11. GIS Analyses of the landslides in Japan
わが国の斜面災害の GIS 解析の諸例

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要旨：最近，わが国には豪雨や地震による表層崩壊や地すべりが数多く発生している。我々はこれらの斜面災害について GIS 技術を利用して、地形解析などを試みた。とくに、豪雨による崩壊では、1983 年の島根県浜田、2003 年北海道日高、2004 年新潟県出雲崎、同年愛媛県新居浜、2009 年山口県防府で発生したものについて、GIS 解析を実施したのでその概要を報告する。また、最近、写真判読による地すべり地形図がほぼ全国が完成し、digital data として配信されているので、これらを使用した GIS 解析を始めている。これらの GIS 解析にあたっては、国土地理院からの 10m_dem データ（基盤地図情報）や、地質情報総合センターからのシームレス地質図データベース(GEO_DB)を活用した。

1.Introduction

Japan Islands are composed mostly of fragile rocks because of young ages and fracturing due to tectonic deformation and faulting. Therefore, Japanese Islands are prone to landsliding caused by earthquakes due to active faulting and heavy rainfalls. Actually, recent heavy rainfalls triggered many shallow landslides and also intensive earthquakes triggered many shallow- and deep-seated landslides. In this paper, we are using GIS analyzing heavy rainfall induced shallow failures in 1983, July, at Hamada, in 2003, August at Hidaka, in 2004 July at Niigata, and in 2004 October at Niihama, and July 21 2009 at Houfu, Yamaguchi. In addition, we are now analyzing deep-seated landslides in Hokkaido and Shikoku Island.

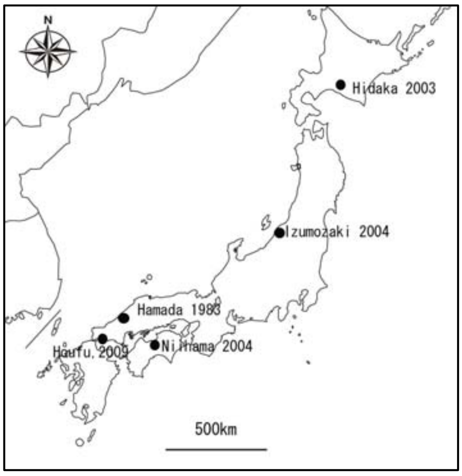

Fig. 1 Location map of the recent heavy rainfall-induced failure area.

2.GIS using analyses of heavy rainfall-induced landslides in Japan

2.1 Heavy rainfall-induced landslides in 1983 in Hamada area, Chugoku region

Gomorophological and geological setting

Hamada area (Fig.1)covers a total area of 155 km^2. The western part of the study area is a coastal area of hills and plains with elevations generally lower than 150 m; but some isolated hills (monadnocks) have elevations of between 260 m and 400 m. The eastern part is more mountainous, with peaks elevations of up to 700 m. Lithologies in the area mainly consist of (a) Paleozoic to Mesozoic pelitic and psammitic schists, (b) Paleogene diorites and granitic rocks, and (c) Paleogene rhyolitic to dacitic pyroclastic and volcanic rocks. In addition to these rocks, Quaternary deposits form terraces and alluvial plains within valleys .Schists form a low hilly terrain with a relatively higher drainage density than the igneous rock terrain. The regional structural trend of the schistose rocks is NE-SW. Dioritic plutonics form isolated high peaks. Volcanic and pyroclastic rocks form a higher mountainous terrain with steep slopes in the northeastern part of the study area.

The 1983 Hamada Rainfall failures

An heavy rainfall occurred between July 20th and 23rd, 1983 and triggered numerous slope failures and caused flooding in western Shimane. The total precipitation was recorded at 742 mm and the maximum hourly intensity was 90 mm/h. This hourly precipitation corresponds to a 150-year recurrence, and the maximum daily precipitation (372 mm/day) corresponds to over a 200-year recurrence.

