Critical Rainfall Analysis of Large-scale Landslide Occurrence

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The disaster event in Xiaolin village awakens the public awareness of large-scale landslide. The pre-warning procedure of large-scale landslide is one of the most important issues in Taiwan recently. In this study, 36 cases from Xiaolin village disaster event were used to estimate possible occurrence rainfall thresholds of large-scale landslide. The methods of rainfall time-series analysis and dimensionless rainfall analysis were taken in this study, the information including area, volume, location, occurrence time, and hydrography data of each landslide sites were considered in those analysis. Some trends of occurrence rainfall in Taiwan could be found in this study.

Key words: large-scale landslide, critical rainfall, pre-warning system

1. ORIGIN

The topography and geological conditions of Taiwan are very special, the mountainous terrain is steep, the valleys are high, many faults and folds, geological environment conditions are complex. Typhoons, heavy rainfalls and earthquakes also made the occurrence of landslides and debris flows frequently in Taiwan. In addition, due to the influence of extreme weather in recent years, there have been even 7 to 8 typhoon attacks every year, the risks of sediment disasters are increasing for each heavy rainfall.

Typhoon Morakot, during 8th to 10th Aug. 2009, is the most serious disaster case. The typhoon and the subsequent southwesterly flow have characteristics with long duration, high intensity, high accumulation, and wide affected area. In the southern-central part of Taiwan, there are 3000mm of rainfall been observed in four consecutive days. Meanwhile, various types of disasters such as deep and shallow landslides, debris flows, landslide dams, and flooding were induced.

These disasters hit the same area at the same time or one after another and cause serious disasters in the region. Xiaolin village case(**Fig.1**) is the most famous one. Due to the large-scale landslide disaster, there are 474 people died, and the property loss is more difficult to be estimated.

This event awakens the public awareness of large-scale landslide disaster. As a preparation for future large-scale landslide prevention, this study was focus on the characteristics of rainfall that triggers large-scale landslide.

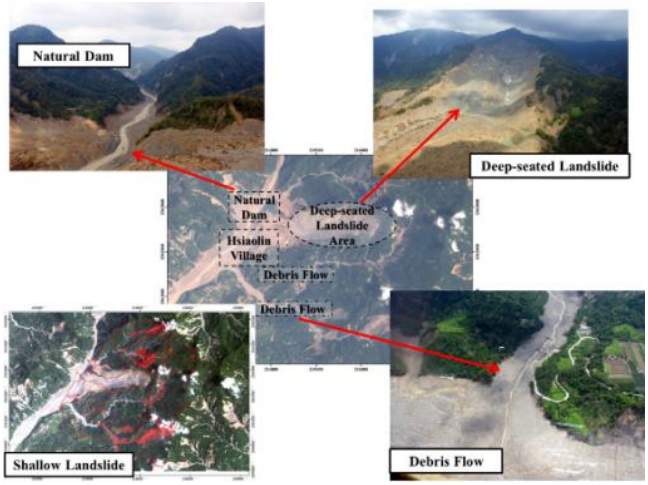


Fig. 1 Large-scale landslide in Xiaolin village during Typhoon Morakot

2. RESEARCH METHODS

As **Fig. 2** shown, to find out the trend of critical rainfall in Taiwan, this study is based on the following procedures. The details are described as follows.

