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Paper:

# Application of ICT to Contribution to Resilient Society Against Landslides

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**Among the three online landslide databases introduced here, we focus on Japan's large-scale online landslide topography distribution mapping as a gratis Software as a Service (SaaS) application that has proven effective in hazard mapping because many large new landslides have recurred at old landslide sites. Google Earth is an effective SaaS hazard-mapping tool for extracting local community landslide microtopography. Combining these maps and hand-written landslide site drawings provides economical, reliable hazard maps for community residents in developing and developed countries. Author proposed a possibility of undergraduate students volunteer acitivties for promoting hazard mapping. The early warning system based on Tropical Rainfall Measuring Mission (TRMM) Multisatellite Precipitation Analysis (TMPA) and the Japanese soil-water index (SWI) may contribute to making society more resilient against landslide disasters.**

**Keywords:** SaaS online database, landslide distribution map, hazard map, student volunteer activity, TRMM

## 1. Introduction

Landslides triggered by heavy rain, earthquakes, underground erosion, weathering, and rock creep cause a high human toll annually both in traditionally vulnerable urban areas and hill districts settled as populations grow and spread. Hazard mapping is one way of effectively raising awareness and the need for preparedness among residents, but detailed maps are as yet available only in developed countries, pinpointing the need for reliable landslide distribution maps.

Bruneau and Reinhorn's "resilient society" concept defines a society resilient against disaster and quick at recovery [1] marked by the 4 Rs of preparedness – robustness, redundancy, resourcefulness, and rapidity. Following the disastrous 1995 Kobe quake, the Resilient Society Research Group of Kyoto University expanded this concept to add that a resilient society has both response and recovery capability and the capability to develop preventive measures [2] Such as structural hardware and information communication technology (ICT) application. ICT has been proven to reduce catastrophic societal damage risk by exchanging information among responsible people and volunteers.

Minimizing landslide disaster effects in developing countries could contribute to community resilience by making reliable hazard maps available on the Internet and increasing residential participation in community meetings and bolstering community resilience by enhancing the 4 Rs of preparedness – robustness, redundancy, resourcefulness, and rapidity.

An important new Internet application pertinent to this discussion is Software as a Service (SaaS) – a Web application used on demand to provide services requiring no user-computer resources. SaaS enables highly secure communication and easy data transmission providing reliable information resources, e.g., on landslide distribution, for hazard maps creating by residents themselves. This two-part paper consists of part 1, which introduces landslide database examples in Japan and developing countries, and part 2, which suggests how to create landslide hazard maps through the joint efforts of residents, volunteers, and experts. plus an early warning concept based on combined landslide databases and satellite rainfall monitoring. Our proposals can contribute to constructing a society more resilient against landslide disasters in developed and developing countries.

## 2. Online Landslide Databases

In 1990, when the International Decade for Natural Disaster Reduction (IDNDR) began as a United Nations General Assembly campaign, UNESCO and three international geotechnical societies launched a working group on world landslide inventory [3] whose objectives included setting up global landslide inventories. Since then, however, with no complete global catalog set up, efforts have been made to contribute to local and global landslide research and engineering communities. We review three representative, widely used online landslide databases below.

### 2.1. Geological Survey of Canada Online News Compilation

One of the most widely used Internet sites on landslide information is the Geological Survey of Canada's


