Attempt for hazard prediction of deep-seated landslide based on stream water chemistry

*Norifumi Hotta[1], Tomohiro Egusa[1], Yosuke Yamakawa[2], Yuan-Jung Tsai[3], Shin-Ping Lee[3]

1. Graduate School of Agricultural and Life Sciences, the University of Tokyo, 2. Faculty of Life and Environmental Sciences, University of Tsukuba, 3. Disaster Prevention Research Center, National Cheng Kung University, Taiwan

Deep-seated landslides can cause catastrophic sediment disasters, which could become more important in the foreseeable future with changing rainfall patterns due to climate change. The infrequency of deep-seated landslides prevents the development of countermeasures. For effective mitigation, it is necessary to identify the potential location and timing of a slide. Previous studies have identified potential deep-seated landslide areas (PLAs). In Taiwan, PLAs have been identified using high-definition topographic data (1 m resolution) obtained with aerial laser scanning, based on the precept that deep-seated landslides are associated with geological signatures such as scarp and double ridge resulting from gradual slope deformation. Slope deformation can be induced by the formation of a potential slip surface in the base rock layer; the path of ground water then changes so that it percolates the weathering layer of the potential slip surface, resulting in changes in water chemistry. Therefore, the water chemistry might indicate the extent to which PLAs evolve into slides, as well as the geological signature. This study attempted to classify PLAs by the degree of risk using stream water chemistry.

We targeted over 400 PLAs mainly in the Chishan and Laonong River basins in southern Taiwan, extracted from the Forest Bureau and Central Geological Survey of Taiwan. We collected water samples at more than 700 sites, streams and springs, covering about 200 PLAs during 2015–2017. Sampling was conducted in all seasons and included repeat sampling at the same locations. In the chemical analysis, the electrical conductivity (EC) was measured using an EC meter, inorganic ion (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, NO_3^-, and SO_4^{2-}) concentrations were measured by ion chromatography, HCO_3^- was calculated by subtracting the sum of the charges of cations from that of anions, and the SiO_2 concentration was measured using the molybdenum yellow method.

The results show that about 40% of the PLAs were concentrated on the Chaochou Formation, which consists of slate and sand rock. The water chemistry in repeated samples was almost identical, regardless of the season, indicating that spring and stream water chemistry can be regarded as representative at the sampling points. Piper diagrams, which illustrate the contributions of anions and cations in water, showed that most of the water was Ca-HCO_3 type, which is common for stream water and shallow groundwater. There was no apparent trend by geology and the EC and major ions (Ca^{2+}, Mg^{2+}, SO_4^{2-}, and HCO_3^-) had good positive linear relationships. However, there was a significant negative relationship between EC and Si for the water samples from the Chaochou Formation, while the correlation was positive for water from other geologies.

Silicon is thought to originate from the weathered bedrock layer, and generally shows a positive correlation with EC. A negative correlation can occur if there is an uneven distribution of layers that are rich in Si but short of other ions, and poor in Si but rich in other ions, with preferential ground water flow. Since the spring water from the Chaochou Formation has a higher Si level for a given EC compared with the stream water, the EC–Si relationship could be affected by the flow path. There was a negative EC–Si relationship shifting outwards to a high EC and/or Si in the area with a high density of PLAs. These results suggest that the combination of EC and Si could be effective for determining the risk of PLAs, rather than

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using a single index such as EC or Si, as suggested in previous reports.

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