# USE OF MULTITEMPORAL LIDAR DEMS FOR REGIONAL LANDSLIDE VOLUME ANALYSIS

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**KEY WORDS:** Remote Sensing, Geohazards, Landslides, Landforms, topographic change

**ABSTRACT:** This study used multi-temporal high-resolution LiDAR DEMs to map new landslides and to establish an empirical relationship between area and volume of landslides in a study area at southern Taiwan. The elevation changes are detected from 2 successive sets of LiDAR DEM in a forested land. They were acquired with a point-cloud density of more than 1.0 point per square meter in 2005 and 2010, respectively. The accuracy standards and survey procedures are based on the 2005 MOI guideline. Active landslides are successfully identified and mapped using differential DEM derived from the 2 data sets, using a change threshold of 0.50 m to remove noise from differential data and visual interpretation of typical landslide morphology with supplemental information from orthophotos. More than 95% of landslides were mapped under the threshold of 0.50m, in comparison to orthophotos. Subsequently, the coverage area and volume of each individual landslide are derived. An empirical relationship between landslide area A ($m^2$) and volume V ($m^3$), $V = kA^a$ with k = 0.099 and a = 1.396, is then proposed in this paper. The power law formula was obtained through linear fit of the landslides with coefficient of determination, R-squared = 0.837. It can be further applied for estimation of the total volume of landslide materials in a whole region. In addition, the differential DEM can be further applied to understand the regional sedimentation activities showing the source areas and the deposition areas**.**

## 1. INTRODUCTION

Landscape of Taiwan is subjected to severe change due to torrential rainfalls. Subsequently, sediments eroded from landslide materials triggered by torrential rainfalls are transported to water reservoirs. In addition to the adverse effects of water turbidity which make the water treatment process difficult, the sustaining time of reservoirs are reduced substantially. Therefore, a good understanding of landslides in watershed becomes critical for sustaining management of reservoirs in Taiwan. It is not possible to estimate watershed-wide volume change due to landslides caused by a torrential rainfall by direct measurements. LiDAR digital elevation model (DEM) with high resolution and high accuracy becomes important tools for the purposes of landslide inventory and management. Thus, the relationship between size and volume of landslides can be derived when individual landslides can be accurately identified.

It is straight-forward to apply the difference of two DEMs for representing landslide volume caused by an event (Liu et al., 2010), e.g.

$$\Delta V = \sum \left( DEM_{T2} - DEM_{T1} \right)$$

Where $DEM_{T2}$ represents the DEM of the accurate topography after torrential event and $DEM_{T1}$ represents that before torrential event. Premises of data quality and common datum are required. ΔV is the volume change after the event. When the value of ΔV is negative, it indicates the area is of depletion. Whereas ΔV is positive, it indicates the area is of accumulation.

The purposes of this study include landslide mapping and establishing an empirical relationship between area and volume of landslides in the study area by using multiple DEMs before and after 2009 Morakot event in southern Taiwan. This relationship allows estimating the total volume of landslide materials in an individual catchment. In addition, the results of cut and fill analysis between two-temporal LiDAR-based DEM in a catchment scale shows distinctly evolution processes of debris flow from the landslide source and subsequent deposition area. Understanding the time scale of landslide mass movement is important to determine the debris flow susceptibility in a catchment.