According to Research Group of San'in heavy rainfall disaster of Shimane Univ. (1984), most failures were shallow, from colluvium and residual soil, and were related to topographic and geologic conditions in addition to precipitaion intensity. The highest frequency of failures occurred on 30º to 40º slopes, and the largest slope failures occurred in granitic rock regions.

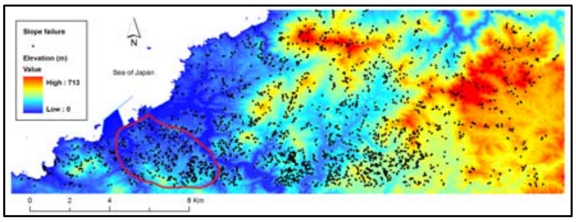

Fig. 2. Distribution of slope failures (Pimiento and Yokota, 2006) and elevation from 10 m DEM (Geographical Survey Institute of Japan, 2009). The centers of the source area of the failures are represented as points. Notice that the encircled area is sub-area which is much concentrated in failures.

Distribution of slope failures

The slope failure distribution (Fig. 2) was obtained from the stereoscopic interpretation of 1:8,000 scale black-and-white aerial photographs that were taken just after the rainstorm. Fig. 2 shows only the source areas of the failures; the deposits of slope failures were omitted. The average size of rupture surface was 1,400 m^2; and 40% of all failures had a surface of rupture between 500-1,000 m^2 (Pimiento and Yokota, 2006).

Slope failures in relation to slope gradient and elevation

The slope failure distribution map (Pimiento and Yokota, 2006) was compared to slope gradient and elevation. The elevation data is the 10m DEM downloaded from the Website of Geographical Survey Institute of Japan (2009). In relation to slope gradient, in the total area (Fig. 2), the failure density increases up to around 35-45^{O} with slope degrees (Fig. 3). While, the failure density of the sub-area (Fig.2) which is highly concentrated, show that the peak of 3.2% for the 25-35 degree slope class.

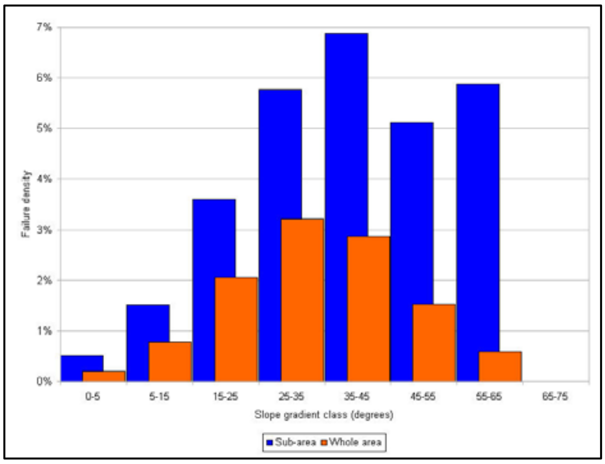

Fig. 3. Frequency distribution of percentage of failure density in relation to slope gradient classes. Whole area analyses indicate that the peak is around 25-30 degrees, but sub-area is that density increases with the slope degree.

In relation to elevation, failure density on the total area was higher than the general density between 100 and 350 m; it was very low for elevations above 650 m and low between 350 and 500 m. The number of failures gradually increased to 459 events for the 150-200 m class, and then the frequency decreased gradually for higher elevation classes.

2) Rainfall-induced failure distribution in the Izumozaki , Niigata from 1961 to 2004

On July 13, 2004, heavy rainfalls due to the strong activities of rain front occurred in the Mid Niigata Region, Japan. They are as much as 400 mm in 24 hours, bringing about serious flooding by breaking the river banks. The heavy rainfalls also triggered more than 3359 failures which were inventoried by air-photographs by Asia Air Survey Co. Ltd. The air-photograph interpretation and field research revealed that two types of landslides were inventoried; one is shallow failure and the other is deep failure which is associated with mudflows. We are focusing the shallow failures in the Izumozaki area. Because the area was affected mostly by many shallow failures due to 2004 July rainfalls, and was also damaged by the same type of failures in 1961 August, and 1976, 1978. Therefore, we have interpreted the air-photographs of Izumozaki area of 1962 (one year later of the heavy rainfalls in

1961), 1980 (1976-1978 rainfalls) and 2004 (just after the July 13 rainfalls) .In this paper, using GIS, we have analyzed the failures on July 13, 2004 in order to make clear the relationship between the failures and slope degrees in the polygonal area as shown in Fig. 4a. W have made slope distribution map derived from 10 m grid DEM(GISMAP) and divided into 5 zones in gradient zones with intervals of 8^{o} degree.