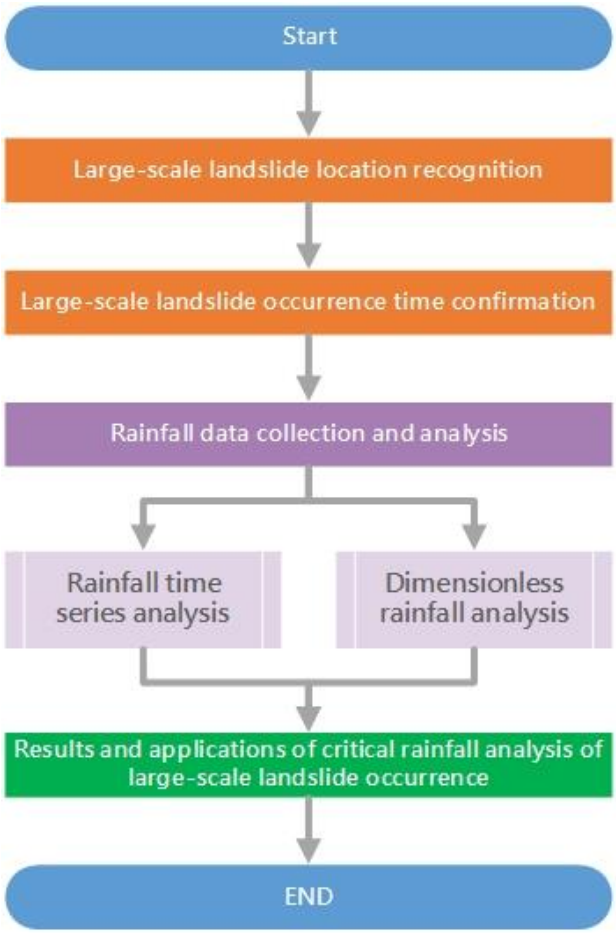


Fig. 2 Research process of critical rainfall analysis of large-scale landslide occurrence

2.1 Large-scale landslide location recognition

In this step, the multi-spectral imagery with original 8m ground resolution of FORMOSAT-II was used to find out the accurate locations and types of landslides.

Follow the procedure from NCKU Research and Development Foundation (2010), using imagery after Typhoon Sinlaku as pre-event imagery and imagery after Typhoon Morakot as post-event imagery, respectively produced catalogues of landslides and then do the comparison.

Fig. 3 shown the workflow of large-scale landslide location recognition. The workflow can be divided into two parts, one is semi-automatic extraction prat, and the other one is manual inspection.

Imagery from different phases may contain some bias cause by shooting, orthorectification, algorithm, and some random issues. In the beginning of semi-automatic extraction is to reduce the spatial bias between images by multi-phase imagery registration.

