Study on Correlation of Electrical Conductivity and Potential Large-scale Landslide in Taiwan

Chieh-Hsuan WENG[1], Yuan-Jung TSAI[2*], Chjeng-Lun SHIEH[3] and Tomohiro EGUSA[4]

[1] Master, International Master Program on Natural Hazards Mitigation and Management, National Cheng Kung University, Taiwan (No.1, University Road, Tainan City 701, Taiwan)

[2] Researcher, Disaster Prevention Research Center, National Cheng Kung University, Taiwan (3F., No.500, Sec. 3, Anming Rd., Annan Dist., Tainan City 709, Taiwan)

[3] Director, Disaster Prevention Research Center, National Cheng Kung University, Taiwan (3F., No.500, Sec. 3, Anming Rd., Annan Dist., Tainan City 709, Taiwan)

[3] Researcher, Agricultural and Life Sciences, the University of Tokyo (7 Chome-3-1 Hongo, Bunkyō, Tokyo 113-8654, Japan)

*Corresponding author. E-mail: rongtsai@dprc.ncku.edu.tw

In this study, a total of 415 water samples were taken in southern and eastern Taiwan. The concentration of inorganic ions is detected using ion chromatography with an electricity conductivity meter to detect the electricity conductivity in water samples. In terms of time difference, the electricity conductivity of dry season is larger than wet season, the electricity conductivity value is about 300 μS/m, as electricity conductivity is affected by rainfall. For spatial difference, out of four study zones, the Kaoping watershed has highest value and coastal area in Taitung has lowest value. In Kaoping watershed, the difference of electricity conductivity value is about 200 μS/m. For the relationship between landslide rate and electricity conductivity, the potential landslide rate is calculated by dividing the sub-watershed area into large-scale potential landslide area, using the measurement points at downstream of the sub-watershed to represent the sub-watershed. It can regress a straight line, which R^2=0.59. If the landslide rate is high, the electricity conductivity will be high. For analysis of electricity conductivity of stream, the electricity conductivity of stream is affected by inrush water from the potential landslide. When the measurement points are close to the inrush water, electricity conductivity will raise, on the contrary, when the measurement point is further from inrush water, the electricity conductivity will decrease. Above all, it can handle the relationship between landslide and electricity conductivity and hope to establish the warning system of the large-scale landslide, to fight for more time to respond to large-scale landslides.

Key words: large-scale landslide, water quality, electricity conductivity

1. INTRODUCTION

Large-scale landslide (depth>10 meter, area> 10 hectare, or volume > 100,000 cube meter) disasters have become an important issue after Typhoon Morakot in 2009, which caused more than 400 deaths in Hsiaolin Village [*Shieh et al.*, 2010]. To avoid reoccurrence of disasters, Taiwanese government has proposed a series of disaster prevention and mitigation projects to establish a risk-based framework for large-scale landslide disasters [*Soil and Water Conservation Bureau*, 2015].

The first step of the framework, high resolution digital elevation models, was used to identify potential large-scale landslide areas (PLA). With microtopography, the location and boundary of potential large-scale landslide could be better identified [*Lin et al*, 2012]. There are more than 2,000 sites of potential large-scale landslides identified by the Forestry Bureau, Council of Agriculture, Executive Yuan and Central Geological Survey, Ministry of Economic Affairs [*Forestry Bureau*, 2012*; Central Geological Survey,* 2011].

After the investigation of potential large-scale landslides, it is necessary to predict the occurrence of the large-scale landslide. Rainfall, infiltration and groundwater variation play important roles in the triggering of large-scale landslides [*Shieh et al*, 2013; *Lee et al*., 2015]. It is important to clarify the volume or ratio variation of groundwater as it is the key for early warning systems of large-scale landslides.

The monitoring of volume or ratio variation of groundwater is not easy in mountainous areas, Jitousono et al tried to use electrical conductivity

(EC) as a factor to respond to groundwater condition changes during rainfall events. [*Jitousono et al.*, 2006]

For potential large-scale landslides, the slip surface was under development; when infiltration occurs, groundwater would path the cracks as the flow path. With the development of slip surface, the flow path would increase. With longer flow duration, the EC of the groundwater will increase with more soluble material [*Jitousono*, 2014]. This concept shows the possibility of the early warning system to detect the occurrence of large-scale landslide through EC.