**Fig. 1.** Recent landslide events worldwide at the Geological Survey of Canada Web site.

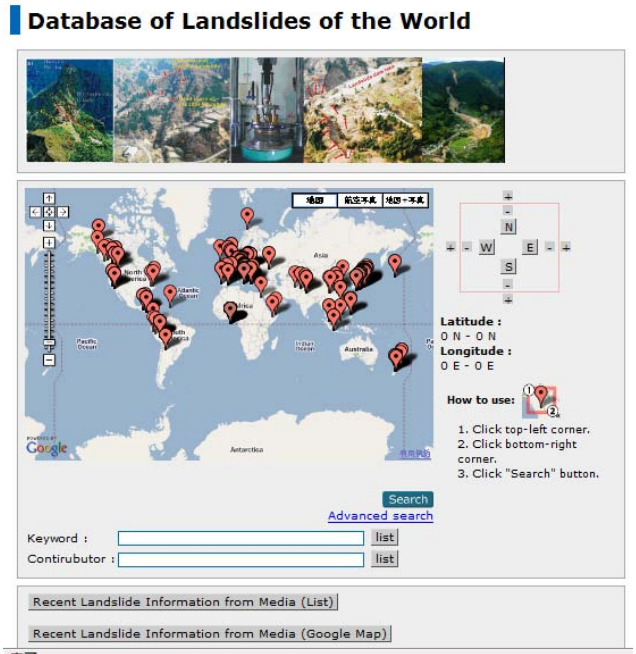


**Fig. 2.** International Consortium on Landslides (ICL) world landslide database Web site.

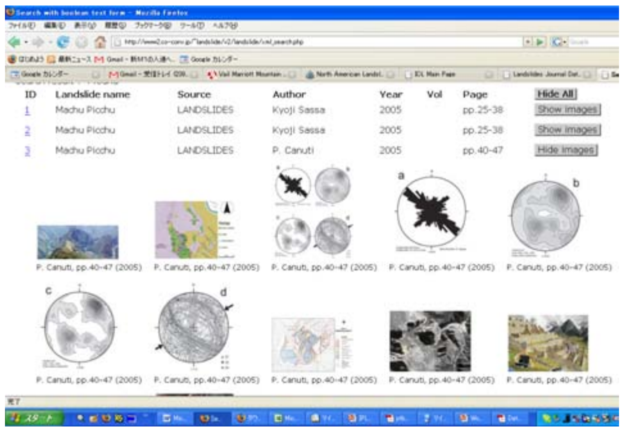

**Fig. 3.** World Landslide Database site examples of thumbnail photos and figures.

Landslides – Recent Events Worldwide (**Fig. 1**) [4], which lists news on landslides collected from English news sites worldwide. This site does not show geographical locations of individual landslides and cannot maintain past news archives due to copyright restrictions.

## 2.2. ICL Online Database

The ICL is the first international organization promoting international joint field research. The ICL has been publishing the "Landslides" journal via Springer Verlag in Germany since 2004, accumulating numerous technical papers on landslides.

The World Landslide Database project of the International Programme on Landslides (IPL), one ICL activity, was launched jointly by our group and colleagues from Italy, Canada, and the US. This project received a scientific research grant-in-aid from the Japan Society for Promotion of Science (JSPS) and constructed a global online landslide database [5, 6]. This database extracts photos and figures from specific landslide sites in papers published in the Landslides journal. **Figs. 2** and **3** show examples of the site's screen copies, i.e., geographical landslide sites and photo and figure thumbnail of selected landslides. While updating is somewhat limited, contents are peer-reviewed and reliable.

## 2.3. Online GIS Landslide Topography Database Distribution in Japan

Located near the tectonic subduction zone, Japan is one of the world's most landslide-prone countries. The Japan Ministry of Land, Infrastructure, Transportation and Tourism (MLITT), the Ministry of Agriculture, Forestry, and Fishery (MAFF), and the Forestry Agency of Government of Japan have designated landslide risk areas – shallow disrupted slides, slow deep-seated slides, and debris flows – for restricting further development and for implementing prevention work. This information is available in printed and electronic Internet media and municipal prefecture or city government sites. Designated sites are, however, limited to slopes exceeding criteria defined by the relevant laws and may have larger societal impact when it fails. Many more slopes do not meet legal criteria and often potentially risk residents.

