Generating Landslide Susceptibility Map using Airborne Lidar Derived Parameters and Geological Mapping Factors for Canada Hill, Miri, Sarawak

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Abstract. Landslide Susceptibility Mapping using GIS software and remote sensing data have been conducted in several location involving geological and geomorphological sensitive at Canada Hill, Miri. The previous researcher has conducted quantitative analyses using different statistical methods with different parameters in the same study area. The mapping of landslides using high-resolution Airborne LiDAR data is a valuable effort. All of this play important role, in the analysis and development of landslide susceptibility map. High-resolution Airborne LiDAR data has the ability to penetrate thick forest cover and produce Digital Terrain Model. Using Digital Terrain Model, the landslide parameter can be generated and extracted. The main objective of this study was to produce landslide susceptibility map using the Probability Frequency Ratio Model method. This study involved the delineating of causative factors from Digital Terrain Model generated by Airborne LiDAR data as well as the data collected from the field. Apart from parameters derived from LiDAR, parameters from filed and site investigation were included into the mapping process. This study was different from the previous studies in the same area in terms of various analytical approaches and samples used. The results of the landslide susceptibility map were verified via randomly selected landslides samples using two different methods. The landslide susceptibility map produced is more refined and is able to predict more effectively compared to the existing map. The landslide susceptibility map produced in this study could be used for land use planning and management by decision makers and land use planners.

Keywords: LiDAR, landslide susceptibility map, digital terrain model, probability frequency ratio, geology

1. Introduction

Sarawak has recorded numerous tragedies due to this geological hazard. Since the occurrence of landslides in Punda Ruan, Simunjan which killed 16 longhouse inhabitants, the Sarawak government and Department of Mineral and Geosciences Malaysia has seriously monitored the areas with risk of landslide. Canada Hill, which stretches 8 km striking northeast-southwest and formed the backbone of Miri City is a prominent landslide risk area. In the span of 5 years since 2009, a total of four (4) was reported in Miri City with two (2) fatalities and damages to infrastructures [1,2,3].
The slopes, anthropogenic activities, vegetation cover, climate, its geomorphological and geological features play important roles in triggering the process. Locating the distribution of these features are substantial as predicting and planning of any development is crucial.

2. Location and Accessibility
The study area is located in the middle of Miri City. It is bounded by Borneo Rectified Skew Orthomorphic (BRSO) 475000mE to 481000mE and 481000mN to 489000mN. The overall accessibility to the study area is excellent. The area is connected by the flight from majority of international airport in Malaysia, major town in Sarawak and rural air service (Figure 1). Miri City is well served by Pan Borneo Highway.

![Figure 1. The location map of Canada Hill, Miri, Sarawak.](image)

3. Material and Method
In this investigation, a probabilistic approach was carried out to reveal the correlation between several landslide causative factors. Frequency ratio method (Fr) as referred to equation (1) was applied to see the spatial relationship between the landslide locations and each landslide related factors. In the relation analysis, the ratio is that of the area where landslides occurred to the total area.

The formula for the calculation of frequency ratio is as follows:

\[
Fr_i = \frac{N_{pix}(Si)}{\sum N_{pix}(Si) / \sum N_{pix}(Ni)}
\]  

Rating of each factor's type or range \(Fr_i\)
Where,
\(N_{pix}(Si)\) = The number of pixels containing slides in class \(i\)
\(N_{pix}(Ni)\) = Total number of pixels having a class \(i\) in the whole study area
\(\sum N_{pix}(Si)\) = Total number of pixels containing landslides and
\(\sum pix(Ni)\) = Total number of pixels in the whole study area
By taking 1 as an average value, if the value of Fri is greater than 1 it means a higher correlation, while the value of Fri lower than 1 means a lower correlation. Factor ratings were summed up to yield Landslide Susceptibility Index (LSI) according to equation (2).

\[ \text{LSI} = \sum \text{Fr}(i…m) \]  

(2)

Where FR is the rating of each factor’s type or range.

3.1. Data Acquisition

The first step for the production of a Landslide Susceptibility Map (LSM) is to gather the available data in an effort of the selection of the effective parameters in preparation of thematic digital maps. All such data, maps used in this study are raster based on a cell size of 0.5 m x 0.5 m. An important step for the production of a landslide susceptibility map is the construction of an inventory map based on previously occurred landslides and the preparation of the causative data layers by extracting them from reliable sources. These data are then converted to raster for the analysis.

Light detection and ranging (LiDAR) is a remote sensing technology that emits intense, focused beams of light. These laser beams travel at the speed of light and the time taken for the laser to return back to the position of the target can be determined accurately. It is similar to radar (radio detecting and ranging), except that it is based on discrete pulses of laser light. However, accurate digital terrain models (DTM) are necessary for this study. DTM accuracies achieved by Shuttle Radar Topographic Mapping (SRTM; 30 m), and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER; 30 m) [4] compared to LiDAR (±0.5 m). The LiDAR data were acquired in 2011 using Optech ALTM 3100 sensors.