As the results, we have revealed that shallow failure density is exponentially increasing up to 31.8-58.3 zone (Fig. 4b). The fact suggests that failure density mostly depends on the slope degrees.

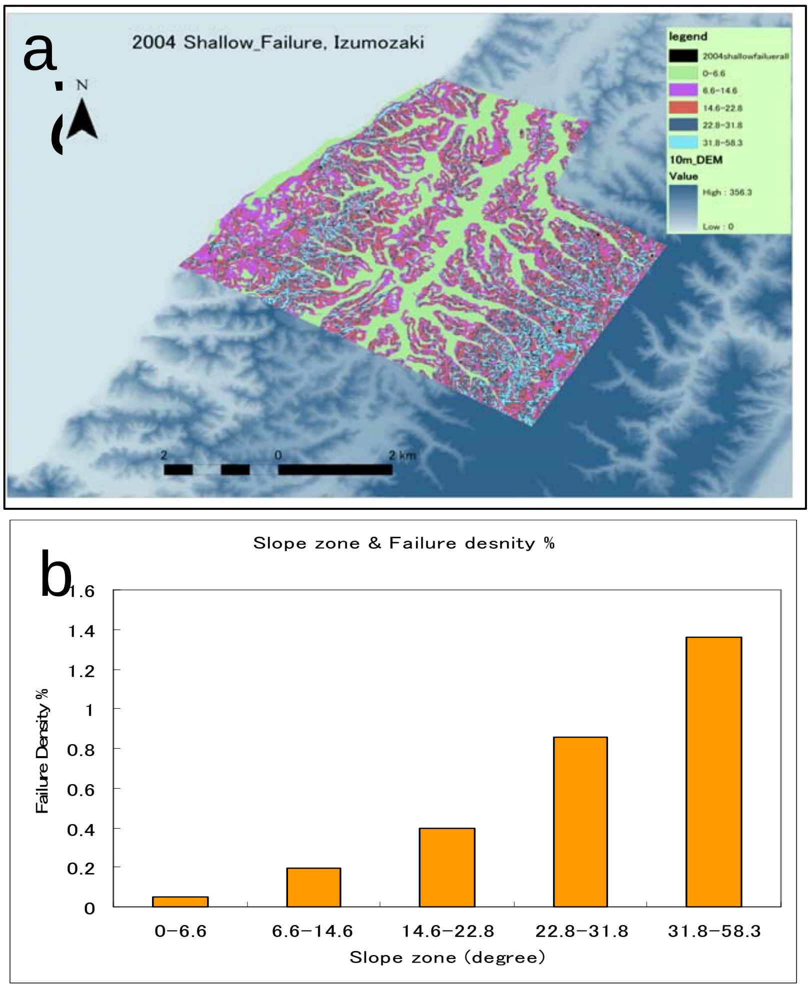

Fig. 4 a: Map showing the interpreted area of the 2004 heavy rainfall-induced failures in Izumozakii, Niigata . b: Graph showing the relationship between the failure density and slope gradient zones

Geologic lithology and failure distribution

Using GIS, we have plotted all of the failures from 1961 to 2004 into the geologic map which was simply divided into sandstone area and mudstone area. As the results, in any year of 1961, 1976,-1978, 2004, the failure density in the mudstone areas is larger than that in the sandstone ones (Yamagishi et al., 2008).