Many landslide researchers and engineers have used aerial photography to determine the distribution of old landslides in Japan, finding many more than the number registered by the government. Landslide block boundaries are clear for recent landslides but unclear for ancient ones. Yamagishi et al. have published distribution maps of 12,800 landslide topography covering 77,000 km$^2$ of Japan's most northeastern island of Hokkaido [7, 8],

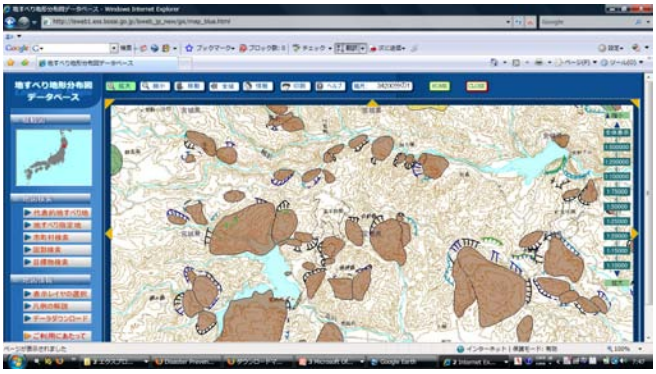

**Fig. 4.** SaaS online map landslide distribution application in Japan, established by the National Research Institute for Earth Science and Disaster Prevention (NIED). Shaded areas are large-scale landslide sites.

**Fig. 5.** Hand-drawn hazard mapping by local residents at a workshop organized in a remote Honduran village.

strongly impacting on the landslide scientist and engineer communities.

The NIED's landslide research group has been geomorphologically studying landslides in Japan, conducting topographical map and aerial photography interpretation of large-scale landslides, publishing a series of 1:50,000 scale maps including information on landslide block boundaries and scars since 1984 [9]. They have cataloged over 600,000 landslides. Since the 1990s, they have moved data to GIS and opened data to the Internet since 2000 [5, 10]. **Fig. 4** shows an example of these maps at the largest scale. Dark brown (shaded) areas show landslides themselves and bold lines head scarps. Although landslides may, of course, occur in less landslide-prone zones, most new landslides have recurred within or near old landslides in this database, which since then has been evaluated as a excellent landslide hazard map by researchers, residents, and those in charge of municipal disaster management.

## 3. Proposal for Hand-Drawn Hazard Maps of Past Events Combined with Landslide Microtopography Mapping

### 3.1. Hand-Drawn Hazard Mapping

The Japan International Cooperation Agency (JICA) has promoted the Community BOSAI (disaster risk mitigation/management) project in six Central American countries since 2002. This project builds local community capacity against floods and landslides through hazard mapping, enhancing preparedness, and installing early warning systems (EWS). We have been involved in education and hazard mapping for this project.

Community landslide and flood hazard mapping developed by the project includes (1) drawing community maps by hand on large sheets, (2) plotting past landslide occurrence sites and casualties/damage by residents themselves mostly based on memory, and (3) determining resources for similar future disasters. This hazard mapping's noteworthy feature is the active participation of residents raising their risk awareness despite of hazard descriptions less precise and reliable than the ones prepared by experts. **Fig. 5** shows the workshop for creating hand-drawn flood and landslide hazard maps by residents of remote communities in Honduras, Central America, jointly organized by JICA and the civil defense department of the Honduran government.

### 3.2. Landslide Microtopography Mapping with Google Earth

We have proposed using Google Earth, a free public SaaS application, for effectively extracting landslide microtopography. It also dramatically lowers cost compared to conventional maps prepared by landslide geomorphology experts. Google Earth provides satellite images and aerial photographs with resolutions from 15 cm to 15 m and contains elevation data supplied by NASA's Shuttle Radar Topography Mission (SRTM) with 1 m vertical resolution and 30 m to 90 m horizontal resolution. It covers global land and the seafloor, providing three-dimensional and oblique view of slopes, even expanding elevation up to 3 times actual measurement.

Landslide types and movement vary widely, meaning that precise geomorphological photointerpretation requires a certain level of experience. Among all types, long-runout landslides are the most dangerous to residents downslope. Locating recent and older long-runout landslides is comparatively easy because paired depressions beneath head scarps and long lobe-shaped debris deposits are often highly visible even to beginners in geomorphology. Head scar-topography sharpness is a good indicator of landslide age, meaning Google Earth data is sufficient for interpreting recent small- to large-scale long-runout landslide topography.