## 2. TWO TIMES OF LiDAR DATA SETS

In this study, two times of LiDAR data are used, for representing the accurate topography before and after Morakot rainfall event. The first LiDAR data set was acquired in 2005 (MOI, 2006a) and the second in 2010 (SWCB, 2010). The point density of both datasets is more than 1 point per square meter. The grid-size of final DEM is 1 meter. The orthometric height of each grid cell conforms to the accuracy standards required by the draft specifications made by the Ministry of The Interior (MOI, 2006b). The premises for applying two DEMs for landslide volume estimation require that both the datum and the quality of the two DEM datasets are maintained. To assure the quality of the DEM, strict standard operation procedures are followed (MOI, 2006b). Five phases of tasks are implemented for obtaining the accurate elevation models by airborne LiDAR survey, including: (1) The planning step; (2) Flights and preprocessing – obtaining point clouds in local projected coordinate system, namely Taiwan Datum 1997 (TWD97); (3) Classification step – The extraction of points hitting the bare earth from all point clouds for the production of LiDAR DEM; (4) Quality validation step - for assuring the conformance of quality and quantity requirements of the results to the MOI guidelines (MOI, 2006b); and (5) The output step with grid of 5k map-sheets – The digital elevation models (i.e. DEM) with ellipsoid height in 1m grid are created by interpolation of the discrete ground points. DEM with orthometric heights are prepared by applying a reduction of geoid undulation model published by the Ministry of The Interior, namely TaiWan Vertical Datum 2001 (TWVD 2001).

The relative error is then evaluated with overlap data and absolute error is evaluated by a comparison with ground control points. The residuals between strips in this study are smaller than 10 cm. A cross flight is designed in every 30 km perpendicular to major flight lines for checking discrepancies between flight strips. Five land-types and transactions for ground survey are also selected for validating the accuracy achieved in this phase. Ground data are collected by GPS and Total Stations. The 5 designated land-cover types include (1) bare land, (2) low vegetation, (3) sparsely-vegetated forest, (4) dense forest, and (5) building-up area. At least 30 measurements are collected for each of the cover types. In addition, 50 check points are collected along a profile of 20 km in length crossing the flight strips. The accuracies (root mean square error) on cover types of bare land, low vegetation, spare forest and building-up areas are all better than 0.16m. The average error for transactions in the study area is 0.131m. However, the RMSE is around 0.25m for dense forest.

These standardized procedures assure the requirement of geodetic and vertical survey datums, as well as the quality of the datasets. As pointed out by Liu et al. (2010) that uncertainties are large in the area covered by dense forest due to artifacts of point cloud filtering, landslide masks with polygons of landslides after the heavy rainfall events are used in this study to extract local DEMs, restricted only the landslide areas. This can effectively eliminate the adverse effect of errors due to dense forest. Therefore, on basis of the results of quality validation phase, the cumulative error of subtracting two DEMs in this study will be maintained to be as low as 0.5m.

## 3. THE STUDY AREA AND THRESHOLDS OF ΔV

An example of LiDAR data for the experiment in this study is selected from national map-sheet number 95183028 with a map-name of Tern-Bau-San One (Figure 1). The extent is about 2579m x 2775m, around 7 square kilometers. There are very few landslides on orthophoto taken in 2005 where as landslides are everywhere on Formosat-2 orthoimage taken in 2010 of the same area. It is also shown that shaded-relief of DEM shows only the bare earth. As a contrast, the shaded-relief of DSM shows better landcover information for visual interpretation of landslides. Landslides are not obvious due to lack of contrast between sliding and non-sliding areas.

Figure 2 shows the ΔV maps derived from 2010 DEM and 2005 DEM of the study area. The differential DEM shows that a maximum negative value is -53.9835 and maximum positive value of 39.3773. In Figure 2, depleted areas are with negative values whereas accumulative areas are with positive values. When comparing Figure 1B, 1D and Fugure 2, it is clearly shown that the landslides are in depleted areas, and the accumulative areas are mainly in stream valleys. To isolate the landslides, a threshold is set to filter out all those areas with a value larger than 0m, as shown in Figure 3A. When the threshold is set to 3m as shown in Figure 3B, all the noises due to the uncertainties of DEM and effects of landcover types are removed and only major landslides are left. It is noteworthy that a threshold of 3m means that all values larger than -3m are filter out. However, some small yet important landslides are also deleted. When threshold is 0m, the total depleted volume is 13,193,828 cubic meters, whereas the threshold is 3m, the total depleted volume is 10,360,912 cubic meters. There is a difference of 21.47%. Therefore, the selection of a proper threshold is meaningful. Thus, various thresholds are tested and their respective ΔV maps are compared with landslide map derived from manual interpretation. It is shown that a threshold larger than 0.50~1.0m can effectively remove noises from the differential DEM. Visual interpretation of typical landslide morphology with supplemental information from orthophotos is carried out for the comparison. More than 95% of landslides were mapped under the threshold of 0.50m. In other words, active landslides can be successfully identified and mapped by applying a threshold of larger than 0.50 m.