Strata dipping and failure distribution

Using GIS, we put all of the vector data of the failures into the raster distribution map of dipping of geologic strata (5 zones) derived from the Neogene sedimentary rocks. As the results, we have obtained that most of the failure density of each strata-dipping zone of 5 zones, are not so much affected by the dipping of the strata (geologic structures of bedrock) (Yamagishi, et al., 2008).

2.2 Heavy rainfall-induced failures in 2004 October at Niihama, Shikoku

In 2004, total ten typhoons were landing on Japanese Islands, and many places were affected by heavy winds and rains throughout Japan.

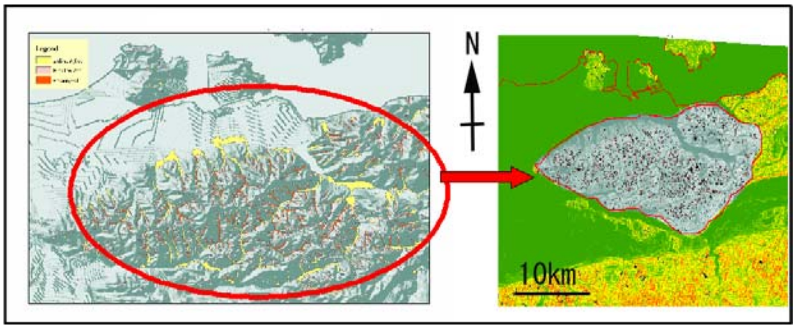

Fig. 5. 2004 failure distribution map of Takihama, west of Niihama. Left; Shallow landslide distribution map inventoried by Aero Asahi Corporation on the basal map derived from 10m_DEM provided by Geographical Survey Institute. Right ;Area for the analyses.

According to the Meteorological Agency, Japan, Typhoon no. 21 took a way to southern island of Japan and reached to the southwest Japan on Sep 27, 2004, and passed Shikoku on Septermber 29- 30th , where totally more than 400 mm precipitation was recorded. By the precipitation, Niihama, Ehime Prefecture were damaged by the many shallow failures which were inventoried as total 1300 failures by Aero Asahi Corporation (Fig 5) .

In the highly affected area (Takihama; Fig.5), east of Niihama City, the total number of slope failures was 900 with a total area of 1.2 km^2. Slope gradient values were reclassified into 10-degree classes and the failure density gradually increased to 9.5% for the 55-65 degree slope class; then it decreased drastically for up to more than 65^o degree (Fig. 6a). In relation to elevation, failure density increased gradually and was higher than the average density between 120 and 250 m; then it decreased for higher elevations. The number of the failures gradually increased to about 300 for the 130-140 m class, and then the frequency decreased gradually for higher elevation classes. Finally, the number (count) of the failures are preferably concentrated to the western original slopes (Fig.6b).

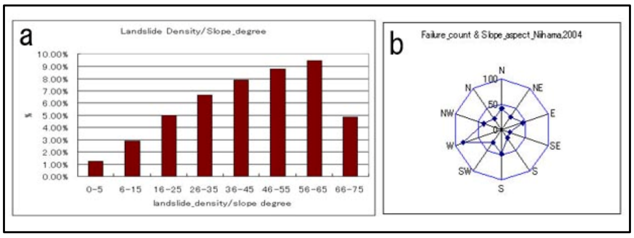

Fig. 6 a: Relationship of the failure density to the slope degree class. b: Radar chart of the failure directions of the 2004 Niihama disasters.

2.3 Heavy rainfall-induced landslides in 2003 in Hidaka, Hokkaido

In Hidaka area, Hokkaido, in August 9th to 10th, 2003, typhoon No.10 was closing and landing at Hidaka Mountains. The typhoon brought about total more than 400mm precipitation within two days. At maximum, 50mm/hour was recorded. As the results, total 20,000 failures were inventoried along the Sarugawa and Appetsugawa tributaries (Fig.7a). In this section, we are focusing the concentrated failure area along the Appetsugawa (Fig.7b).