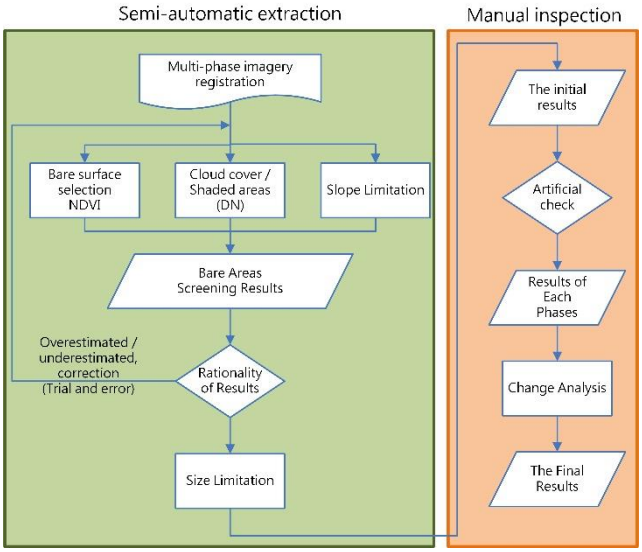


Fig. 3 Workflow of large-scale landslide location recognition

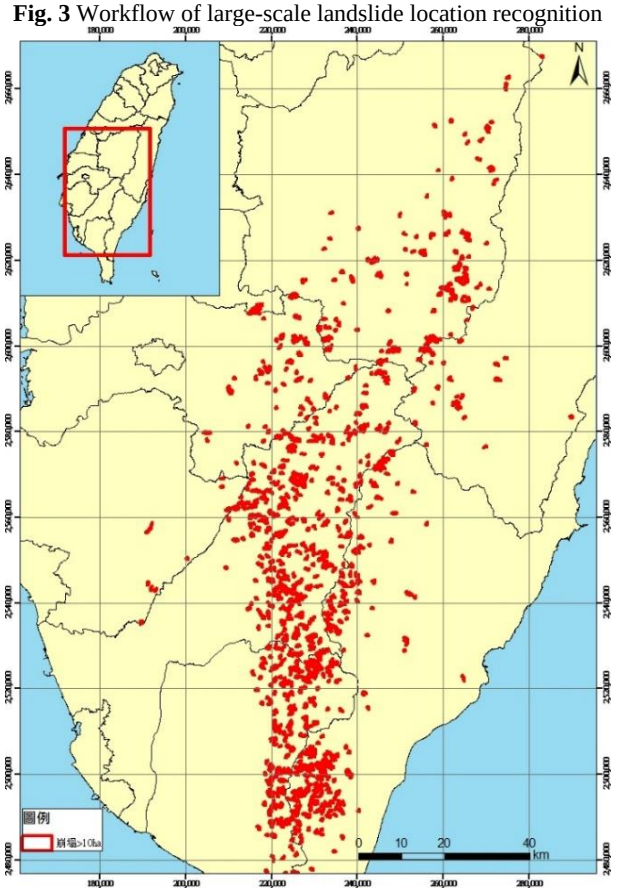
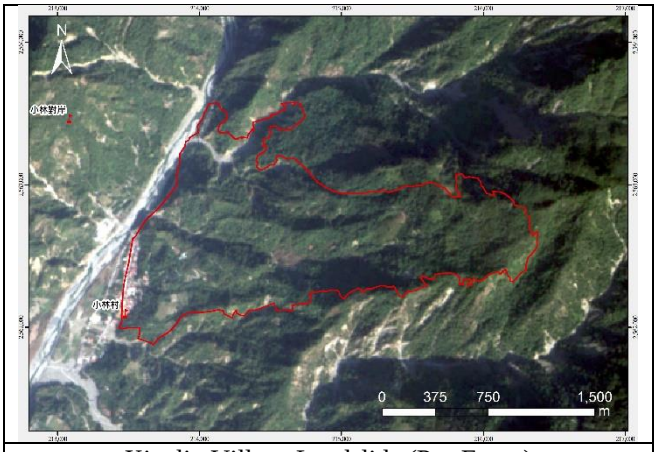


Fig.4 The distribution of variants larger than 10 ha

After multi-phases imagery registration, some indexes such as NDVI, brightness, and slope were used to quickly filtering the bare areas. The results of this part need to confirm whether the overestimation or underestimation is through rational analysis and use the trial and error method to correct the parameters until the results are

reasonable. Finally, through the size parameters remove those under reasonable recognizable size objects, the semi-automatic extraction part is finished, the catalogues of landslides were made. Each result from the semi-automatic extraction should pass the artificial check, to make sure the result of each phase is correct. Then compare results from different phases, the variant regions will be found.

In this study, 10 ha condition was used to filter large-scale landslide form variant regions. There are total 764 landslides met the qualify, of which there were 308 new landslides (**Fig. 5**) and 456 expanded ones (**Fig. 6**). These large-scale landslides are the targets of this study. GIS software was used to collect the need data from landslide such as area size and average slope.

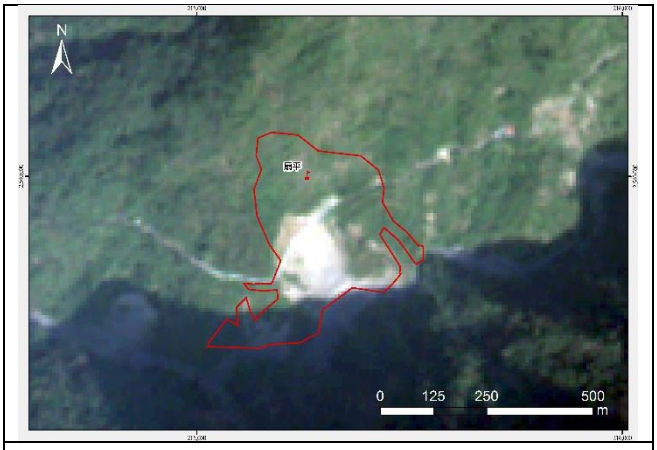


Xiaolin Village Landslide (Pre-Event)