The main purpose of this research is to reproduce the relationship between EC and PLA in Taiwan. Furthermore, to find the possibility of early-warning through monitoring EC of stream water in mountain area.

2. RESEARCH METHOD

2.1 Study area

To reproduce the relationship between EC and PLA in Taiwan, this research attempts to use wide range survey for EC at investigated PLA in south and east Taiwan. In **Fig.1**, PLA, with microtopography of landslide and area is larger than 10ha, were identified from 2010 to 2012 by Forestry Bureau and Central Geological Survey.

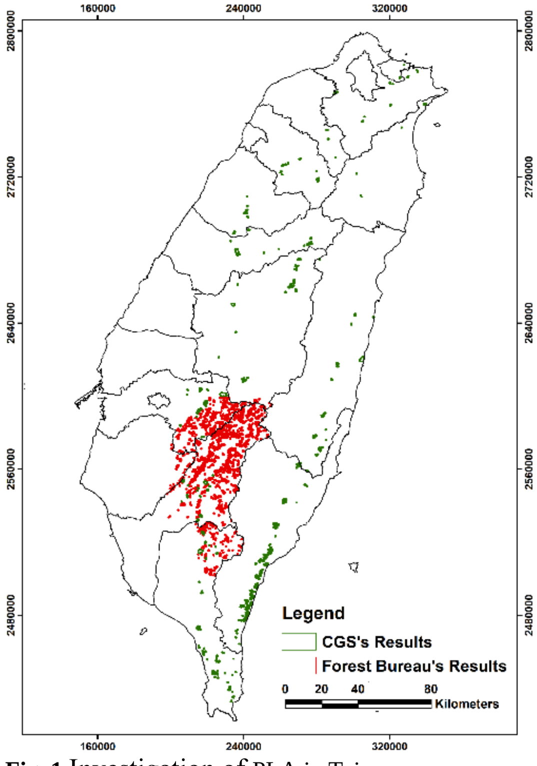

Fig. 1 Investigation of PLA in Taiwan

2.2 Water sampling

To set the relationship between EC and PLA, different geology, seasons, and locations were considered.

For different geology, water sampling work was taken in 8 different watersheds, such as Tsengwen, Kaoping, Linbian watersheds, from western Taiwan, and Zhiben, Dazhu, Beinan and Daniao watersheds, from eastern Taiwan. In consideration of the effect of different seasons, sampling was taken in dry and wet seasons at the same locations. In consideration of spatial difference, the sampling work was taken at three locations in the same watershed (**Fig.2**) such as spring on the slope, start of the stream, and outlet of the stream.

Water samples were collected in a 200 ml pre-washed plastic bottles filled with source water and ensuring there was no air in the bottle for more reliable samples.

	i. Sample at spring on the slope To analyze the water from subsurface water of groundwater.
	ii. Sample at the initial of the stream To clarify the basic condition without groundwater.
	iii. Sample at the outlet of the stream To clarify the mixture condition of stream water and groundwater.

Fig. 2 Location of water sampling

2.3 Source analysis

To avoid polluted water samples, Piper diagram were applied. Piper diagram was used to separate groundwater into four catalogues (**Fig.3**) by anions and cations in the groundwater [*Chiang*, 1994].

Zone I, called Carbonate hardness, was focused on $Ca\text{-}HCO_3$ and identified as unconfined groundwater, rainfall or stream water. Zone II, called Carbonate alkali, was focused on Na-HCO3 and identified as deep confined groundwater. Zone III was called Non-carbonate hardness, focused on Ca-SO4 and Ca-Cl, usually found in volcanic areas. Zone IV, called Non-carbonate alkali, focused on Na-SO4 and Na-Cl, usually identified as saltation by sea water. In this research, only water samples belong to Zone I and Zone II were used for further analysis.

