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Spatial probabilistic approach on landslide susceptibility assessment from high resolution sensors derived parameters

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Abstract. 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 the susceptibility of landslide 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) as well as NDVI generated from IKONOS imagery. Subsequently, a probabilistic based frequency 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.

1. Introduction

Over the following two decades, a series of a catastrophic and small to medium- sized landslides have been reported. According to the data sources from the Ampang Jaya Municipal Council (MPAJ) and the Slope Engineering Branch of Public Works Department Malaysia (PWD), a total of 28 historical landslide events have been reported in Ulu Klang areas implying hillside development has caused disturbance to the ecosystem, and hence the stability of the natural slopes.

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 [1]. One of the most advance technology in remotely sensed application is Light Detection and Ranging (LiDAR)[14].

In landslide investigation, 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 [2,3]. As landslides are often referred to slope instability where its occurrences are induced by many geomorphological 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 is focusing 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 approach.

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2. Study area

The study was carried out in Ulu Klang with an area of 600 hectares located at the latitude of 3°12'30''N and 101° 45' 28''E. Ulu Klang is on a rapid track of urbanization while having very progressive demands on its land property and housing development especially at the hillside area. The most common types of landslides in 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 [1].

3. Methodology

Spatial prediction of landslide hazard map preparation is considered as the first important step in landslide hazard mitigation and management. The spatial probability of landslide hazard can be expressed as the probability of spatial occurrence of slope failures with a set of geo-environmental conditions [4]. In this investigation, a probabilistic approach was carried out to reveal the correlation between several landslide inducing factors. Eight landslide inducing factors such as slope angle, aspect, planar and profile curvature, topographic wetness index (TWI), surface area ratio (SAR), stream power index (SPI) and NDVI 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. Frequency ratio method (Fr) was applied to see the spatial relationship between the landslide locations and each landslide inducing factors [5]. 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 [6].

3.1. LiDAR high resolution DEM

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. As topography is one of the major factors in landslide hazard analysis, the generation of a digital representation of the surface elevation, called Digital Elevation Model (DEM), plays a major role. Digital Elevation Model is prepared by interpolating the xyz bare earth LiDAR point using Topo to Raster technique. 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.

3.2. Preliminary LiDAR derived parameters

DEM with 1m x 1m resolution derived from LiDAR data was the most important model in this study as it will be used to extract other parameters. In this case, the LiDAR ground points were interpolated by preserving the hydrological characteristic which is the key in formulating the primary landslide parameters such as slope, aspect, planar curvature as well as profile curvature. This was followed by modeling the compound landslides parameters which mainly derived from slope model. In this study both profile convexity and plan convexity measures were used [7]. The functionality of both profile and plan curvature can be seen as an element to measure the rate of change of slope and aspect [8].

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Figure 1. Slope parameter

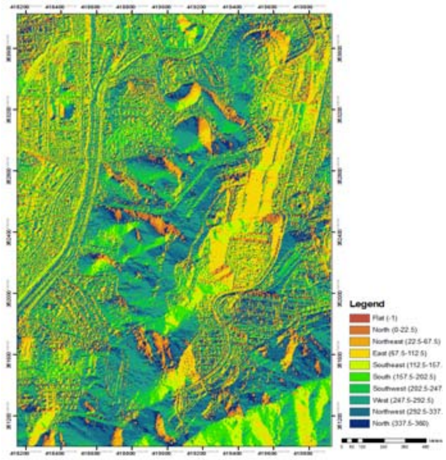

Figure 2. Aspect parameter

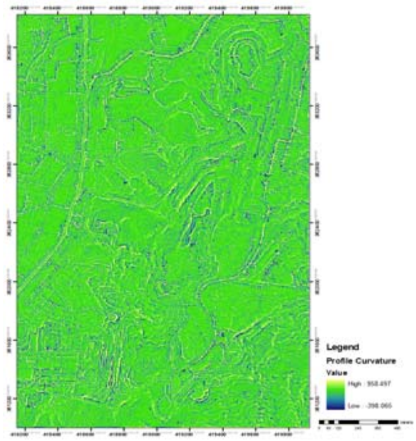

Figure 3. Profile curvature parameter

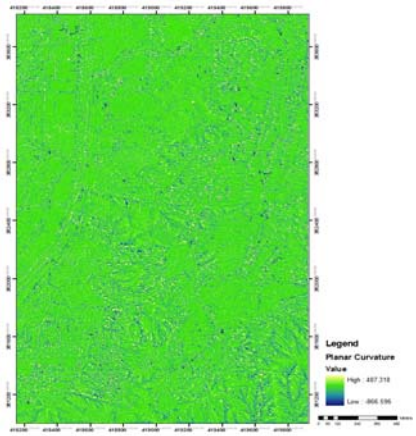

Figure 4. Planar curvature parameter

3.3. Secondary LiDAR derived parameters.

TWI is important in characterizing hydrological similarity of landslide prone area by quantifying the control of local topography on hydrological process and indicates the spatial distribution of soil moisture and surface saturation [9]. The formulation of TWI is derived as Equation 1 where A_s is the upslope contributing area per unit contour length and β is the local gradient at the point.