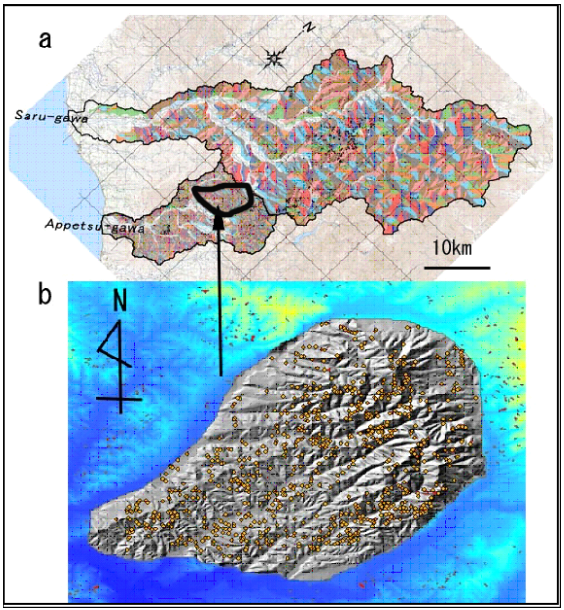

Fig. 7 a: Failure distribution map of Sarugawa and Appetsugawa Tributaries. b:Failure concentrated area which is dealt using GIS.

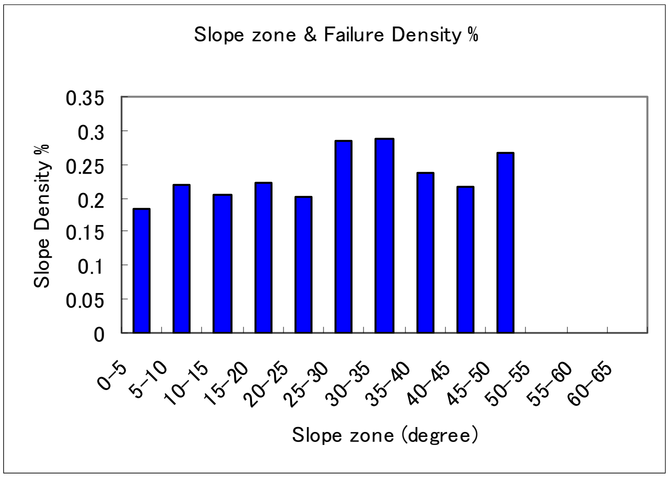

Fig.8 Bar graph showing the relationship between the failure density and slope-class.

We are analyzing the failures using GIS and 10m_DEM for clarify the relationship to slope gradient.

As the results, we have obtained the graph in Fig.8.The graph shows different patterns from the failures of the other areas; even gentle slopes show relatively high failure density, and the highest peaks are ranging from 25 to 35 degrees. While, the failure number related to slope gradient has a peak at 25-30 degree.

2.4 Heavy rainfall-induced landslides in 2009 in Houfu, Yamaguchi

On July 21 to 22, 2009, heavy rainfall attacked the Houfu Area, Yamaguchi Prefecture (Fig. 9). In particular, on 21th, total daily precipitation reached 275 mm and maximum hour precipitation was documented at 72.5mm (Japan Meteological Agency). As the results, many failures and debris flows occurred along the Sabagawa Tributaries, killing 14 peoples and destroyed many houses and facilities. These areas are composed of mostly deep-weathering deposits from granites. We have analyesed only the slope failures along the Tsurugigawa tributary (left photo of Fig.9) by GIS technologies using 10m_DEM derived from Geographical Institute, Japan. As the results, both of the failure number (Fig. 10b) and density(Fig.10c) show the peak 23 to 29 degree zones.(Fig.10)

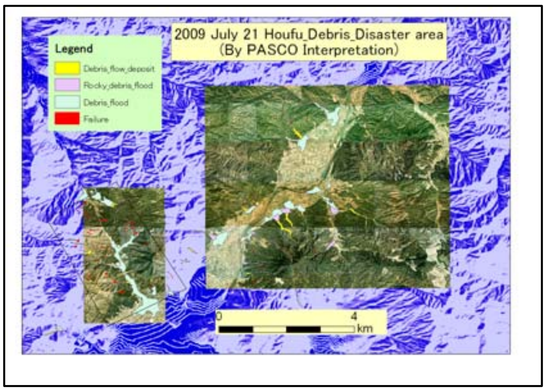

Fig. 9: Map showing the disaster zones by July heavy rainfalls in Houfu city, Yamaguchi Pref. Left photo shows the Tsurugigawa Tributary. Right photo shows the Sabagawa Tributary. Photo interpreted by PASCO Co. Lt,