2.4 Water sample analysis

To classify the water sample with Piper diagram, the concentration ions of water samples need to be valued. All water samples were send to

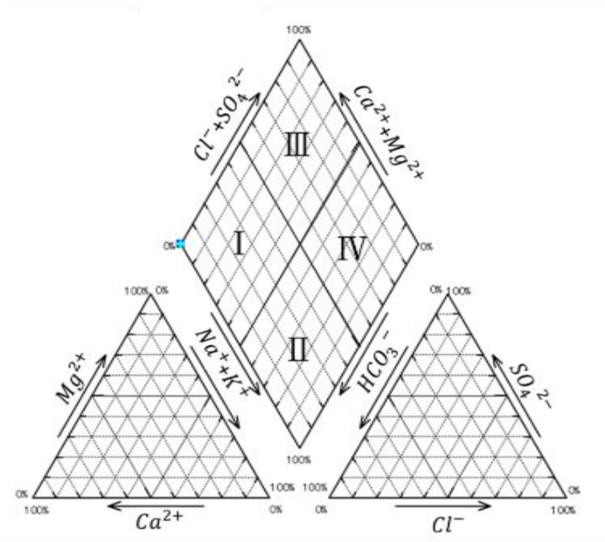

Fig. 3 Piper diagram

the University of Tokyo for ion chromatography (with Shimadzu LC10-A). EC was measured with EC meter such as HORIBA B-713.

Box-and-Whisker Plot was selected to confirm the basic value of EC. This method can show not only maximum, minimum and median, but also first quartile, third quartile and Interquartile range (IQR). The IQR is the 1st quartile subtracted from the 3rd quartile; these quartiles can be clearly seen on a box plot and the interquartile range is a measure of variability, based on dividing a data set into quartiles. The quartile won't be affected by extremum.

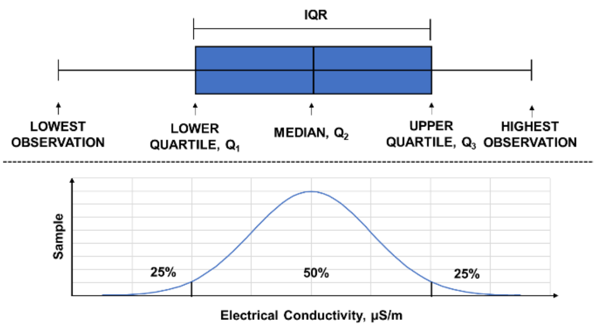

Fig. 4 Box-and-Whisker Plot

3. RESULT

3.1 Result of source analysis

There were 415 water samples collected from PLA in southern Taiwan and coastal areas in Taitung (**Fig.5**). After source analysis (**Fig.6**), 6 samples were removed to reduce the effect of human activities or saltation by sea water, all reliable water samples are as listed in **Tab.1**.

