MORPHOLOGICAL ANALYSIS OF RIVERBED ROUGHNESS BY AIRBORNE LIDAR

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ABSTRACT: With the advancement for efficiency and accuracy of investigation techniques and equipment, the remote sensing techniques have been widely employed in the river circumstance investigations. In the past, quantifying the morphology along a river channel has been proven to be difficult till the airborne laser altimetry technology, Light Detection and Ranging (LiDAR), has provided high-resolution and high-accuracy topographical data. Data derived from airborne LiDAR were used for analyses in recognition of riverbed morphology. Roughness data derived from pre-disaster riverbed by different reaches were compared with the post-disaster data. Results showed the upper-reaches appear high roughness value than lower-reaches. Thus, the post-disaster riverbed surface relief is close to the derived smoothed relief. Such characteristics also reflected in the major differences evaluated by slope measurement for riverbed morphological analysis; of which the location of peak value also appears changes after disaster. It concluded that the remote sensing techniques have become an essential source to assist the ordinary survey for regional investigation by its rapid and accurate construction of an integrated plane-wise fluvial circumstance of a river watershed area.

KEY WORDS: Digital Elevation Model, River Circumstance Investigation, Morphological Analysis

1. INTRODUCTION

Geomorphometry, which is defined by Chorley et al. (1957) as the science “which treats the geometry of the landscape,” attempts to describe quantitatively the form of the land surface. In a general sense, roughness refers to the irregularity of a topographic surface. The terrain roughness can be measured by significant wavelengths. The significant wavelengths of topography are termed as grain or texture, while amplitudes associated with these wavelengths correspond to the concept of relief. The relationship between the horizontal and vertical dimensions of the topography is embodied in the land slope and the dispersion of slope magnitude and orientation, while vertical distribution of mass under the topographic surface is contained of hypsometry (Mark, 1975) .

In general, riverbed roughness has been referred to the terrain irregularity of a river channel; which can be measured by some significant wavelengths. These significant wavelengths, signals responded by riverbed topography, are termed as grain or texture. The amplitudes associated with these wavelengths correspond to the concept of relieves. Namely, the morphological roughness was specifically defined as the standard deviation of residual topography derived from the differences of two relieves; the original relief and a smoothed relief. A 5x5-moving window defined a smoothed relief. Residuals between the smoothed and the original relieves are regarded as the morphological roughness of riverbed surface.

2. STUDY AREA AND MATERIALS

The study area with 5.5×7 km^2 that located in northeast part of Kaohsiung City in Taiwan and it is situated in a sub-basin of Kao-Ping Reservoir. The high accuracy and high-resolution images of Airborne LiDAR, within the Kao-Ping Reservoir, were adapted for pre-disaster and post-disaster riverbed roughness evaluation and analysis.

2.1 Landslide Event

The Hsiaolin village large landslide event in Kao-Ping Reservoir where is located on the northeast part of Kaohsiung City. It was induced by Morakot typhoon and caused great damage on August of 2009. The Hsiaolin landslide was recognized as a wedge type of failure. The failure wedge is formed by N26^{o}W/22^{o}W bedding plane of Pliocene-Miocene Tangenshan Sandstone and N80^{o}E/84^{o}N high angle fractures with sliding direction to west-southwest (262/21)(Li, 2011).

2.2 Regional Geological Setting

The riverbed geological lithology of Hsiaolin village reach was deposited with alternation of sandstone and shale. Serious landslides occurred after typhoon and rainfall, especially surrounding the riverbanks and the proximity of provincial highway.

2.3 Topographic Data

The materials used in this study include Airborne LiDAR Digital Elevation Model (DEM) and derived roughness data. LiDAR DEM derived from point clouds and resampled to 1 meter. The LiDAR data are both conducted pre-disaster and post-disaster of Typhoon Morakot in August of 2009.

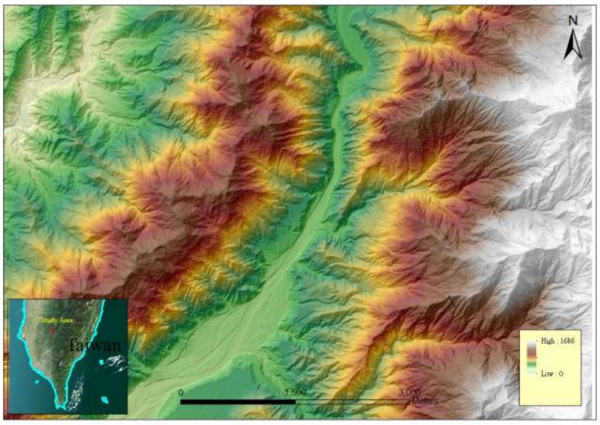


Figure 1. Study Area Image

3. METHODOLOGY

One-meter resolution raster were created from the LiDAR water surface grids using ArcGIS Spatial Analyst©. The roughness index were derived from LiDAR DEM, the detail procedure describe as follow.

3.1 Surface Roughness

The surface roughness is an expression of the variability of a topographic surface at a given scale. The roughness is described using surface-elevation values and can be used to characterize landforms over a variety of different scales; however, the roughness can be quantified using the reflection of electromagnetic radiation from a surface, ranging from specular to diffuse(Thomas Lillesand et al., 2008),it indicated that a single definition of surface roughness may not be possible. Surface roughness is treated here as a geomorphometric variable, not as a parameter, A variable is a measurable property of a phenomenon (e.g., slope angle), while a parameter is a summary measurement of the characteristics of a population, such as mean slope angle(Grohmann et al., 2011). Several methods have been developed for the definition, calculation, and application of surface roughness (Cavalli et al., 2008; Glenn et al., 2006).