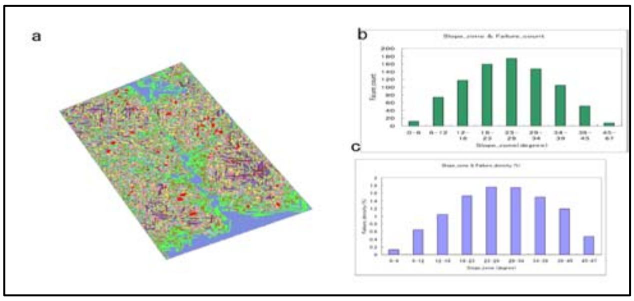

Fig. 10 a: Distribution of slope zone of along (western Sabagawa Tributries), b: Graph showing the relationship between the slope zone (5 degree m interval) and failure number (10m grid cell count), c: Graph showing failure density (failure cell count/ total area count) related to the slope zone.

3.GIS analyses of deep-seated landslides in Hokkaido and Shikoku

In Japan, there are many deep-seated landslides which were inventoried through air-photographs (Fig. 11). Those in Hokkaido island were inventoried by Yamagishi, H. (1994) and those in Honshu, Kyushou and Shikoku were inventoried by NIED. Some of the landslides are prone to reactivation triggered by snow melting, heavy rainfall and earthquakes etc.

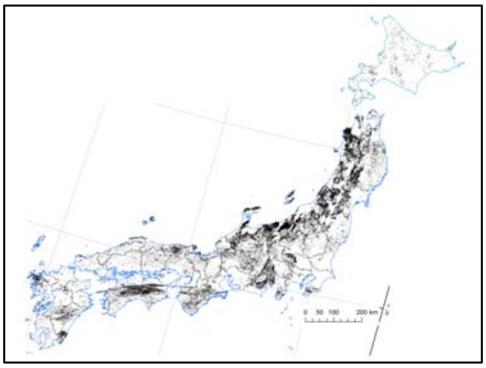

Fig. 11 Map showing the distribution of deep seated landslides in Japan (Yamagishi, 1994 and NIED.

Hokkaido Island has more than 12,000 deep-seated landslide sites according to Yamagishi (1994). GIS analyses of the landslides related to Geology (total 200 legends of GeoDB were dissolved into 13 legends) has revealed that most of the landslides are distributed in the Late Cretaceous to Miocene volcanic rock areas as shown in Fig. 11.

Shikoku Island has a few plains and most of the island has slope areas (more than 15^{o} in inclination) of 78% which is much more the average of whole Japan. Therefore, the Shikoku island has many landslides some of which are historical landslides from ancient times (Fig.13). In addition, famous

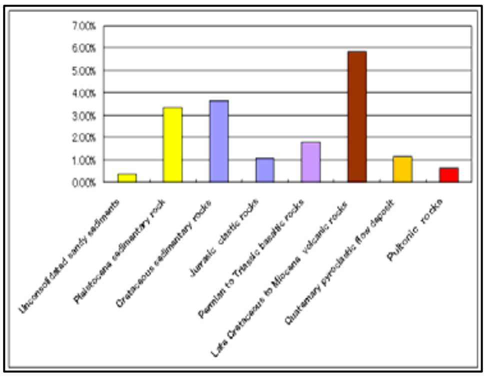

Fig.12 Bar graph showing the landslide density at each geologic unit (total 13 geologic units).