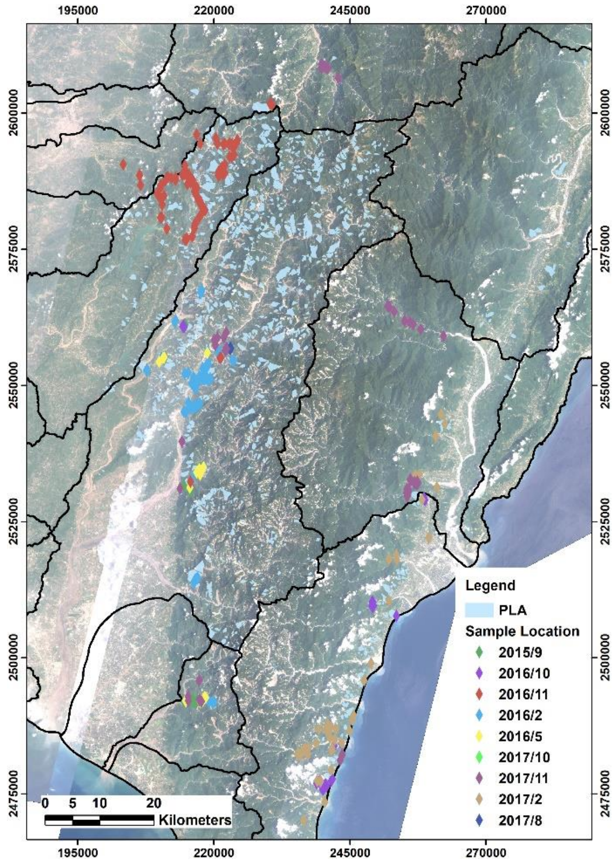

Fig. 5 Location of water sampling

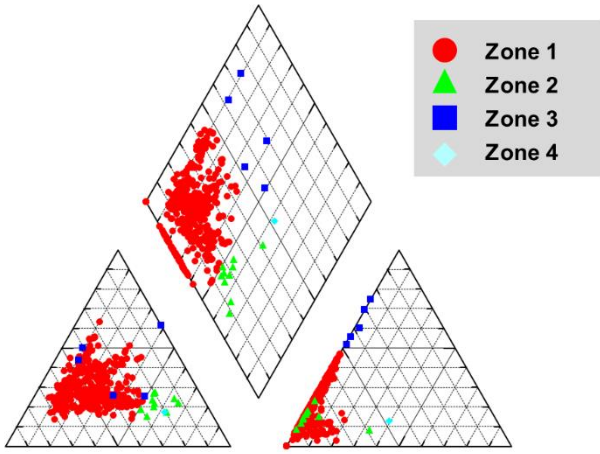

Fig. 6 Source analysis with Piper diagram

Table 1. List of water samples in different basin

Name of basin	Number
Tsengwen	101
Kaoping	207
Linbian	51
Coastal areas in Taitung	48
Total	409

3.2 Time difference of water sample

The time difference was considered dry and wet season. It is obvious that dry season is larger than wet season that electricity conductivity is affected by rainfall. Hence, the electricity conductivity in dry season is higher. It means EC in dry season could be more discernible.

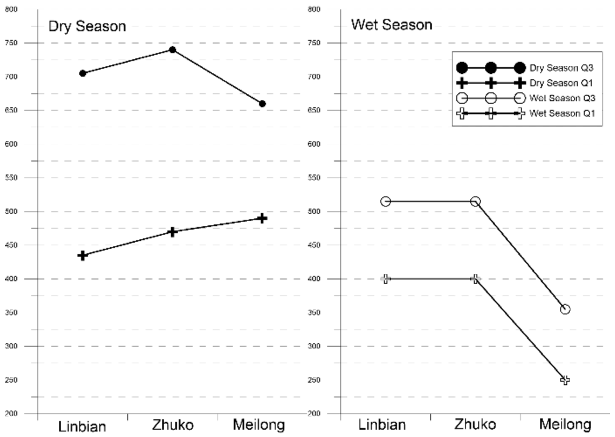

Fig. 7 Time difference of water samples

3.3 Spatial difference of water sample

The spatial difference was compared with dry season water sample from four different watersheds. Kaoping watershed has highest EC, following with Linbian watershed, Tsengwen watershed and coastal area in Taitung (**Fig.8**). This indicates each watershed had different background values of EC.

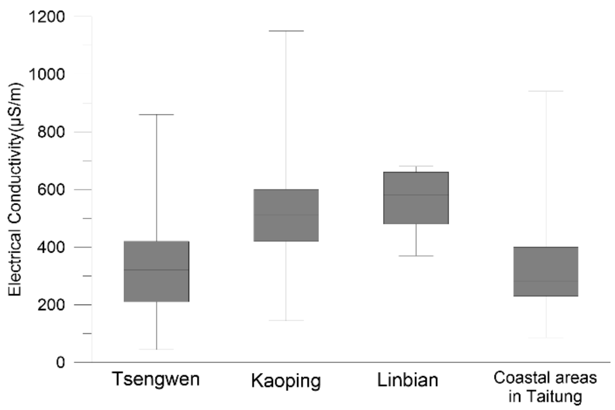

Fig. 8 The variation of EC in different watershed

3.4 Relationship between Potential landslide and conductivity

From results of time difference and spatial difference, EC could be used to clarify for different watersheds or seasons. It would be possible to set EC as a pre-warning factor for PLA. To verify the idea, EC should have some relationship with PLA.