**Figures 6** and **7** examples of oblique Google Earth photo interpretation show mountain slopes behind a local community where the hazard mapping workshop was or-

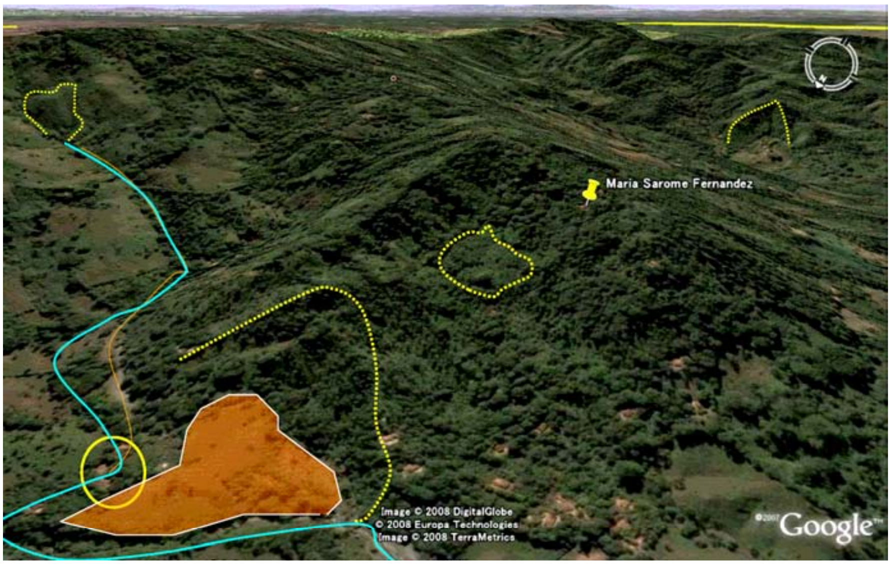


**Fig. 6.** Example of landslide microtopography mapping in a remote Honduran village.

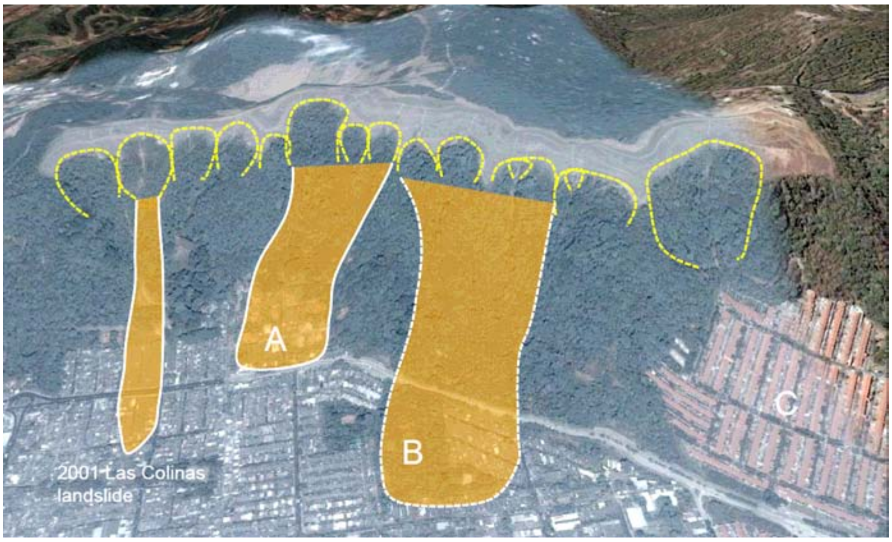


**Fig. 7.** Example of landslide microtopography mapping in densely populated El Salvador.

ganized in a remote village of Honduras. Yellow dashed lines show recent and potentially suspicious landslides. Orange parts indicate possible landslide deposits from the slope. This is confirmed geomorphologically by a mound associated with irregularly deflected torrents shown as blue lines. Isolated smooth and projecting slope areas are regarded potential landslides such as that marked by a yellow dashed line at upper left and center. **Fig. 7** focuses on a cliff in densely populated Nueva San Salvador, El Salvador, Central America. The map indicates that the cliff was formed in large-scale volcanic subsidence. The Las Colinas landslide at this cliff was triggered by the 2001 Offshore El Salvador Earthquake, which killed over 500 residents of the downslope town (orange area at left). Along the cliff top, we found many past and potential head scarps (yellow dashed lines), some associated with visible landslide deposits downslope (orange). The many luxurious dwellings located on landslide deposit A provide highly desirable views, but are exposed to high future landslide risk induced on the upslope. No houses were constructed at left of deposit B, although housing is constructed to the right of the mass, also at similar risk. The new residential estate developed recently at C is similarly threatened by landslides from surrounding cliffs.

The NIED online landslide database includes only large-scale deep-seated slides generally exceeding 150 m, rather than smaller shallower landslides, landslides more generally frequent and often affecting communities. Google Earth imagery enables much smaller landslides to be extracted, making it a good landslide microtopography tool, especially for areas covered by high spatial resolution photography and elevation data.

