Spatial mapping of tropical landslides area using LiDAR

Siti Nur Afiqah AMAN and Zulkiflee ABD LATIF, Malaysia

Key words: Landslides, likelihood ratio, landslides susceptibilty index

SUMMARY

Landslide occurrence depends on various interrelating factors which consequently initiate to massive mass of soil and rock debris that move downhill due to the gravity action. LiDAR has come with a progressive approach in mitigating landslide by permitting the formation of more accurate DEM compared to other active space-borne and airborne remote sensing techniques.The objective of this research is to assess landslide susceptibility in Ulu Klang area by investigating the correlation between past landslide events with geo environmental factors. A high resolution LiDAR DEM was constructed to produce topographic attributes such as slope, curvature and aspect. These data were utilized to derive second deliverables of landslide parameters such as topographic wetness index (TWI), surface area ratio (SAR) and stream power index (SPI). A probabilistic based likelihood ratio model was applied to establish the spatial relationship between the landslide locations and each landslide related factor. Factor ratings were summed up to obtain Landslide Susceptibility Index (LSI) to construct the landslide susceptibility map.

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1. INTRODUCTION

Remote sensing techniques for landslides studies are undergoing swift developments. The possibility of acquiring 3D information of the terrain with high accuracy and high spatial resolution is opening up new ways of investigating the landslide phenomena (Lee et al., 2006). One of the most advanced technologies in remotely sensed application ranges is Light Detection and ranging (LiDAR).In landslides prediction and mapping, LiDAR is used to produce a high resolution Digital Elevation Model (DEM) which is the main data source for extraction of landslides inducing parameters. LiDAR based DEM allows a detailed delimitation of the landslides on the topographical surface (Corsini et al., 2009).As landslides are often referred to slope instability where its occurrences are induced by many geomorphologic factors, an extensive focus have to be put on controlling the mechanism of sliding especially slope angle, strength of materials and pour water pressure. This research focuses on the ability of LiDAR in improving landslide susceptibility assessment by producing a set of landslide parameters mainly derived from a high resolution of LiDAR based DEM with probabilistic based approach.

2. MATERIALS AND METHOD

2.1 Study area

In conjunction with several fatalities report of landslide occurrences which started with tragedy of highland tower in 1993 and major slope failures in Bukit Antarabangsa in 2008 and 2010, Ulu Klang was selected as study area for this investigation.Located at the latitude of 3°12’30’’N and 101° 45’ 28’’E, Ulu Klang is known to have a rapid track of urbanization. The most common types of landslides in tropical Malaysia are shallow slides where the slide surface is usually less than 4 m and deep and occurs during or immediately after intense rainfall in particular between the months of September to January (van den Eeckhaut et al., 2007).

2.2 Methodology

The prediction of landslide hazard can be expressed as the probability of spatial occurrence of slope failures with a set of geo-environmental conditions (Abd Latif et al., 2012). In this research, a probabilistic approach was carried out to reveal the correlation between several landslide conditioning factors. Four landslide conditioning factors such as slope angle, topographic wetness index (TWI), surface area ratio (SAR), and stream power index (SPI) were extracted from spatial database. For the purpose of analysis and verify the model performance, landslides inventory data were divided into two sets; training data and test data. A likelihood ratio method (Fr) was applied to see the spatial relationship between the landslide locations and each landslide inducing factors (Abd Latif et al., 2012, Pradhan et al., 2010). In the relation analysis, the ratio is that of the area where landslides occurred to the total area. By taking 1 as an average value, if the value is greater than 1 it means a higher correlation while a value lower than 1 means a lower correlation (Qin et al., 2011).

2.3 Generation of LiDAR DEM

As topography is one of the major factors in landslide hazard analysis, the generation of a digital representation of the surface plays a major role (Van Westen et al., 2008). Digital Elevation Model is prepared by interpolating the xyz bare earth LiDAR point using Topo to Raster technique. For that purpose, 1m grid spacing was used to interpolate the ground strike data. This is an appropriate grid spacing which found relative to the ground strike spacing and density in geologically critical areas like steep slopes.In LiDAR point cloud environment, filtering of ground points is one of the most important routines to ensure only ground and near ground are extracted to form a DEM.