The potential landslide rate of the watershed was evaluated by the area of PLA and watershed by Eq. (1). **Fig.9** shows the concept of analysis. EC of the watershed was measured at the outlet of the watershed plotted as red points. The boundary of PLA was shown in red lines and the boundary of the watershed was shown in yellow lines. Landslide potential rate was counted as follows:

$$\alpha=(A_{PLA}/A_w) \text{ X } 100\% \qquad (1)$$

where α is potential landslide rate, A_{PLA} is total area of PLA in the watershed, A_w is area of the watershed.

There are 24 watersheds (**Table2.**) from 4 different basins were selected to clarify the relationship between EC and PLA. Based on the results of the experiment, geology differences didn't alter EC value.

The relationship between EC and potential landslide rate was plotted as **Fig.10**. It could regress as a straight line, which R^2=0.59. It shows EC getting higher with increased potential landslide rate in the watershed. The relationship between EC and PLA could be confirmed.

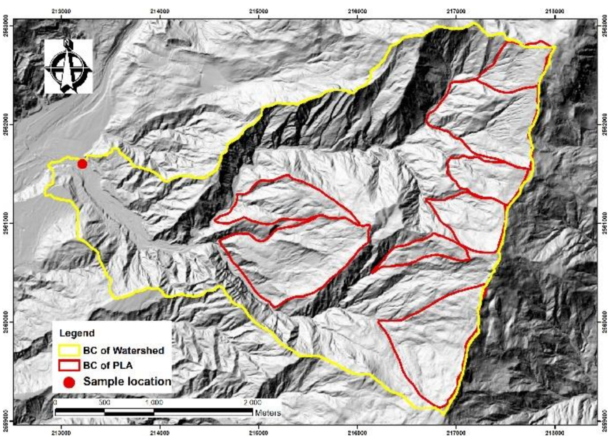

Fig. 9 Illustration of potential landslide rate

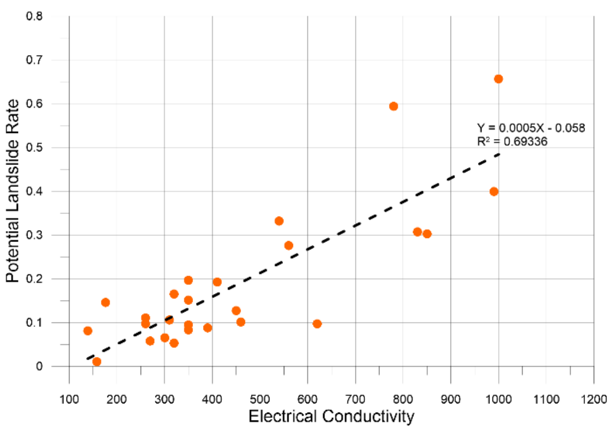

Fig. 10 Relationship between potential landslide rate and EC

Table 2. List of water sample in different watershed

Name of watershed	Area of watershed (ha)	Basin	Geology	Area of PLA (ha)	Potential landslide rate (%)	EC (μS/m)
Zhiben	15,578	Taitung	Alluvium	164	1.05	158
Daxi	3,990	Taitung	Alluvium	440	11.02	260
Daniao	4,346	Taitung	Sandstone Lentils	422	9.71	260
Nanpingpu	1,249	Kaoping	Massive Sandstone	66	5.30	320
Youkuang	1,308	Kaoping	Massive Sandstone	216	16.50	320
Huaguoshan	5,093	Kaoping	Massive Sandstone	421	8.26	350
Putou	3,042	Kaoping	Massive Sandstone	267	8.77	390
Zhipu river	879	Kaoping	Massive Sandstone	111	12.66	450
Wuziliaobei	1,042	Kaoping	Massive Sandstone	345	33.15	540
Huaguoshan	448	Kaoping	Massive Sandstone	43	9.70	620
Putou	98	Kaoping	Massive Sandstone	39	39.92	990