Xiaolin Village Landslide (Post-Event)

Fig. 5 The demonstration of new landslides

In this step, the results shown some more type of landslides, include multiple landslides merged cases. Therefore, there two types of landslides were defined for following discussion, one type is newborn type, only single new landslide included, the other one is mixed type, include single expanded landslide, multiple new/expand landslides merged cases, and new and expand landslides merged cases.



Shanping Landslide (Pre-Event)

Shanping Landslide (Post-Event)

Fig. 6 The demonstration of expanded landslides

2.2 Large-scale landslide occurrence time confirmation

This step is trying to link the records from formal government reports or seismic data with landslides found in foregoing step to confirm the occurrence time of landslides. The time data used in this study mainly comes from the research report of the Sinotech Engineering Consultants, Inc. (2013) and Chinese Geoscience Union (2010), NCKU Research and Development Foundation (2015, 2016) and the investigation and interview records of the National Cheng Kung University Disaster Prevention Research Center.

Those time data from Sinotech Engineering Consultants, Inc. (2013) which referred to the major landslide disaster report of SWCB are also investigation and interview records of filed works.

Those time data from Chinese Geoscience Union (2010), used the records of Broadband Array in Taiwan for Seismology, built by the Institute of Earth Sciences of the Academia Sinica and the Central Meteorological Bureau, and was analyzed with the HYPO 71 software.

Those time data from NCKU Research and Development Foundation (2015, 2016), also used the records of Broadband Array in Taiwan for Seismology and follow the locating method from Wech & Creager (2008) to confirm every landslide event.

After the comparison, the link between location and time of large-scale landslide were founded in 36 cases, the distribution of these cases shown as **Fig. 7**. Half of these cases are newborn type, and the other half are mixed type.