Developed nations such as Japan, the US, and European countries can use experts for territorial surveys to extract landslide risk sites and create precise, reliable hazard map, even using simulation to predict future flood and landslide scenario in densely populated, socially important areas, but most developing countries cannot do so due to restricted national and municipal budgets and to legislative or legal restrictions such as the illegal occupation of hilly residential areas.

### 3.3. Voluntary Hazard Mapping Activities by University Undergraduates

We have organized preliminary volunteer field testing using university undergraduates whom we have visit residents at a Malaysian landslide disaster site, making students aware of the price of disaster in, for example, lost family members and/or property. Students may have no professional skills, but they can engage in psychological care to minimize post-traumatic stress disorder (PTSD) and other effects. Simply listening to the experiences of disaster victims and showing sympathy, i.e., active listening and sympathy, can reduce PTSD. **Fig. 8** shows students interviewing residents hit by the 2006 Zoo View landslide disaster in Kuala Lumpur, Malaysia. This landslide occurred at an artificial fill in an expensive residential area, with the landslide flowing into a low-income residential area downslope and killing 4 [11]. They detailed the circumstances of the landslide but had no understanding of background mechanisms, further landslide risk, and signs of potential landslides. Combining student volunteer activities with hand-drawn hazard mapping based on landslide microtopography using Google Earth is thus a promising, powerful methodology for raising awareness and preparedness in local communities. Because Google Earth is a SaaS application enabling cooperative Internet activities among nations, landslide microtopography mapping could be supported by an expert community in quasi-real time – another feature that should be highlighted. SaaS applications such as Google Earth could thus enhance and promote local community resilience against landslide disasters using ICT supported by the "wisdom of the crowd" on the Internet.

**Fig. 8.** Interviews of victims of the Zoo-View landslide in Kuala Lumpur, Malaysia, by the author and undergraduate volunteers.