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

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 [10].

$$SPI = A_s \times \tan \beta \quad (2)$$

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.

$$SAR = S/A_s \quad (3)$$

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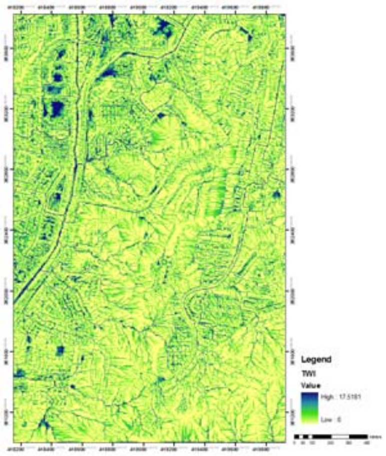

Figure 5. Topographic wetness index parameter

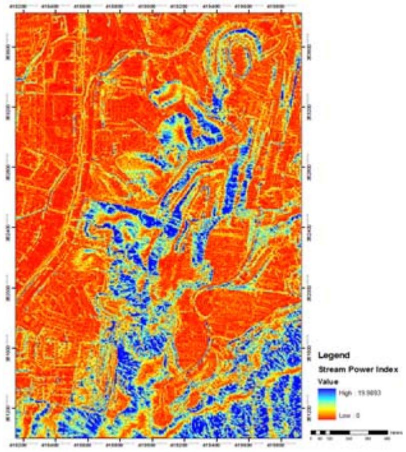

Figure 6. Stream power index parameter

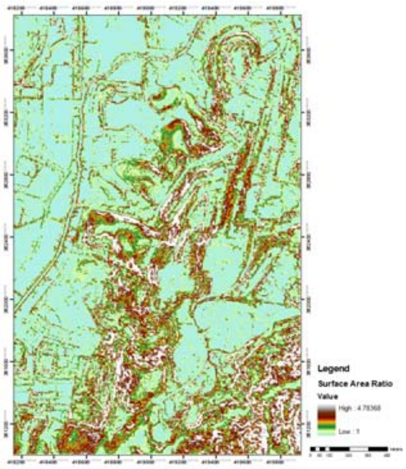

Figure 7. Surface area ratio parameter

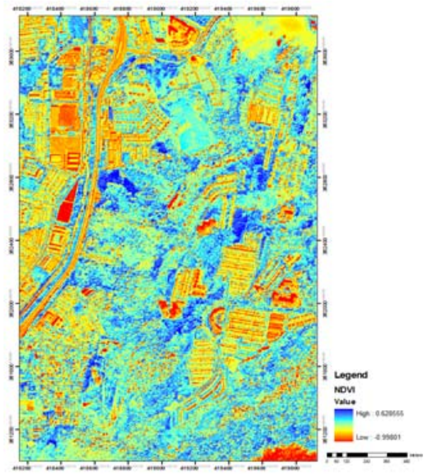

Figure 8. NDVI parameter

4. Results and Discussion

Frequency value obtained from each parameter was tabulated in Table 1. Landslide Susceptibility Index (LSI) map as shown in Figure 9 was constructed from multiple of landslide parameters by following Equation 4 [11]:

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

The frequency 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 [11]. The potential of landslide occurrence in the future time could be predicted by investigating the correlation between each geomorphological surfaces and the historical records of past landslide events.

Table 1. Frequency Ratio of each parameter

Parameters	Classification	Frequency Ratio	Parameters	Classification	Frequency Ratio
Slope	0°-15°	0.139	**Stream**	0-1.087	0.380
	16°-25°	0.954	**Power**	1.088-2.159	3.486
	26°-35°	2.819	**Index**	2.160-19.980	8.19
	>35°	4.069	**Surface**	1	-
Profile	Concave	1.614	**Area Ratio**	>1	1.000
Curvature	Flat	-	**Aspect**	North	3.837
	Convex	0.608		Northeast	0.834
Plan	Concave	-		East	0.724
Curvature	Flat	0.728		Southeast	0.833
	Convex	1.230		South	-
Topographic	0-0.0134	0.689		Southwest	1.496
Wetness	0.0135-	4.326		West	0.499
Index	1.17165-	-		Northwest	0.975
	0 - -1	4.291		North	1.108z
	0 -1	0.332			

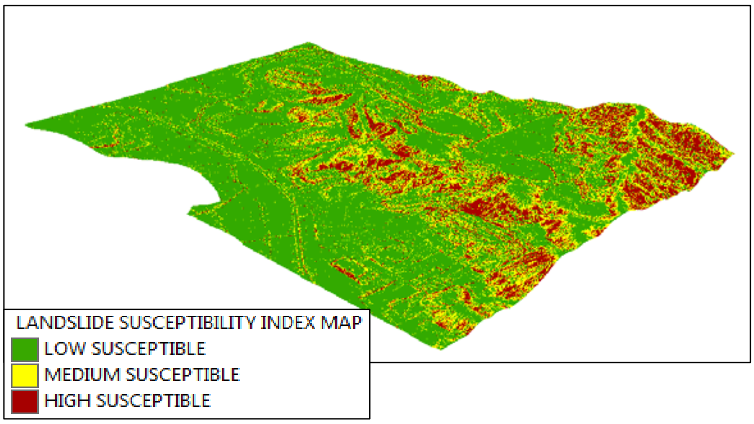

Figure 8. Final landslide susceptibility index map

5. Conclusion

It can be concluded that LiDAR greatly contributes in producing a high resolution DEM as a main data layer in landslide susceptibility assessment which definitely allow for a better analysis. LiDAR appears to offer detailed elevation information acquired over large areas at a higher resolution than conventional DEM and thus reduces the costs required to do field-based data collection. Its ability to penetrate dense vegetation allows a detail interpretation and derivation of landslide parameters which is the key factor in this study. 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.

6. References

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