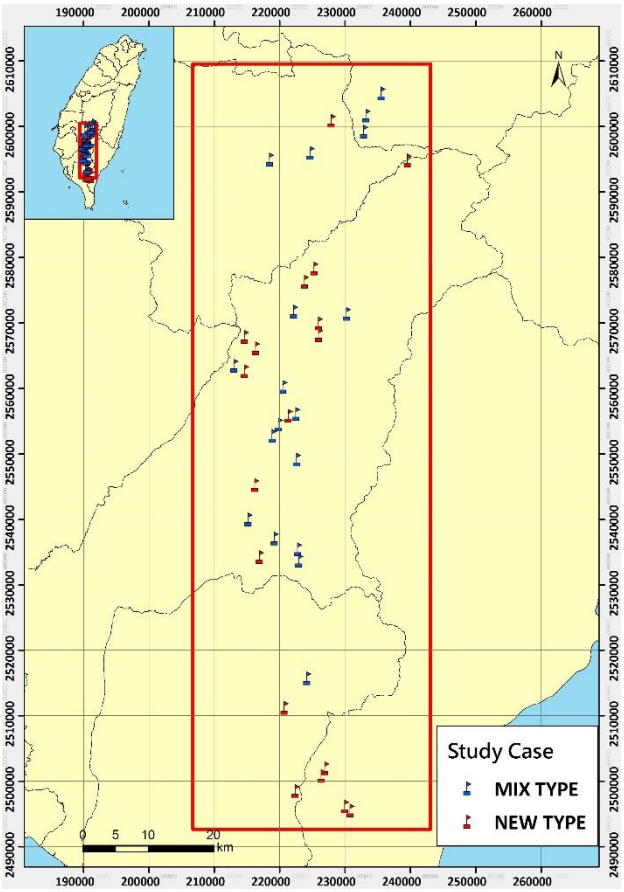


Fig. 7 Study cases distribution

2.3 Rainfall data collection and analysis

In terms of rainfall data, the precipitation data assurance by the Central Weather Bureau was used in this study. The rainfall period has been defined from 0 o'clock on August 6, 2009 to 23 o'clock on August 10, 2009. After removing the stations with missing data, the final amount of station used was 354 stations. Base on the data of those stations, each rainfall value at landslide site were calculated with inverse distance weight method, and the result is shown in Figure 8.

After data preparing stage, two analysis Rainfall time series analysis and Dimensionless rainfall analysis were executed.

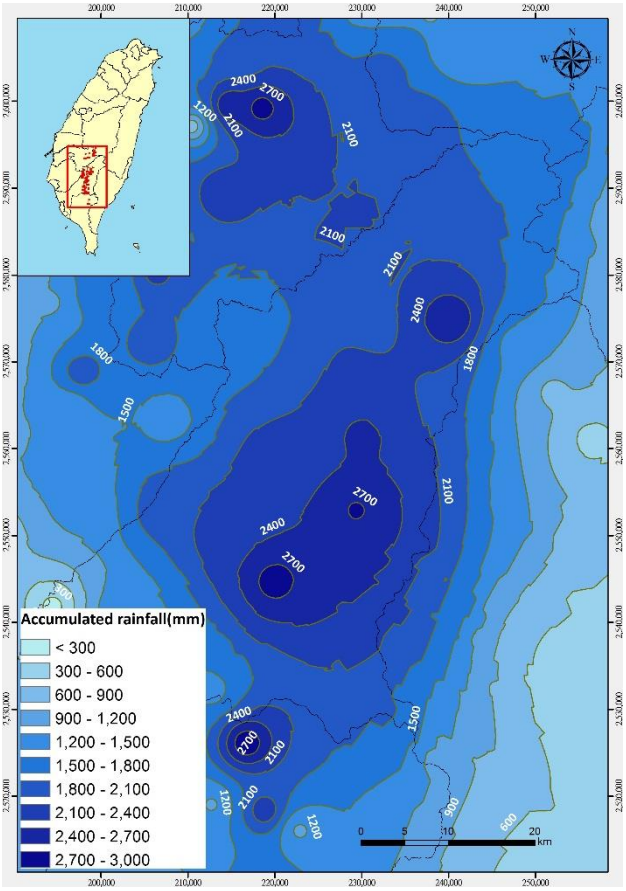


Fig. 8 Rainfall distribution of the study area

2.3.1 Rainfall time series analysis

Draw two kinds of hydrograph, rainfall intensity-duration diagram and rainfall accumulation-duration diagram then mark the landslide occurrence point on them. Then try to find out the trend and zoning for large-scale landslide.

2.3.2 Dimensionless rainfall analysis

Two dimensionless factors, the ratio accumulate rainfall (R) to landslide depth (D) and the ratio of equivalent friction angle (ψ) to average slope (θ) of landslide, were used to draw a regression relationship.

(a) Accumulate rainfall, R:

The hourly precipitation data of each landslide case was calculated with inverse distance weight method, the total amount of rainfall was accumulated from 0:00 on August 6, 2009 to the time of occurrence of landslides, as cumulative rainfall R (unit: m).

(b) Landslide depth, D:

The projected area of landslide was calculated with ArcGIS software in this study. The empirical formula from National Cheng Kung University (2013) was used, volume V (m^3), was calculated from Eq. (1), and landslide depth D (m) was calculated from Eq. (2).

$$V = 0.075A^{1.45} \quad (1)$$

$$D = \frac{V}{A} \quad (2)$$

(c) Average slope, θ:

Due to the nature terrain was not uniformed, the slope of landslide site maybe changes in gradient. Therefore, the slope here was defined as the average slope within the landslide range. The average slope was calculated with the spatial statistics function of the spatial analysis module of the ArcGIS software.