active fault called Median Tectonic Line is running in E-W direction throughout the island（Fig.13）.Namely, Shikoku Island has relatively high potential of natural hazardsin Japan although it has no active volcanoes. Climatologically, the island has been attacked sometimes by typhoons. Actually, in 2004, Niihama area of the Ehime Prefecture was damaged by numberless failures by heavy rainfall which is similar to the disaster occurring in July 13, 2004, in Niigata region as we mentioned above. Finally, we are afraid of the big earthquakes called Nankai-Tonankai Earthquake which was 300 years ago, therefore it will be presumably occurring along the plate boundary of the Pacific Ocean. Therefore, it is urgent topic how to prevent the big hazards from Shikoku Island. Thus, we are now preparing Shikoku GIS Disaster Maps for the basic database for detailed hazard maps using GIS and many available data provided from governmental organizations, such as NIED, Japan etc.

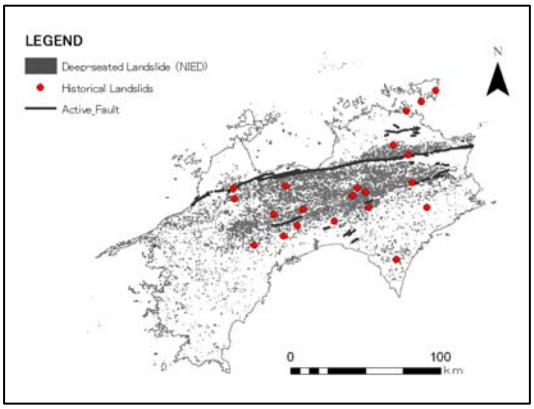

Fig. 13 Map showing Landslide inventory map from NIED and historical landslides (MLIT) and active faults in Shikoku)

4.Conclusion and summary

In this paper, at first we have analyzed using GIS the recent heavy rainfall landslides at 2003 Hidaka, Hokkaido, 2004 Izumozaki, Niigata, 1983 Hamada, Shimane,2004 Niihama, Ehime, and 2009 Houfu, Yamaguchi in Japan. We have analyzed the failure distributions and their relationship to elevation, slope degrees and curvature in places, using 10_DEM. As the results, particularly on the relationship to slope degrees, at Izumozaki and Niihama, highest failure densities are up to 58^o-65^o degree, while at Hidaka, Hamada and Houfu, those are up to 23^o-35^o degree. The bedrock geology of former two are composed of sedimentary rocks, while that of the latter three are of granites and metamorphic rock, excepting for Hidaka area which shows different patterns from the two. Namely, this area consists of sedimentary rocks as bedrocks, covered by Quaternary pumice deposits. The mentioned above may be due to the difference in surface materials rather than bedrock geology. However, the slope zones of the highest count (number) of the failures exist, in common, within 23 and 32（Table 1）.

Fialure Disaster Name	2003 Hidaka Failure	2004 Izumozaki Failure	1983 Hamada Failure	2004 Niihama Failure	2009 Houfu Failure
Slope zone (degree) of highest failure numbers	25-30	23-32	25-30	25-30	23-29
Slope zone (degree) of highest failure density	25-35	31 –58	25 –35	28 –65	23 –29
Bedrock geology	Tertiary sandstone/ mudstone	Tertiary sandstone/ mudstone	Cretaceous grantite, Metamorph icrcoks	Cretaceous sandstone /mudstone	Cretaceous granite
Surface geology	Quaternary pumice deposits	Weathered sandstone/mudstone	Deep weathered granite, weathering soil	Weatherings sand,sandston e/mudstone	Deep weathered granite

Table 1: Summary of the relationship between the failures numbers/ density and slope gradients, and geology of each area.

In addition, we are now starting GIS analyses of the deep-seated landslides in Hokkaido and Shikoku, for susceptibility mapping for reactivation in the future. **Acknowledgement:** We are grateful to Aero Asahi Corporation, PASCO, Ehime Prefecture, National Research Institute for Earth Science and Disaster Prevention (NIED), Geological Survey of Japan (GSJ, GEODB) and Civil Engineering Research Institute for Cold Region (CERI), for useful digital data for GIS analyses.