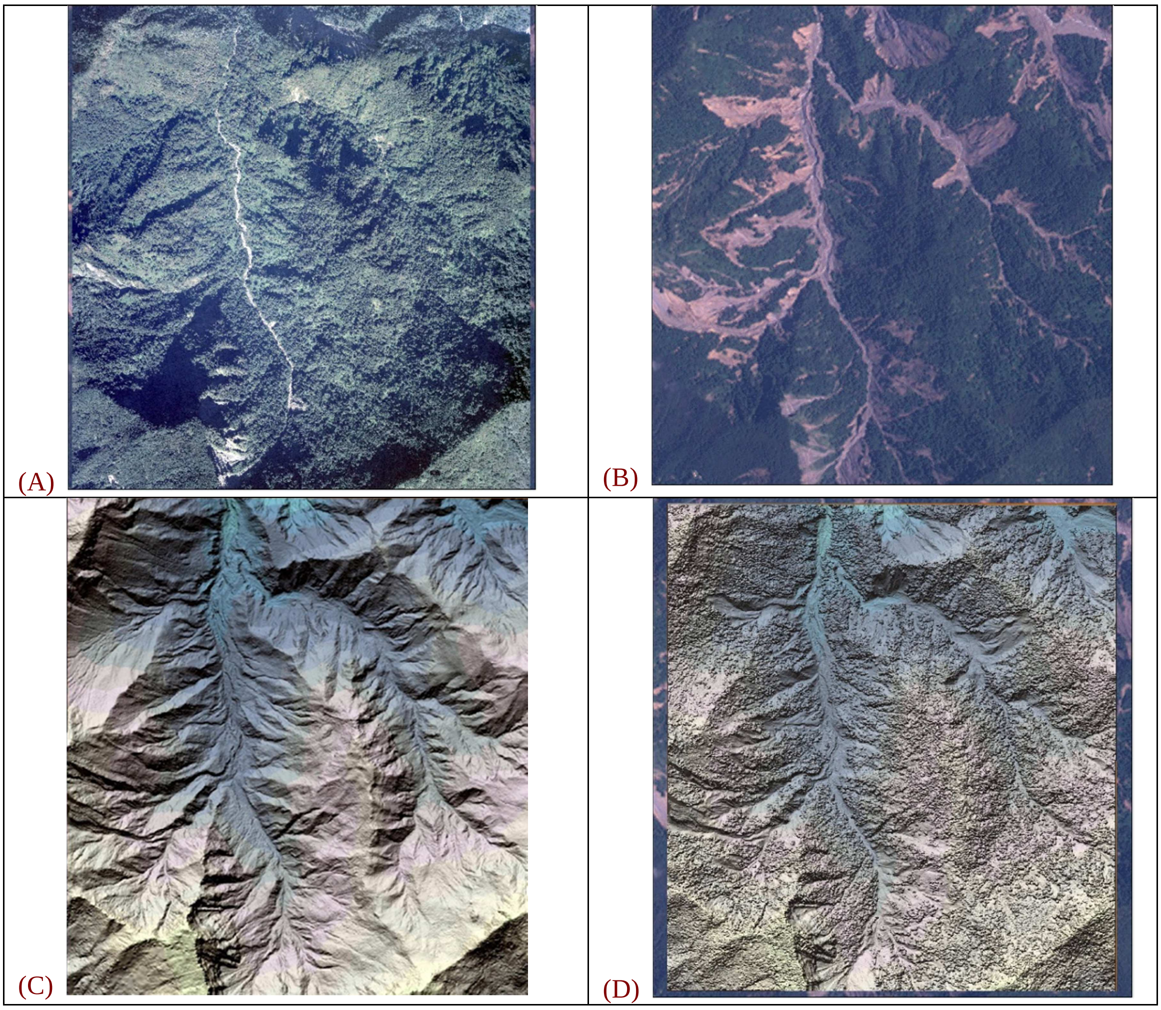


Figure 1 Images of the study area before and after 2009 Morakot event, (A) 2005 Orthophoto; (B) 2010 Orthoimage; (C) 2010 LiDAR DEM; (D) 2010 LiDAR DSM.

