in Izumozaki area, the former are concentrated in steep slopes which show rectangular and parallel drainage systems along anticlinal axis of the Nishiyama hills (Fig. 3). In Higashiyama to Tochio, most of the landslides and mudflows are mapped in the mudstone-rich zone rather than sandstone-rich localities.

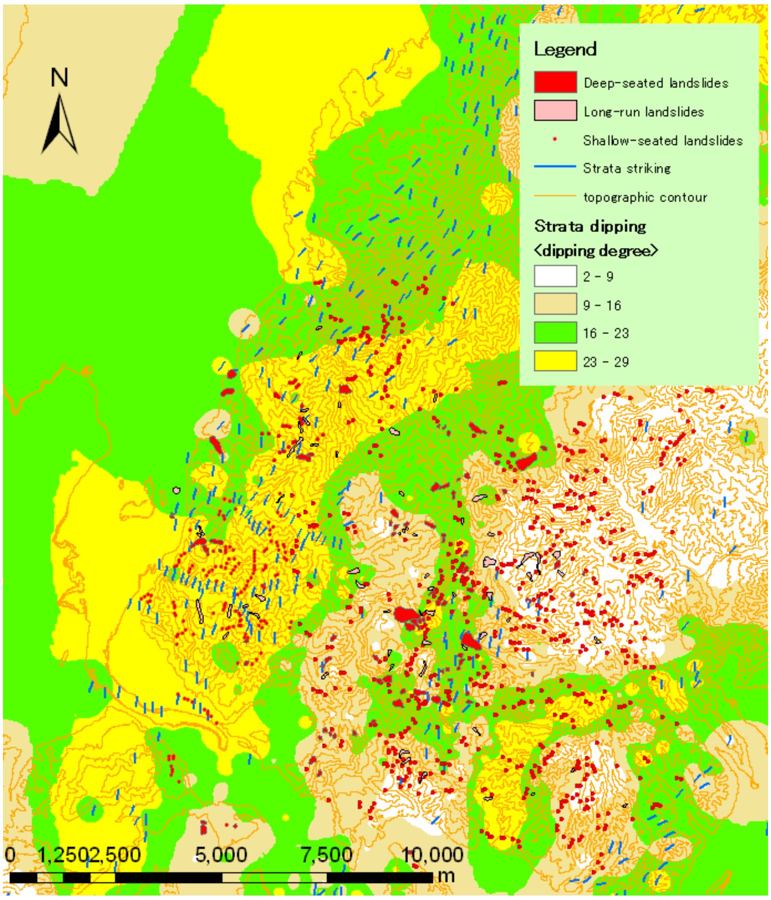

Fig. 5. Map showing landslide distribution underlain by topographic contours, strata striking and dipping maps.

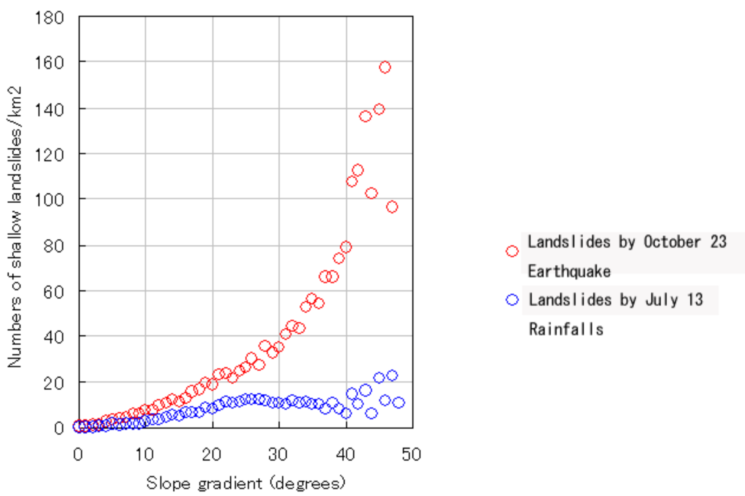

Fig. 6. Comparison between the densities of the shallow landslides by the two events. Note that the slopes with more than 40 degrees show variable plotting, because that such steep slopes have small number of grid cells compared with the gentle slopes with less than 40 degrees. The data of the landslides by the earthquakes were derived from Geological Survey Institite.