Zhenwoshan	10,710	Kaoping	Sandstone and Shale	614	5.74	270
Zhuowushan North	1,957	Kaoping	Sandstone and Shale	184	9.42	350
Meilunshan	525	Kaoping	Sandstone and Shale	161	30.70	830
Dongtengzhi	2,869	Kaoping	Argillite or Slate	289	10.06	460
Ailiaobei	2,407	Kaoping	Argillite or Slate	663	27.53	560
Zhipu	98	Kaoping	Argillite or Slate	58	59.36	780
Shanhuangma	2,697	Tsengwen	Limestone lentils	530	19.64	350
Shanmeiqiao	551	Tsengwen	Massive Sandstone	58	10.55	310
Caoshan	915	Tsengwen	Sandstone and Shale	74	8.07	139
Hudiqiao	890	Tsengwen	Sandstone and Shale	130	14.57	176
Dabang	1,097	Tsengwen	Sandstone and Shale	71	6.51	300
Huanggoukeng	695	Tsengwen	Sandstone and Shale	105	15.11	350
Longmei	647	Tsengwen	Sandstone and Shale	125	19.24	410

4. EFFECT BETWEEN PLA AND EC

After the relationship between EC and PLA was established, two watersheds were selected in Kaoping watershed to discuss the effect of PLA to EC along the stream flow.

4.1 Watershed I

4.1.1 Basic characteristics

Watershed I was located at midstream of Kaoping watershed (**Fig.11**). The watershed was listed as a potential debris flow torrent by the Soil and Water Conservation Bureau due to historical events, such as Typhoon Morakot. Lots of PLA were identified upstream of the watershed. The area of watershed is 478 ha, and area of total PLA is 166ha. The area of PLA at downstream is 28 ha. The main geology is argillite or slate

4.1.2 Investigation results

EC collected in the dry season were used in Watershed I. Sampling locations were shown in **Fig.12** with green cross. Main stream was shown with blue line and red line means the boundary of PLA. There are total five PLA in the watershed.

EC along Watershed I from downstream to upstream was showed in **Fig.13**. From upstream to downstream, EC got higher while got close to the PLA (point 6 to 8). After passing through the PLA, EC decreased (Point 8 to 10). The EC value changed little once passed the PLA. Numbers of PLA in the upstream didn't affect the EC value.