(d) Equivalent friction angle, φ:

The relation between the equivalent friction coefficient f and the landslide volume V was described in Scheidegger (1973) shown as Eq. (3). The relationship between the equivalent friction coefficient f and the equivalent friction angle φ was existed as Eq. (4). From Eq. (1), the relationship between the projected area A and the volume of the landslide surface V can be deduced from the equivalent friction angleψ.

$$\log_{10} f = -0.1466 \log_{10} V + 0.62419 \quad (3)$$

$$f = \tan \phi \quad (4)$$

2.4 Results and applications of critical rainfall analysis of large-scale landslide occurrence

Base on the foregoing results, the threshold for pre-warning system of large-scale landslide could be setup, and the volume of soil production will be estimated easily.

3. RESULTS

In this study, the following results were found.

3.1 The distribution of study case

Base on **Fig. 7** and **Fig. 8**, the distribution of study cases and rainfall distribution of the study area where are drawn as **Fig. 9**. According to the distribution of known cases, mix type cases and new type cases are occurred as randomly distributed, meanwhile all the cases are occurred nearby the rainfall hotspot.

3.2 The rainfall threshold of triggering large-scale landslide

As **Fig. 10** shown, those study cases could be divided into two groups; the red colored group were composed with new born type landslides, the large-scale landslides were occurred after the peak rainfall, the relative accumulated rainfall value exceeded 800 mm and the occurrence time was close to the turn point of hydrograph curve. In the other group, the blue colored group were composed with mix type landslides, the large-scale landslides were occurred before or close to the peak rainfall, the relative accumulated rainfall value was around 600 mm and the occurrence time was fall into the rise part of hydrograph curve.