4. The October 23 intensive earthquakes

At 17:56 on October 23th, 2004, an intensive earthquake occurred in the Yamakoshi area with a hypocenter at a latitude of 37° 17.4" N and longitude of 138° 52.2" E. The earthquake started at a depth of 13

Fig. 7. Paddy field in the hilly area of Ojiya, Niigata (taken by Yamamoto, H)

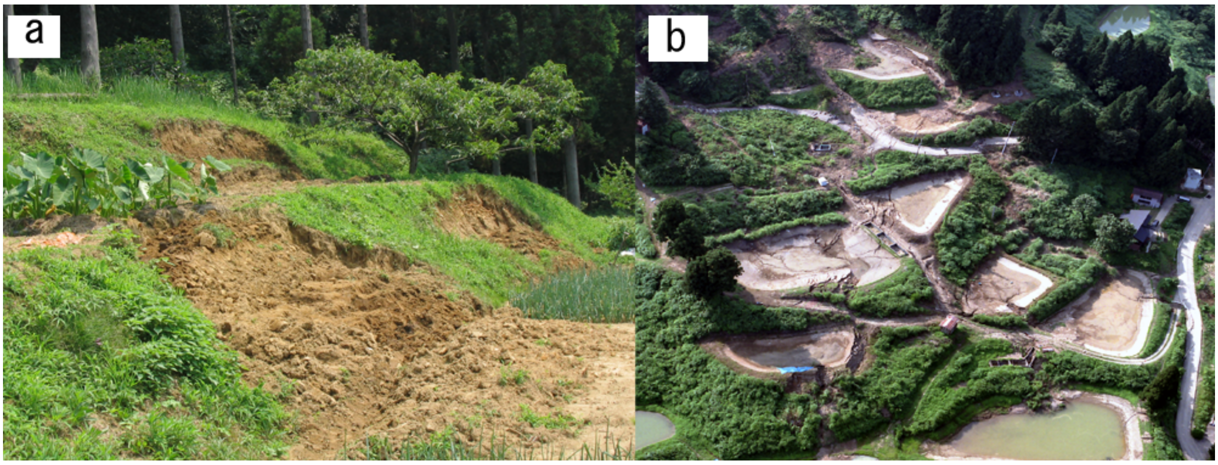

Fig. 8. Photos showing collapsed paddy fields by the 7.13 heavy rainfalls. a: Shallow slidng from the rims of the paddy fields (Izumozaki area), b: Cracks crossing the paddy fields (Minami Nikoro, Yamakoshi area. Taken by Nakanihon Air Survice Co., Ltd.)

kilometers, and had a magnitude of 6.8 on the Richter Scale. In Kawaguchi town, the earthquake registered a seismic intensity of 7 on the Japanese Meteorological Agency scale, which is the maximum in Japan. The main shock was followed by a number of large aftershocks in an interval of two hours. The maximum acceleration exceeded 1000 gal, 7 km away from the epicenter. This earthquake and the following aftershocks were related to geologic folding structures trending in NNE-SSW directions, some of which are associated with active faulting and fracturing (Geological Survey of Japan, 2004b).

5. GIS analyses of earthquake-induced landslides

Many landslides were triggered by the October 23 earthquake and its aftershocks. Aerial photograph interpretation and field investigation have revealed that the landslides are classified into three types as discussed by Yamagishi et al (2005).

Some areas are characterized by dipping stratified sedimentary rocks. As shown in Fig. 4, most of the landslides took place in the sandstone-rich zone rather than mudstone-rich localities. Fig. 5 indicates also the relationship of the distribution of the landslides, topography and geological features of the Yamakoshi area. The map suggests that most of the shallow-seated landslides are distributed more or less on steep slopes, but, large-scale and deep-seated landslides are concentrated in gentle dipping strata. Such large-scale landslides formed more than 10 landslide-dams along the Imogawa tributary. The numbers of the landslides triggered by