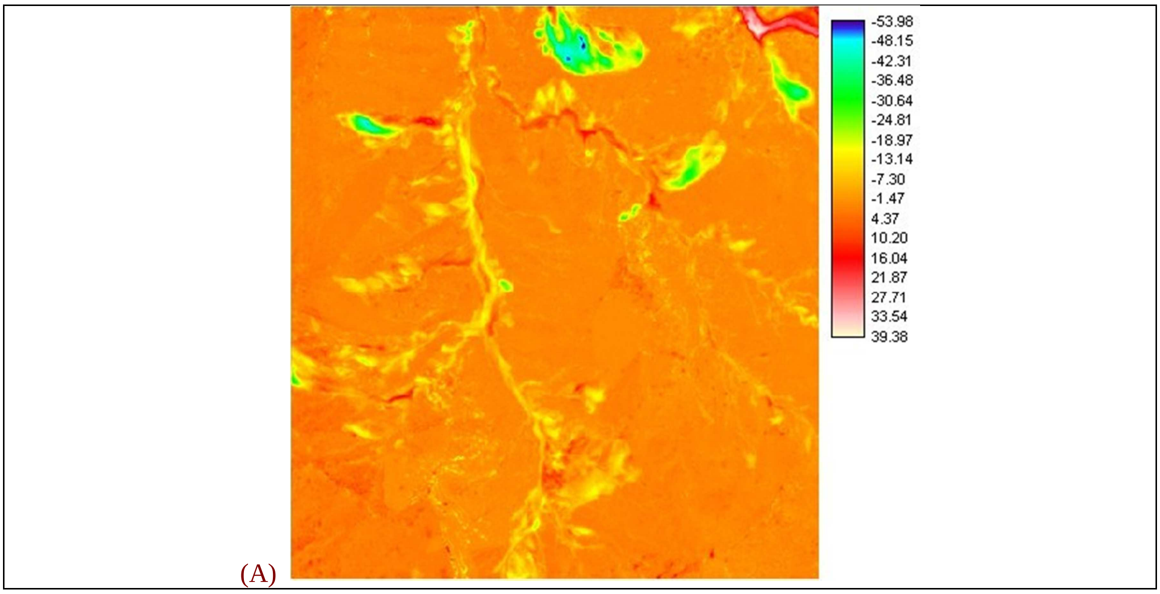


Figure 2 ΔV map showing the depleted areas with negative values and accumulative areas with positive values.