## 4. Proposal for Regional Quasi-Real-Time Landslide EWS Using Remote Satellite Precipitation Sensing

The Japan Aerospace Exploration Agency (JAXA) and its US counterpart NASA jointly launched a rainfall monitoring satellite Tropical Rainfall Monitoring Mission" (TRMM) in 1997 targeting precipitation distribution from the tropical to middle latitude areas. The satellite's active radar sensors detect precipitation and its infrared sensors measure cloud temperatures. Radar sensors scan narrow areas supplemented by wide-range infrared sensor sweeps. This project was later expanded combining similar satellites to create TRMM Multisatellite Precipitation Analysis (TMPA). This system now provides almost real-time 3-hour rainfall via 0.25-degree (latitude/longitude) grid cells. These estimates are based on infrared data and calibrated locally by ground-based rain gages. Several groups in Japan and the US are now developing more precise TMPA readings. Because this system monitors areas 24/7, it can potentially provide quasi-real-time rainfall information to local communities in developing countries having no rain gauges. **Fig. 9** shows photos of Beichuan after the May 12, 2008, China-Wenchuan Earthquake, near whose epicenter a serious debris flow occurred on September 24, 4 months after the quake. Dozens of residents were killed in the debris flow because the lack of rain gauges, for example, prevented local authorities from issuing an alert. TMPA grid cell records including this are shown in **Fig. 10**. Total precipitation in the three days preceding the debris flow exceeded 200 mm, triggering the debris flow. If such information had been available, it is likely that local residents could have been evacuated rather than decimated [12, 13].

Hong et al. and Liao et al. developed a quasi-real-time flood and landslide warning system [14, 15] based on the relationship between mean rainfall intensity (mm/hour) vs. rainfall duration (hours) as a landslide triggering threshold proposed by Caine [16]. They prepared landslide susceptibility maps based on global topography, soil properties, land cover, geology, and morphology. They combined TMPA rainfall data with susceptibility to create a new risk map. Test results for a certain period showed a good correlation with actual landslide occurrence in Indonesia [17].

We are working with the TMPA research group at the University of Oklahoma in the US combined with the Japanese rain-water index (RWI) to create new, reliable landslide warnings for developing countries. The RWI was developed by the Meteorological Agency of Government of Japan (JMA) to issue landslide alerts in Japan based on the real-time Automated Meteorological Data Acquisition System (AMeDAS) rain gauge station network located at 21 km intervals and covering Japan. Index calculation is based on a "tank model" of 3 cascaded tanks. Observed hourly precipitation is input at the first tank representing the surface soil layer in which water

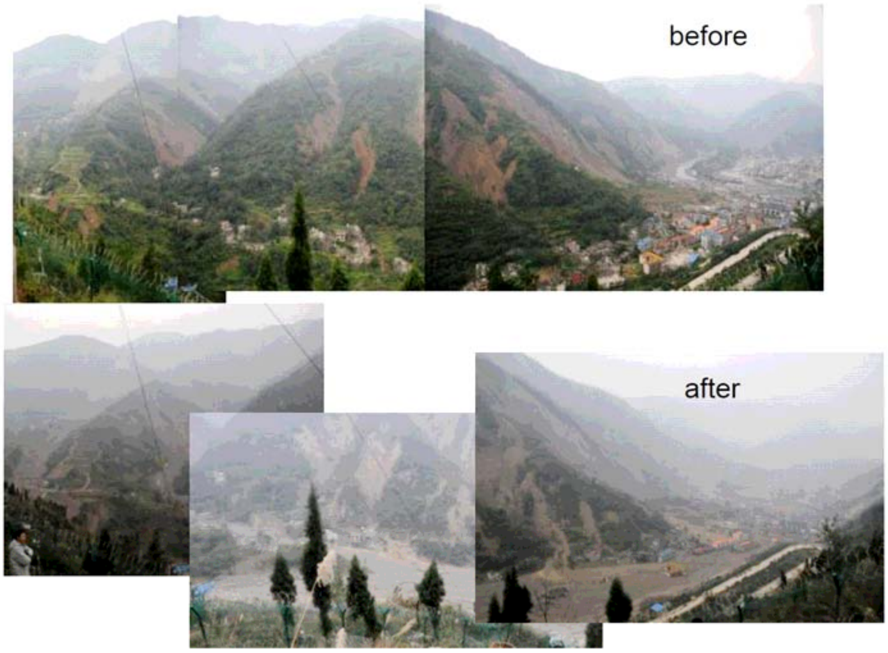


**Fig. 9.** Beichuan, China, before (above) and after (below) the large-scale September 24, 2008, debris flow triggered by 3 days of extreme rainfall.