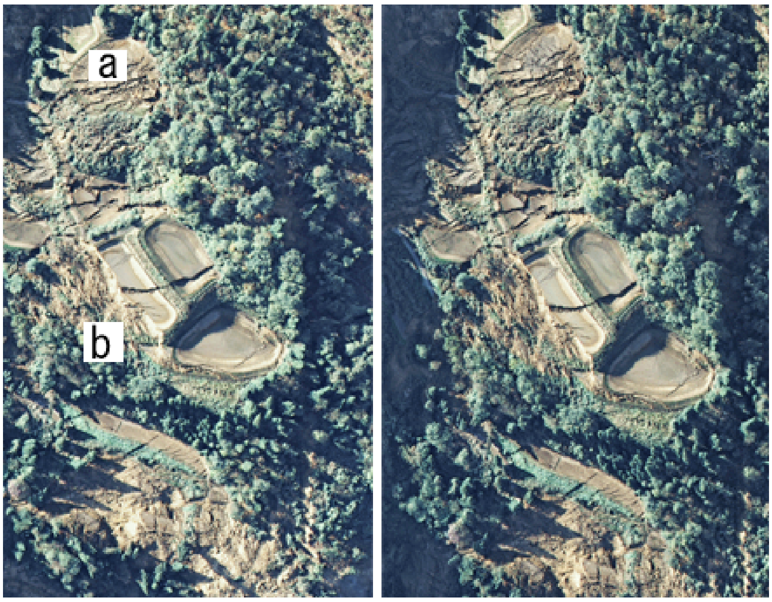

Fig. 9. Stereo-paired photographs of paddy fields showing cracking patterns due to the earthquakes. Notice that cracks (a) are crossing the ponds and the others; (b) are arranged along the ponds developing to a landslide.

Fig. 10. Long-run landslide from the pond with water (Broken pond) probably due to mixing with much water and debris.

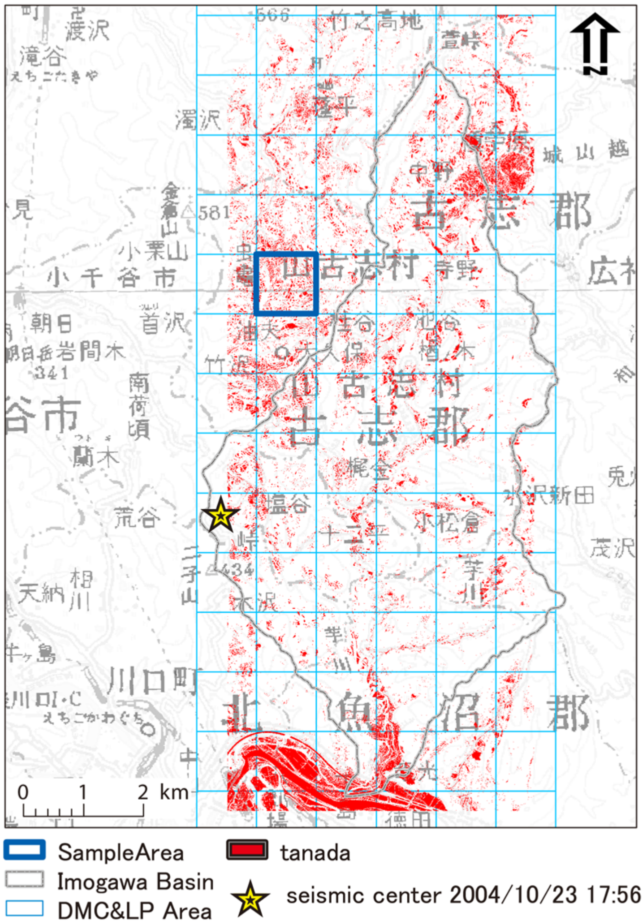

Fig. 11. DMC orthophotograph (taken on October 24, 2004) along the Imogawa River, based on 1m DEM made from LiDAR data (taken on October 28). Note that red-colored spots indicate the paddy fields (tanata) selected by a remote sensing and that the indicated quadrangle is selected area (Figs. 12 and 13) for analysis (10481034)