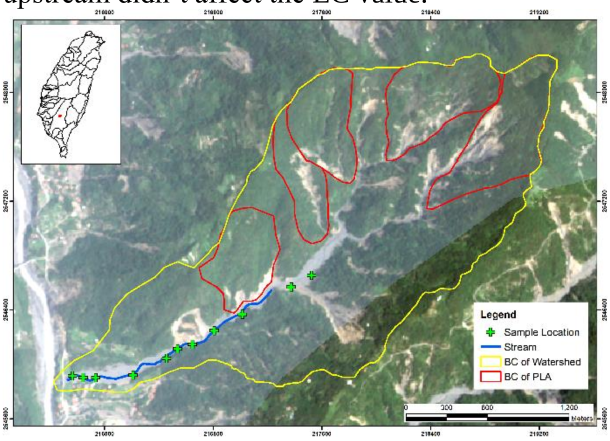

Fig. 11 Location of watershed I

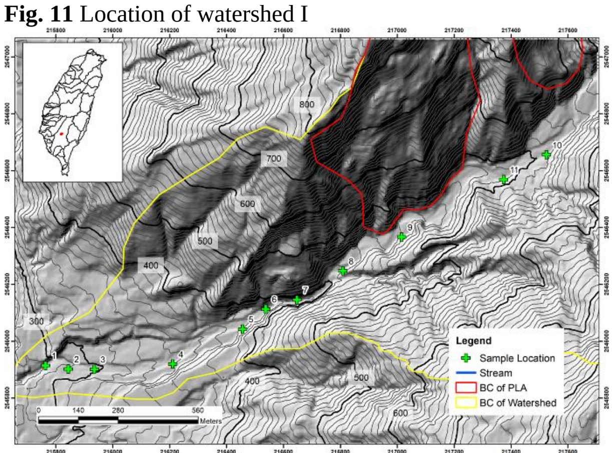

Fig. 12 Sampling locations in Watershed I

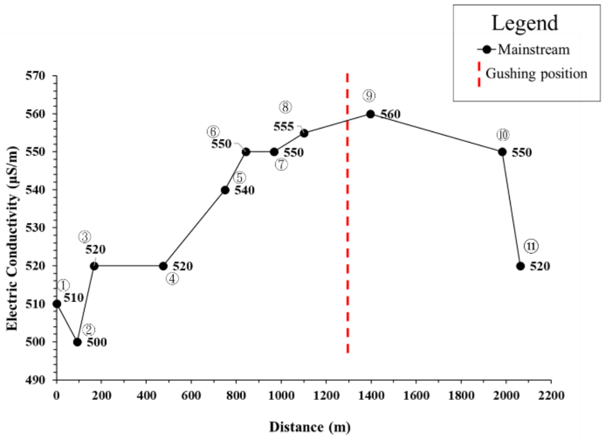

Fig. 13 EC distribution in Watershed I

4.2 Watershed II

4.2.1 Basic Characteristics

Watershed II was also the sub-watershed of Kaoping watershed. The watershed area is 561 hectares, as shown in **Fig.14**. There is only one PLA (39 ha) at the upper boundary of the watershed and many existing landslides in the watershed.

4.2.2 Investigation results

EC was investigated in watersheds during the dry season. Water samples were collected from downstream to the end of the streams where no water flowed. In **Fig.15**, green cross means sampling locations of the main stream shown by blue line from downstream to upstream. Red lines are the boundaries of PLA.

Based on the samples, there were three peaks along the stream. For first peak, EC value increased from point 2 to 5 because of the existing landslide in the brunch. After point 6, leaving the landslide area, EC decreased. EC increased significantly as it passed through PLA (point 6 to 8). The results showed that the idea from Jitousono could be reproduced in Taiwan. From point 10, EC increased again with another existing landslide area.