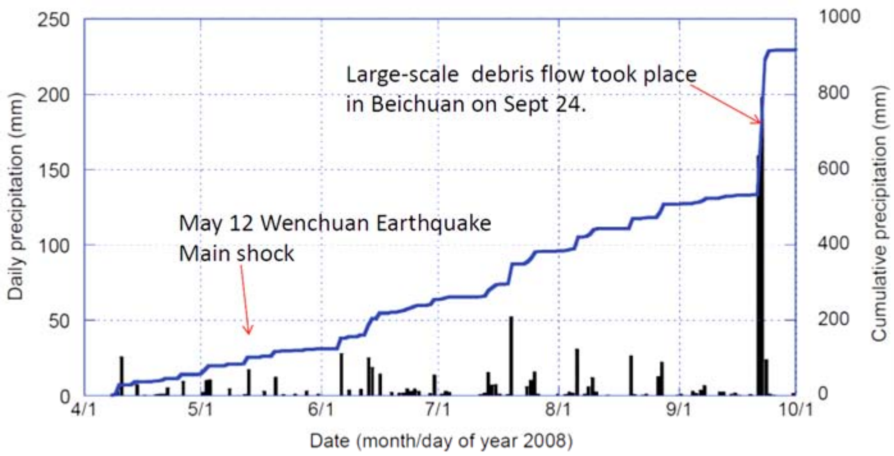


**Fig. 10.** Daily and cumulative precipitation in Beichuan and its vicinity observed by TMPA satellite rainfall monitoring. Extreme rainfall was observed for 3 days preceding the debris flow.

flows into the ground surface and penetrates into a second tank, representing the middle soil layer and a repetition into the third tank representing the deep soil layer. The SWI represents total water in the three tanks. When this amount exceeds the maximum in the last 10 years, the JMA issues landslide alerts to region surrounding the rain gauge [18-20]. This calculation and empirical approach, although simple compared to most of the latest water penetration simulations, predicted 60% of resulting landslide disasters according to a JMA report. Although fixing the tank model coefficients requires considerable assistance from the meteorology communities of targeted countries, the combination of TMPA quasi-real-time precipitation data with SWI is promising for developing smart and simple landslide warning systems covering very wide areas.

## 5. Conclusions

This study presents the following conclusions:

(1) Three online landslide databases were reviewed. The NIED landslide distribution database, a gratis SaaS application, is reliable because original maps were created by landslide experts at the institute. It has proven effective in creating landslide hazard maps because many new landslides have been reactivated at old cataloged sites. Although it covers only Japan, similar maps prepared for other countries through joint international framework effort such as ICL could provide similar assistance.

(2) Google Earth, an advanced smart SaaS application available globally, is a good tool for extracting land-

slide microtopography in local communities. Local engineers and undergraduate students could extract landslide topography under online supervision and collaboration with landslide experts.

(3) Past landslide and flood information should be overlaid by hand on landslide topography maps by community residents. Because many landslides recur in the same place or nearby, past landslide information is valuable. Note that the above activities in local communities could be realized effectively through volunteer activities in disaster areas by undergraduate students. Thanks to (1), above, this could be promoted as an reliable, economical hazard mapping methodology, especially in developing countries; Thanks to (2), ICT and SaaS applications enable the use of the "wisdom of crowds," including exchanges with experts over the Internet.

(4) Implementing EWS based on TMPA and the Japanese SWI could enable an effective evacuation system for remote communities in developing countries having no rain gauge networks.

The author believes that the ideas proposed in this paper can contribute to constructing societies more resilient against landslide disasters in both developed and developing countries.

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• "Influence of shear speed and normal stress on the shear behavior and shear zone structure of granular materials in naturally drained ring shear tests," Landslides, Vol.4, No.1, pp. 63-74, 2007.

**Academic Societies & Scientific Organizations:**

• Board member, The Japan Landslide Society (JLS)

• Board member, International Consortium on Landslides (ICL)

• American Geophysical Union (AGU)