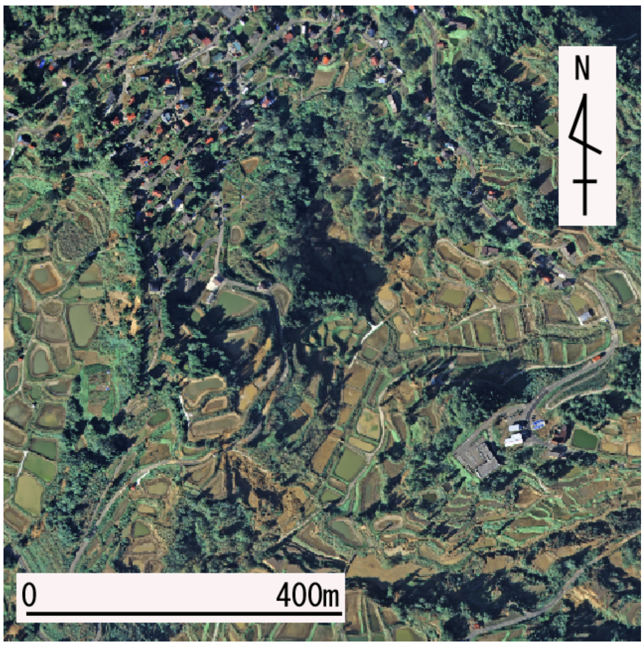

Fig. 12. DMC Orthophoto (Mushigame; 10481034) for the analysis of paddy fields and ponds with cracking and landsliding.

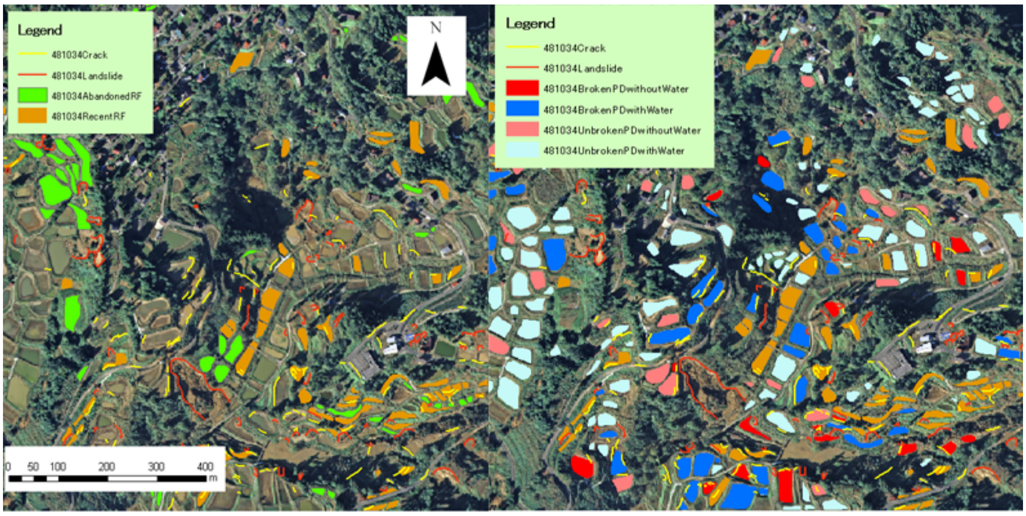

Fig. 13. DMC orthophoto (Mushigame ; 10481034) showing cracks, landslides and classification of paddy fields (left) and ponds (right).

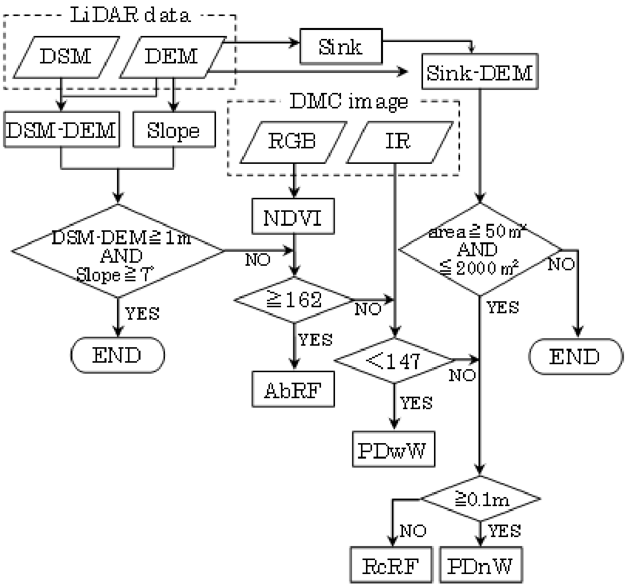

Fig. 14. Flow chart showing the process of the remote sensing analysis for paddy fields.

the October 23 earthquake and its aftershocks are counted to be more than several thousands.