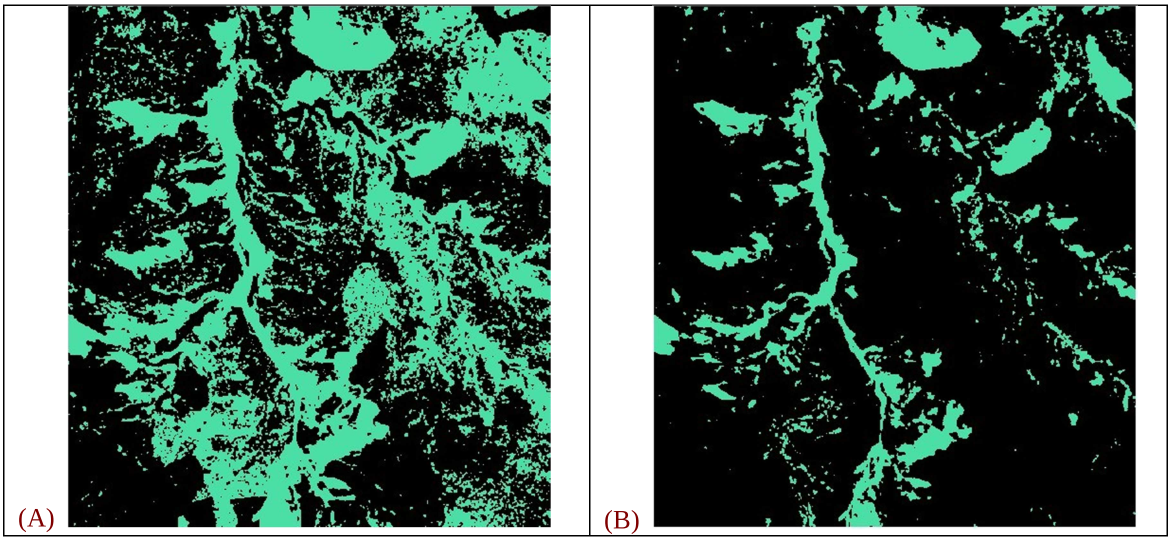


Figure 3 ΔV map showing the depleted areas with a threshold of 0m (A) and 3m (B), respectively. Noises are obvious when no threshold is set, i.e. 0m.

## 4. THE APPROACH TO DERIVE THE RELATIONSHIP OF A AND V

When 2 times of airborne LiDAR DEM are used, there are two approaches for deriving the relationship between the 2D area of a landslide and its 3D volume, as shown in Figure 4. Landslide maps of 2005 and 2010 are established before new landslides triggered by designated event are identified, as shown in Approach 1. However, new landslides can also be established in a more efficient way by just applying a threshold to the differential DEM, as shown in the Approach 2. The later one is adopted in this study. The manually interpreted landslide polygons are used as cutting template to extract individual landslide in differential DEM. And, thus a list of area (A) and volume (V) of each landslide are established.

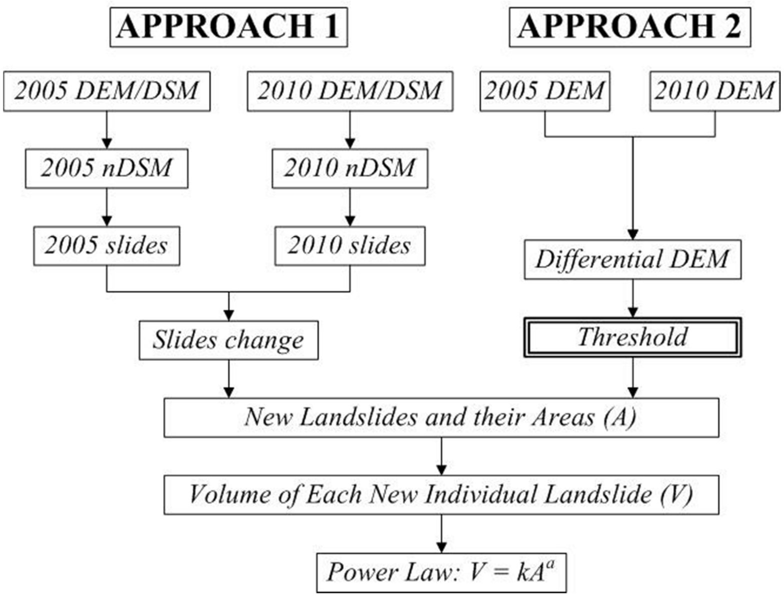


Figure 4 Flowchart for deriving the relationship between A and V of landslides using 2 times of DEM