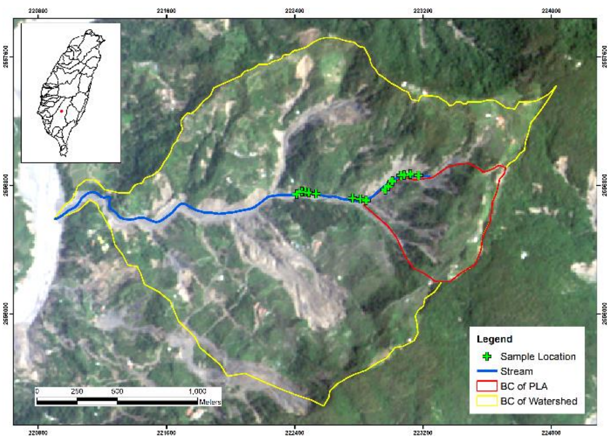

Fig. 14 Location of Watershed II

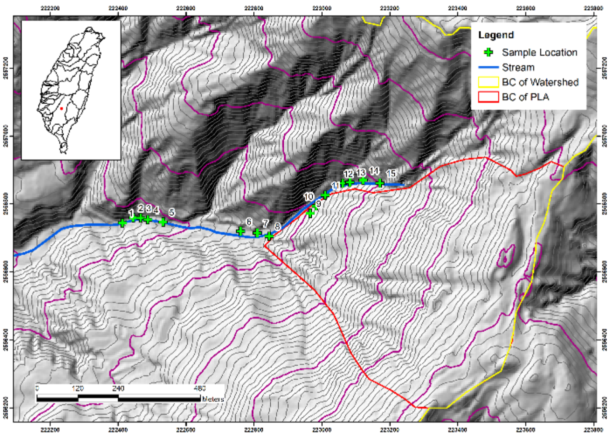

Fig. 15 Distribution of sampling locations in Watershed II

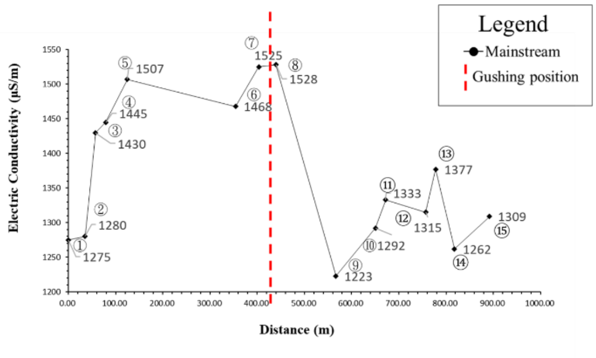

Fig. 16 EC distribution in Watershed II

According to the experimental results from two watersheds, there are some significant relationship between PLA and EC. Firstly, EC is higher with existing landslide area compare to those with no landslides. Secondly, EC rises rapidly before entering PLA and slowly decreases within PLA.

5. CONCLUSIONS

This study tried to clarify the relationship between EC and PLA in Taiwan. EC of stream is affected by inrush water from the potential landslides or existing landslides. When the sample collection points get close to inrush water, the electricity conductivity raises. On the contrary, when the sample collection points get away from the inrush water, the electricity conductivity decreases.

In short, this study proved the relationship between landslide and EC and intends to establish the warning system of the large-scale landslide using EC as an indicator for more emergency response time.

ACKNOWLEDGMENT

We thank the Soil and Water Conservation Bureau of the Council of Agriculture under the Executive Yuan for providing information regarding Large-Scale Landslides project. We also thank the Ministry of Science and Technology for support.

REFERENCES

Central Geological Survey, Ministry of Economic Affairs (2010) Project of Investigation and Analysis for Geologically Sensitive Areas under the Program of National Land Preservation (in Chinese)

Chiang H.C. (1994): Principal Chemical Constituents in Groundwater of Lan-Yang Plain. Journal of Agricultural Engineering Vol.40, No. 4, December. (in Chinese with English abstract)

Jitousono T., Shimokawa E., Teramoto Y. (2006): Potnetial site prediction of deep-seated landslide on the western flank of Mt. Yahazu-dake, Izumi City, Kagoshima Prefecture, Japan. Journal of the Japan Society of Erosion Control Engineering, Vol. 59, NO. 2, pp 5-12(in Japanese with English abstract)

Jitousono T. (2014): Site prediction of potential deep-seated landslides by using electric conductivity of mountain stream water, Journal of the Japan Society of Erosion Control Engineering, Vol. 6, No. 6, pp 56-59. (in Japanese with English abstract)

Lee W.L., Lin Y.F., Shieh C.L., Miyamoto K., Tai Y.C., (2015): The study on seepage hummer in the process of vertical seepage, The 16th Conference on Current Researches in Geotechnical Engineering in Taiwan. (in Chinese with English abstract)

Lin C.W., Yi D.C., Huang M.L. (2012) Digital terrain from airborne LiDAR - an effective tool for seeking potential large-scale landslides. Geo Topic 31(2):44–48

Shieh C.L., Lee W.L., Tai Y.C. and Lin Y.F. (2014): Occurrence Mechanism of Rainfall-induced Catastrophic Landslide. 2014 International Debris-Flow Workshop, Tainan, Taiwan

Shieh C.L., Wang C.M., Chen Y.S., Tsai Y.J. and Tseng W.H. (2010): An overview of disasters resulted from typhoon Morakot in Taiwan. Journal of Disaster Research. Vol 5, No3, pp. 236–244

Soil and Water Conservation Bureau, Council of Agriculture, Executive Yuan (2015): Development and application of disaster prevention and mitigation technologies for large-scale landslides. Nantou Taiwan (in Chinese)

Forestry Bureau, Council of Agriculture, Executive Yuan (2012) Investigation and Assessment of Deep-Seated Landslide Risk of National Forest – Key Watersheds in Southern Taiwan (in Chinese).