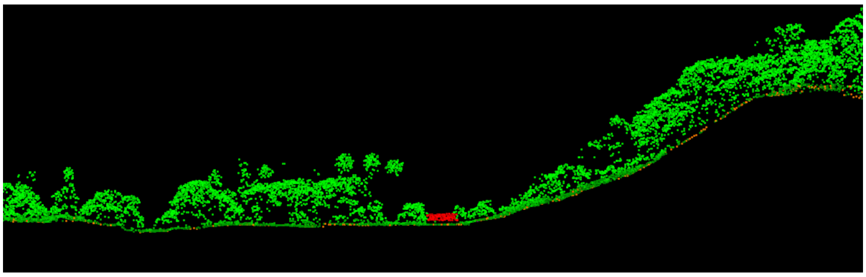

Figure1. Profile view of hill slope terrain.

The first and the most important parameter in landslide susceptibility is slope. Slope identifies the steepest downhill slope for a location on a surface. In GIS tool environment, slope is calculated for each triangle in TINs and for each cell in raster. The cell size is maintained to 1 m. The highest value recorded is 73° while the lowest slope angle is set to 0°.

2.3 Derivation of compound landslide parameters

Compound parameters basically are derived from the primary landslide parameters. Slope map was used as major parameter to derive Topographic wetness Index (TWI), Surface Roughness Index and Stream Power Index.

2.3.1 Topographic Wetness Index

Topographic wetness index is defined as the natural log of the ratio of the Specific Catchment Area (SCA; upslope area per unit contour length). Topographic wetness index (TWI) can quantify the control of local topography on hydrological process and indicate the spatial distribution of soil moisture and surface saturation.

$$TWI=\ln (A_s/\tan \beta)(1)$$

2.3.2 Surface Roughness Index

Surface roughness index computation is based on the calculation of deviation between the elevation model surface and a trend-surface. Surface area also is a basis for a useful measure of landscape topographic roughness. The surface area ratio of any particular region on the landscape can be calculated by dividing the surface area of that region by the planimetric area. Measured value of 1 indicated smoothness while greater than 1 (>1) indicated roughness surface.

$$SAR = S/A_s \qquad (2)$$

2.3.3 Stream Power Index

SPI is a measure of the erosive power of water flow based on the assumption that discharge (q) is proportional to specific catchment area (A_s).As the specific catchment's area and gradient increase, the amount of water contributed by upslope areas and the velocity of water contributed by upslope areas and the velocity of water flow increase; hence the SPI and slope erosion risk increase (Oh and Pradhan, 2011).

$$SPI = A_s \text{ x } \tan \beta \qquad (3)$$

Each of this parameters was then structured in a Model Builder database to compute likelihood ratio. Model Builder in ArcGIS was used for this purpose.

3. RESULTS AND DISCUSSION

In statistical analysis at medium scale, these parameters are appropriate to be used. In this research, all parameters extracted from LiDAR-derived DEM were mapped into 1:10000 scales. As shown in Figure2-5, every parameter has been classified based on standard classification scheme following the literature. Likelihood ratio value (Fr) obtained from each parameter tabulated in Table 1. Each parameters was break into individual classification based on standard deviation breaking method. Each classification is prepared for individual assessment for every ratio reflected to the parameters. Finally, each Fr for every parameters is summed up to obtain Landslide Susceptibility Index (LSI) following Equation 4, and the final map is shown in Fig.6:

$$LSI = \sum Fr\ (_{i..m}) \qquad (4)$$

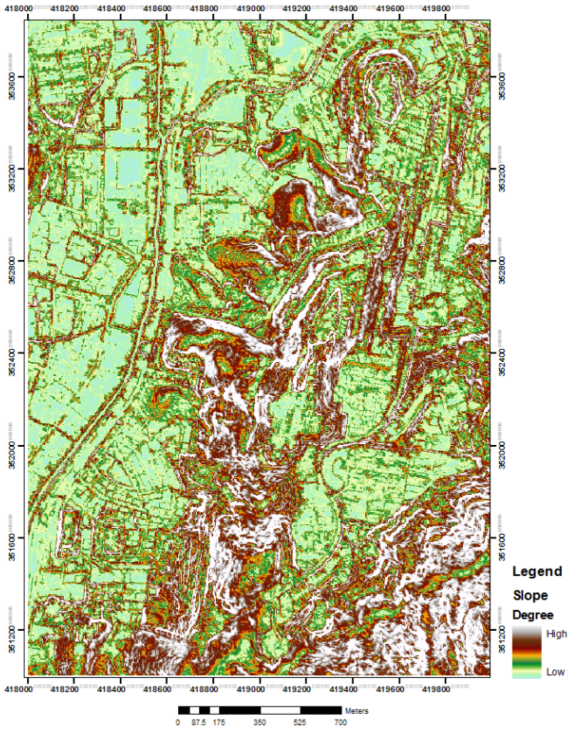

Figure2.Slope parameter

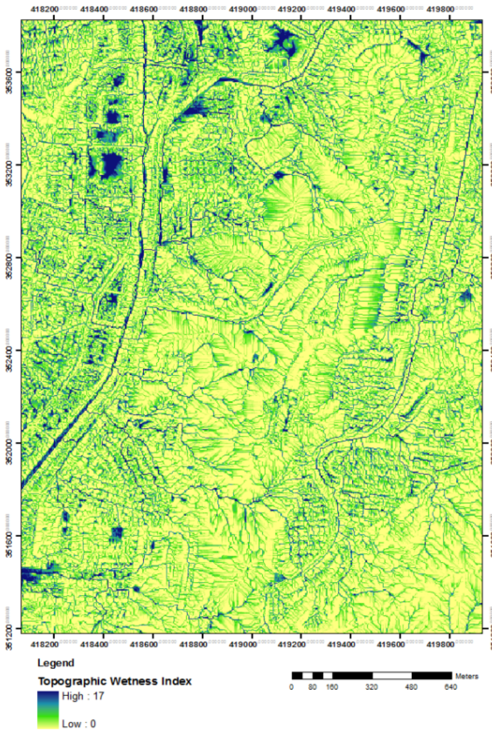

Figure3.TWI parameter

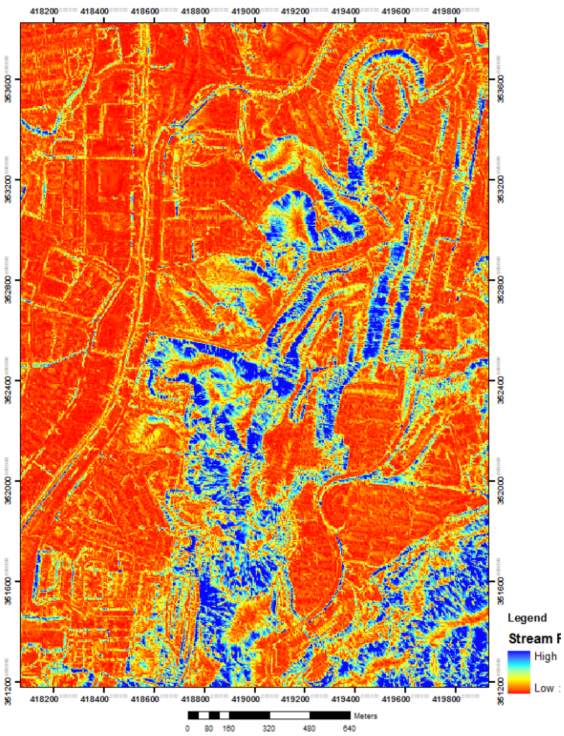

Figure 4.SPI parameter

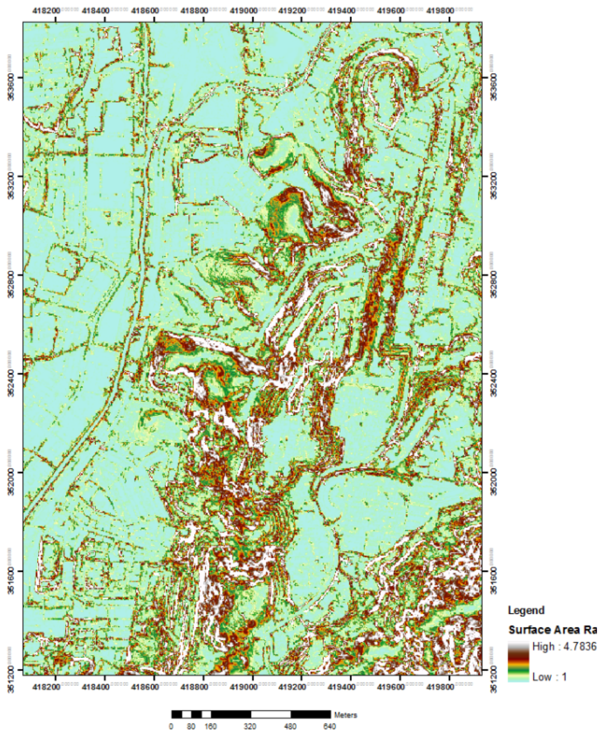

Figure5.SAR parameter

Table 1. Likelihood Ratio of landslide parameters

Parameters	Classification	Frequency Ratio	Parameters	Classification	Frequency Ratio
Slope	0°-15°	0.139	**Stream Power Index**	0-1.087	0.380
	16°-25°	0.954		1.088-2.159	3.486
	26°-35°	2.819		2.160-19.980	8.19
	>35°	4.069	**Surface Area Ratio**	1	-
Topographic Wetness Index	0-0.0134	0.689		>1	1.000
	0.0135-1.17164	4.326			
	1.17165-17.518	0			

The likelihood ratio value of each landslide inducing parameters derived from LiDAR is very important in identifying the trend of landslide occurrences. Furthermore, landslides are among the most hazardous natural disasters in Malaysia. Therefore, the Government and research institutions are trying to analyze the landslide hazard and risk and to show its spatial distribution over the regions. The potential of landslide occurrence in the future time could be predicted byinvestigating the correlation between each geomorphologic surfaces and the historical records of past landslide events**.**

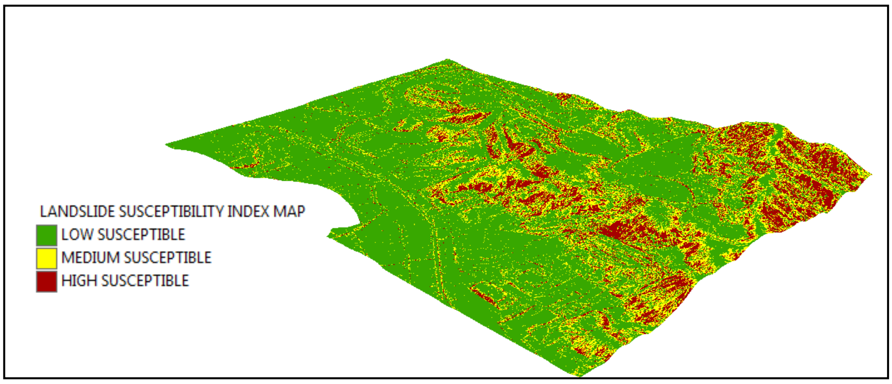

Figure 6. Landslides susceptibility index map

4. CONCLUSION

The reaults of this study provide a scientific background for estimation on the risk areas with respect to landslides, and may serve as a basis for decisions for the authorities concerned. The results demonstrated here can be used as a basis data to assist slope mnagement and land use planning in the study