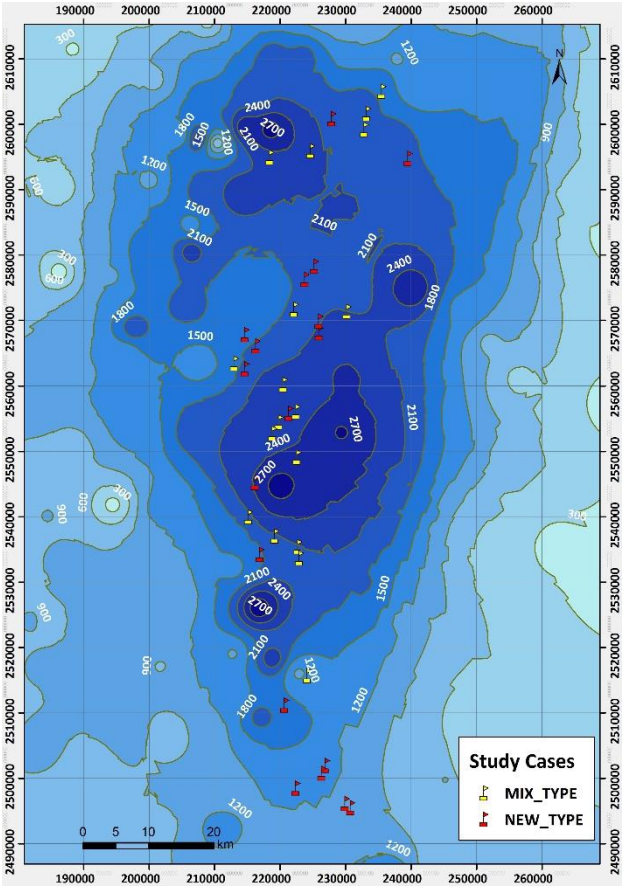


Fig. 9 Hydrograph of study cases

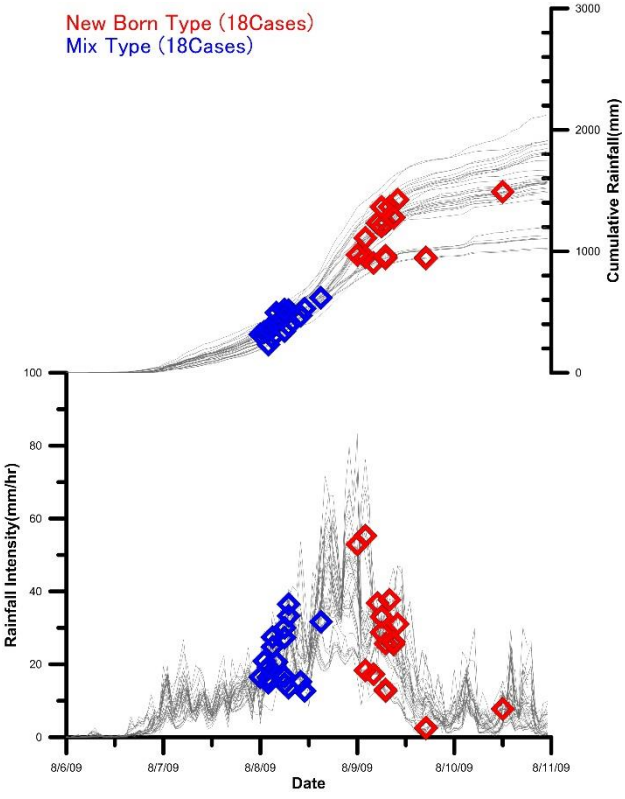


Fig. 10 Hydrograph of study cases

As 2.1 mentioned, mix type landslides include single expanded landslide, multiple new/expanded landslides merged cases. For expanded landslide case, the surface of landslide is not covered or poorly covered by plants, it's reasonable that expanded landslides would be triggered in lower accumulated rainfall value than new born ones. Base on this condition, study cases in Fig 10 shown as two groups were quite reasonable.

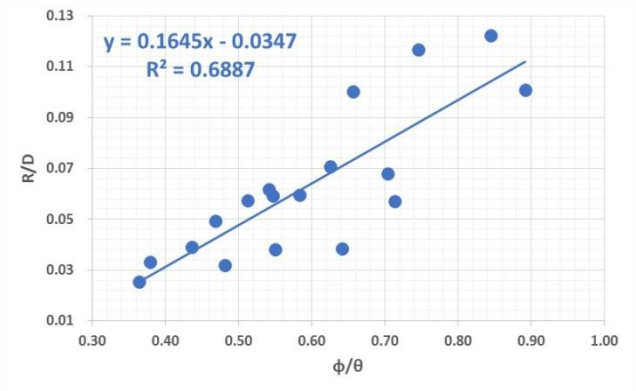


Fig. 11 Dimensionless rainfall analysis results

3.2 The result of Dimensionless rainfall analysis

As **Fig. 11** shown, through linear regression the relationship of the ratio of equivalent friction angle (ψ) to average slope (θ) of landslide and the ratio accumulate rainfall (R) to landslide depth (D) was found as the Eq. (5), and it's R2 value is about 0.6887.

$$\frac{R}{D} = 1.645 \times \frac{\phi}{\theta} - 0.0347 \qquad (5)$$

As Eq. (5) shown, R toψand D to θ both shown the positive relationship, these means the more rainfall would cause the more soil mass been moved and the steeper slope would cause the deeper landslide.

4. CONCLUSIONS

Purely single new large-scale landslide will occur after the peak rainfall, the relative accumulated rainfall value exceeded 800 mm and the occurrence time was close to the turn point of hydrograph curve; although there are obvious groups in the hydrograph, there was still need more cases to support. Since it is not easy to obtain the exact time of occurrence, the number of valid samples is still insufficient. Therefore, this research needs to include other analytical methods in the future to obtain more reliable research results. The study is still ongoing.

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