## **5. RESULT AND DISCUSSION**

In this study area, 50 landslides are interpreted and used for the experiment. A list of area and volume of each of the 50 landslides can be extracted using the intersection of landslide polygons and differential DEM. Subsequently, an empirical relationship linking landslide area A ($m^2$) and volume V ($m^3$), $V = kA^a$ can be established. The result shows that k = 0.099 and a = 1.395 with R-squared coefficient of determination = 83.7%. As a comparison to a separate study using 488 points of landslides in a well-cemented sandstone and shale geological environment, k = 0.0146, a = 1.523, and R-squared coefficient of determination = 89.6% (Tseng et al., 2011). Figure 5 shows the fitting curves from these two cases. It was also reported by Guzzetti et al. (2008) that $V=0.0844A^{1.4234}$ with k = 0.0844 and a = 1.423. These empirical formulas reflect different physiographic conditions including geology, soils, climate and denudation processes (Kalderon-Asael et al., 2008).

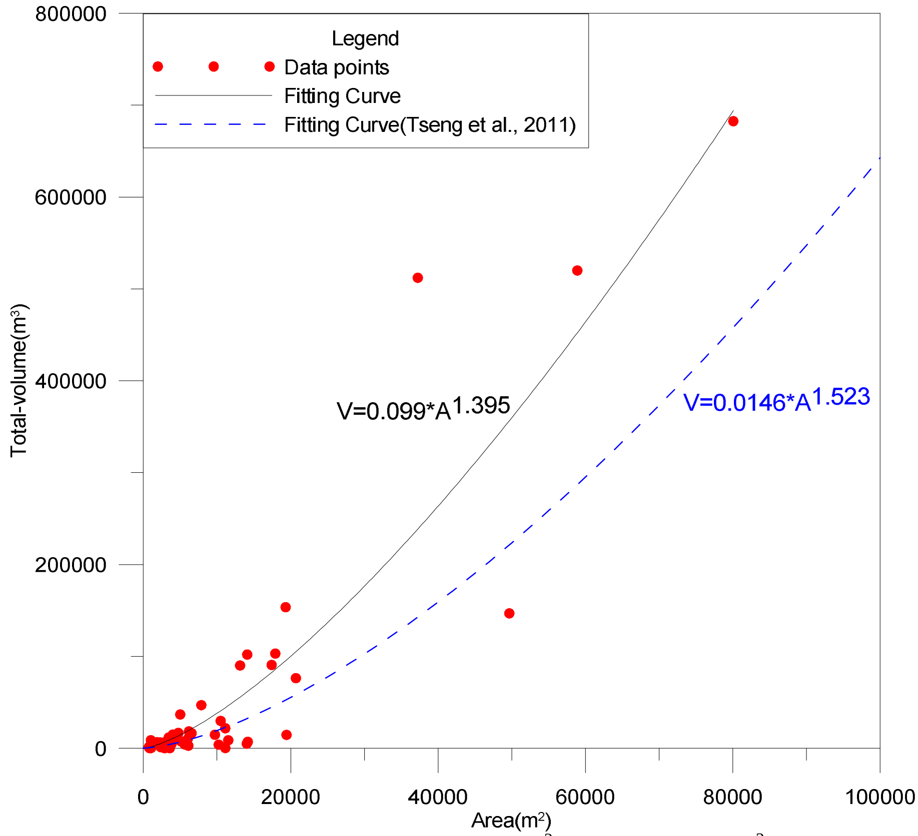


Figure 5 Empirical formula of landslide area A ($m^2$) and volume V ($m^3$), $V=kA^a$.

## 6. CONCLUSIONS AND SUGGESTIONS

Multi-temporal LiDAR DEM can be applied to model the relation between area and volume of landslides. In this study, 50 landslides of the test area are used to establish the empirical formula linking landslide area and their volumes under a well-cemented sandstone and shale geology. A national LiDAR mapping program is under going in Taiwan (Liu and Fei, 2011). Empirical formula for different physiographical conditions can thus be further established when a complete coverage of accurate DEM of the whole territory is completed.

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