area. It can be concluded that LiDAR greatly contributes in producing a high resolution DEM as a main data layer in landslide predictions. LiDAR appears to offer detailed elevation information acquired over large areas at a higher resolution thanconventional DEM and thus reduces the costs required to do field-based datacollection.

By integrating LiDAR in developing landslide susceptibility model, the relative contribution of the parameters is assessed and spatially the terrain surface is categorized into respective level of susceptibility. It is found that the susceptibility classes produced in this study will definitely give beneficial insight to local authority in planning and mitigating the landslide issues.

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BIOGRAPHICAL NOTES

Dr. Zulkiflee is currently Head of Applied Remote Sensing and Geospatial Research Group and Associate Professor at the Centre of Studies for Surveying Science and Geomatics, Universiti Teknologi MARA, Shah Alam, Malaysia. He received his Bachelor of Geomatics at the University of Melbourne, Australia and Ph.D. in Remote Sensing at Lancaster University, UK. His research interest focuses on developing remote sensing and GIS techniques for environmental applications, particularly in climatology, ecology and biodiversity.

CONTACTS

Associate Professor Dr. Zulkiflee Abd Latif
Applied Remote Sensing and Geospatial Research Group
Faculty of Architecture, Planning & Surveying
Universiti Teknologi MARA
40450 Shah Alam, Selangor
MALAYSIA
Tel. +603 5544 4399
Fax + 603 5544 4545
Email: zulki721@salam.uitm.edu.my/zabdlatif@gmail.com
Web site: https://www.researchgate.net/profile/Zulkiflee_Abd_latif/?ev=hdr_xprf