The “roughness index” in this study has defined as the standard deviation of residual topography. The variable moving window was used to derive the smoothed DEM. Standard deviation of residual topography was used as a measure of roughness where the residual topography is the difference between the original and a smoothed DEM. The LiDAR DEM was performance by averaging moving window by 5x5 cells. Some studies have shown a relationship between the between standard deviation of residual topography and river-bed roughness (Cavalli et al., 2008),the formula describe as follow.

$$r = \sqrt{\frac{\sum_{i=1}^{25}\left(x_i - x_a\right)}{25}} \qquad (1)$$

The spatial variability of geomorphometric variables is important—it is not enough to know that a given area is “rougher” or “smoother” than another but rather how much and where this difference happens since it may be related to geological features such as lithological boundaries and tectonic structures(Grohmann et al., 2011).

3.2 Slope-Based Roughness Index

The surface roughness index was derived from LiDAR DEM by standard deviation of residual topography method, and the roughness index was also used for generating slope to comparison with elevation-based slope. The third-order finite difference weighted by reciprocal of squared distance algorithm was performed for slope gradient assessing.

$$f(x) = \frac{(z_3 - z_1) + 2(z_6 - z_4) - (z_9 - z_7)}{8 \times cell\ size} \qquad (2)$$

$$f(y) = \frac{(z_7 - z_1) + 2(z_8 - z_2) - (z_9 - z_3)}{8 \times cell\ size}$$

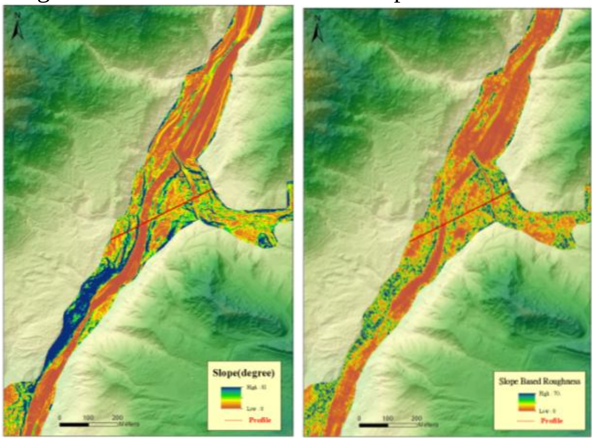
Where *z* is the standard deviation of residual topography, the standard deviation of slope was then computed within 3x3 moving window.

4. RESULTS AND DISCUSSIONS

The slope-based roughness index was used for pre-disaster and post-disaster data; the different reaches were comparing under this method. The slope gradient without performed with surface roughness was also joining to compare with.

4.1 Results and Discusses

The results show both methods could reflect the variability of a topographic surface. The Figure 2 has shown the stream topographic in slope gradient and slope-based roughness, the stream and flood land area show significance difference in slope and slope-based roughness index, the major stream can be identified by1-D colour palette. However, the boundary of stream in slope index appears higher value than in slope-based roughness index; it indicated that the slope-based roughness index is smoother than slope index.



(Left: Slope; Right: Slope-Based Roughness Index)

Figure 2. Two Roughness Index

Two indexes show an increase in roughness when breaks of topographic are occurred. In particular, slope index shows sensitive than slope-based roughness when break points shows. Figure 3 indicated significance difference in spectrum profile, as mentioned previously; slope shows large amplitude than roughness index. In flat area, the slope-based roughness index appears smooth than slope index, the variability gradient of roughness index less than slope index.

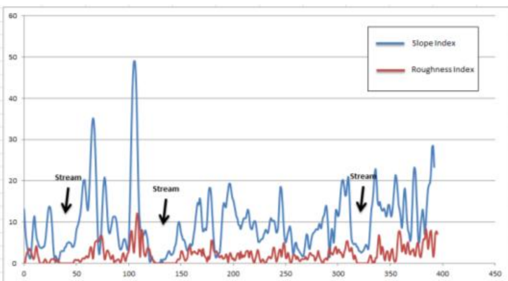
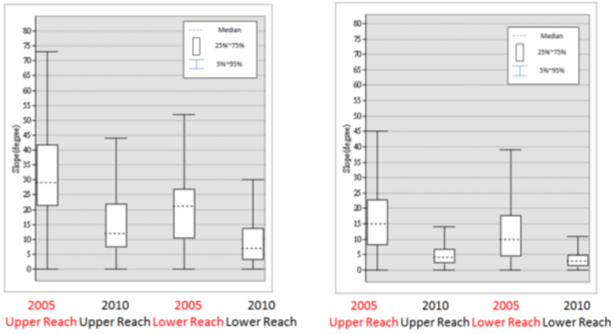


Figure 3. Compare Two Roughness Index In Different Reach.

Figure 4 shows the distribution frequency in two methods, the left figure of Figure 4 indicated the slope method in pre-disaster and post-disaster and also shows the characteristic both on upper-reach and lower-reach. The mean slope in two reaches reduced which after the disaster, it may relate to the landslides material support from upper-reach and also make great contribute from flooding area increase.



2005: Pre-Disaster; 2010: Post-Disaster
(Left: Slope; Right: Slope-Based Roughness Index)
Figure 4. Compare Two Roughness Index In Different Reach.

The slope-based roughness index shows smoother surface that after the disaster, and the data range is narrow than slope index, but appears the same feature for disaster monitoring.

5. CONCLUSIONS

The slope-based roughness index was used for monitoring and compared with slope method; the results show two methods could reflect the riverbed morphologic characteristic.

The major different between slope-based roughness index and slope for describe topographic morphology shown in the spectrum pattern, the slope-based roughness appear smoother than slope index, it may relate to the slope-based roughness is the standard deviation of residual topography, so this index could reflect the whole river feature, it shown a continue properties of river channel and shown the pattern of riverbed, it provides important hydrological parameters for channel.

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