6. Comparison between the two landslides using GIS

GIS-based analyses of the landslides triggered by the July 13, 2004 heavy rainfall and the October 23, 2004 intensive earthquakes and the aftershocks, has revealed the differences as discussed by Yamagishi et al (2005). Firstly, the landslides triggered by the heavy rainfall do not necessarily coincide with old deep-seated landslides from the Web Site of NIED (2006). Most of landslides are small in scale and shallow-seated. They are distributed in steep slopes and in areas where there are steeply dipping sediment strata (Yamagishi et al., 2005). In addition, they occurred lithologically in mudstone-rich zones rather than sandstone-rich localities. On the otherhand, the landslides triggered by the intensive earthquake and its aftershocks coincided with the old deep-seated landslides shown by NIED.

Most of the deep-seated landslides are distributed in gentle slopes, and gently dipping strata areas (Fig.5). Most shallow-seated landslides by the earthquakes, on the other hand, are present on steep slopes. Besides, they are mostly distributed in sandstone-rich zone rather than mudstone-rich regions (Fig. 6). Sec-

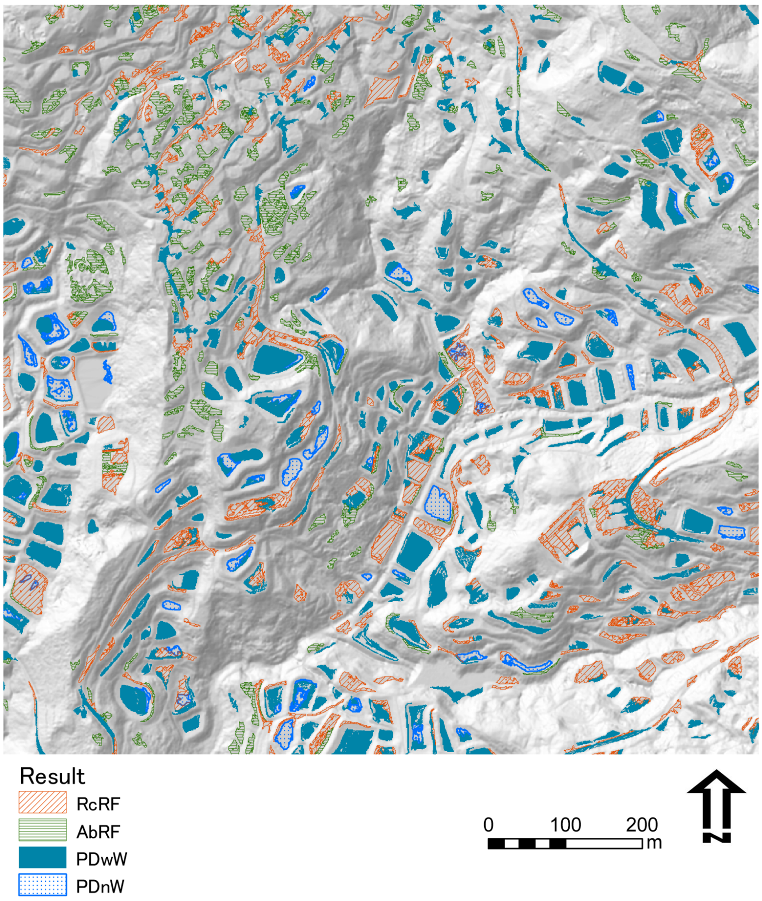

Fig. 15. Result of the classification of paddy fields and ponds.

ondly, using such shallow-seated landslide densities, a comparison of density (numbers of landslides per km^2) was done between the two triggering mechanisms (Fig.6). The graph shown in Fig. 6 shows that the densities of the landslides by heavy rainfall on July 13, remained almost constant over 25 degrees. However, those by intensive earthquakes on October 23 show drastically upward curve toward 40 degree in slope inclination. Namely, with inclination of slopes, the densities of the landslides by the earthquakes are increasing more and more than those by the heavy rainfalls.

7. Landscape changes

Mid-Niigata areas is known for its fertile rice fields. Gentle slope areas between hills, which are mostly sites of old deep-seated landslides, are used as paddy fields (Tanata) for producing delicious rice such as Koshihikari. These rice fields also display beautiful landscape changes in colors from spring to winter (Fig. 7). However, because of the July 13 heavy rainfalls and October 23 intensive earthquakes, the paddy fields and the landscape, are highly affected and destroyed (Figs. 7 and 8). Air-photos taken just after the destruction were important to describe the damage patterns of the paddy fields. Particularly, images of high resolution airborne digital mapping camera (DMC) were very useful to analyze landscape failure in a GIS and to provide faster mapping techniques. We have analyzed the damage patterns using the DMC images combined with GIS.

8. Patterns of the rainfall-induced paddy field landslides

Most of the July13 landslides took place on natural steep slopes, and the displaced materials covered the paddy fields. However, in some places, failures originated from the edges of the paddy fields themselves (Fig.8a). In some other places, landslide cracks crossed the rim of the paddy fields (Fig. 8b).

9. Patterns of intensive-earthquake induced paddy field destruction

The Yamakoshi area which was devastated by the earthquakes on October 23, has been also sites of many rice fields. Since the 1970th most of the paddy fields have been changed into ponds for irrigation and feeding ornamental carps. Therefore, many ponds are distributed in the areas. However, when the earthquakes occurred in 2004 many ponds as well as the paddy fields were broken as shown in Figs. 9 and 10. The cracking of ponds accelerated the process of landsliding because of water flowing out the ponds (Fig. 10). In order to investigate how the failure of ponds promoted the landsliding processes, the paddy fields and ponds were recognized and classified using DMC images taken by Asia Air Survey Co. Ltd. The criteria for the recognizing these features are color and tonal difference due to reflection patterns and vegetation.

The pattern of cracking in the paddy fields was highly variable. Some cracks crossed the paddy fields vertically or obliquely as shown in Fig. 9a, and others are arranged along the shape (Fig. 10). Most of the cracks are considered as tensional because they are thought to be the result of gravitational slipping, although some of the cracks are as compressional on the marginal toe of the landslide. Some of the landslide did not move far due to scarcity of water (Fig.9b). However, long run-out distance due the induction of water from the ponds (Fig. 10).

10. Classification of paddy fields using DMC images

Paddy fields were analyzed in a GIS using DMC orthophoto images (25cm resolution , taken on October 24, 2004) provided by Asia Air Survey Co. Ltd. combined with GIS technology. The DMC orthophoto images associated with Digital Elevation Model (DEM) prepared from airborne laser sensor (LiDAR) are very useful for analyzing the micro-topography (Takayama et al., 2005). On the basis of these images, paddy fields were classified using Erdas IMAGINE and ARCGIS and the result is shown in Figs. 13 and 15.

Use of DMC orthophoto (Fig. 11) and LiDAR data allowed us to identify not only cracks and landslides, but also 1) abandoned old rice fields and 2) recent rice fields (Left of Fig. 13). Using these information, ponds were classified into four categories; 1) broken ponds with water, 2) broken ponds without water, 3)unbroken ponds with water and 4)broken ponds without water (Right of Fig.13). Comparison between the left and right image, revealed that the broken ponds with and without water are more ore less related to cracking rather than the rice fields.

Finally, the DMC orthophoto (10481034) was analyzed using remote sensing techniques to classify rice fields and ponds. The flow chart for analyzing the orthophoto using remote sensing is given in Fig.14. As shown in Fig.15, the analysis also involved LiDAR data (DSM-Digital Surface Model- and DEM) and DMC image. The result is such 4 categories were obtained (Fig. 15); abandoned rice fields (AbRF), recent rice fields (RcRF), pond with water (PDwW), and pond without water (PDnW).

Summary and Conclusion

By the heavy rainfalls on July 13th and intensive earthquakes on October 13th in the Mid-Niigata hills, many landslides occurred and landscapes such as paddy fields changed drastically. We have analyzed the distribution characteristics and comparison of the two landslides using GIS. As the results, we have cleared that the relationship of the two landslides to topography and geology, and the comparisons, such as landslide density. As the result, the landslides by the earthquakes are distributed in the sandstone-rich zone rather than mudstone-rich ones. The density by the earthquakes increases exponentially with the slope inclinations, although that by the rainfalls keeps constant over 25 degrees.

Finally, in order to reveal the relationship between the two events and landuse of the hills, such as rice fields and ponds, we are analyzing the landslides and the landscape change, the damage on paddy fields, the pattern of destruction of ponds in a GIS using various techniques and imputs. In conclusion, we have classified the paddy fields and ponds into four categories.

We thank Mr. Ryuji Nakada and Mr. Takahiro Hiramatsu of Asia Air Survey Co., Ltd. for data preparation and helpful suggestions. We are also grateful to Dr. Ayalew Lulseged for improving our draft, and finally expressing appreciation to anonymous referees for correcting our draft and useful comments.

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