The spot (Satellite Pour-1’Observation de la Terre) satellites in orbit are Spot 2, Spot 4 and Spot 5 provide images with a large choice of resolutions (2.5 m – 1 km). Spot 5 is a high-resolution satellite that was launched in 2002. It is owned and operated by Airbus Defence & Space. The satellite of Spot 5 captures both panchromatic (black and white) and multispectral (colour) digital imagery. The Spot 5 imagery used in the study was acquired on the 1st August 2011 and was purchased from MACRES in 3 bands mode (BGR) after undergoing atmospheric correction with the pixel resolution of 2.5 m.

The Airborne Laser Scanning (ALS) data were processed to create Digital Terrain Models (DTM) out of ALS ground points and Digital Surface Models (DSM) out of the adjusted first return ALS data with a 0.5 m resolution. The ground point data are interpolated with different ground routines such as binning interpolation type, simple nearest neighbour or complex kriging techniques to produce hillshades together with slope gradient map and topographic contours. Hillshades which are calculated from DTMs is a grayscale 3D representation of the surface, with the sun's relative position taken into account for shading the image. This function uses the altitude and azimuth properties to specify the sun's position. This will produce a 3D false image of the landscape that creates illumination and shadowing to emphasize and highlight geomorphic features.

High resolution DTM and high resolution of derivative maps enables a high level of accuracy and visibility of main landslide features. Landslide body is clearly visible, including main scarp as well as the zone of accumulation and zone of depletion on topographic derivatives, hillshades and slope maps (Figure 2 & Figure 3). These landslides are relict rotational slides which have been covered by thick overgrowth and hampered visualisation by satellite images. Slope and contour maps were the two that proved to be the most useful maps of all three topographic derivative map types used to identify landslides. Hillshade maps can provide a very powerful visual interpretation when trying to identify landslides, but their usefulness depends on the sun angle and the azimuth with which the derivative map was processed (Figure 3 & Figure 4). A total number of 35 landslides were detected and mapped either by visual inspection of LiDAR imagery or field investigation, or both (Figure 4 & Figure 5). Some of these landslides were abstract from previous study and are confirm using hillshades and field observation.
Figure 2. Composite display of three different maps (hillshades, slope and orthophoto) of the landslide at Kg. Lereng Bukit.

Figure 3. The cross-section of landslide’s relict with its location and 3D image.

3.2. LiDAR Derived Parameters

3.2.1. Slope Gradient. The slope gradient map of the study area was created in ArcMap in degrees from the DTM which itself was processed from LiDAR data (Figure 6). The slope map is reclassify manually based on the slope data used by [5] for the hillside development procedure.
3.2.2. **Slope Aspect.** A map of aspect direction was created for the field area from the high-resolution DEM by using the aspect tool from the spatial analyst's toolbox, in ArcGIS. The aspect tool uses an algorithm similar to the slope to fit a plane and then determines the direction that this plane faces [6]. The cell values (0° to 360° and -1 for flat cells) were rounded up to the nearest integer. The aspect direction for each hillslope failure was determined by using the majority value of aspect direction cells.

3.2.3. **Curvature.** The Spatial Analyst Tools Curvature creates the raster curvature, profile curvature, and plan curvature by inputting the DTM of the study area. The curvature is the combination of plan and profile curvature, which separates the concavity of the slope in different directions. A negative value equals to the concave slope, a positive value indicates a convex slope and a value zero is linear. Curvature analysis also allows areas to be identified on a surface where this plan features are more or less localized and consequently, could help to identify zones prone to landslides.
3.2.4. LS Factor. The Slope Length and Steepness Factors (LS) factors represent erodibility due to a combination of slope length and steepness relative to a standard unit plot. It expresses the effect of topography, specifically hill slopes length and steepness, on soil erosion. An increase in hillslope length and steepness results in an increase in the LS factor which may contribute to the slope failure with another triggering factor. The LS factor which, influenced by slope length and steepness were analysed using the equation below (Equation 3):

\[
LS = (\lambda/22.1)\sqrt{65.41 \sin^2 \theta + 4.56 \sin \theta + 0.065}
\]  

Where \( \lambda \) is the horizontally measured plot length, \( \theta \) is the slope angle and \( m \) is a variable plot exponent adjustable to match terrain and soil variants. \( m \) varies between 0.5 (slopes of 5% or more) and 0.2 (slopes of < 1%).

The flow accumulation raster was calculated using Spatial Analyst Tools hydrology based on the DTM LiDAR data. Finally, the LS factor was analysed using a raster calculator in Spatial Analyst Tool of ArcMap.

3.2.5. Lineament Density. Many authors have noted the correlations between faulting and the distribution of landslides [7]. Since the intensity of fault-related rock fracturing in the zone around the fault increase with the density of landslides, the lineament or fault density is a good indicator of rock mass strength [8]. The lineaments of the study area are extracted from previous studies, satellite images, aerial photographs and high-resolution DTM LiDAR data. Lineament density of a lineament is the total line length of the fault network divided by the area. A high density indicated one or more lineament exist in that particular area.

3.2.6. Distance to Drainage. The stream networks of the study area were extracted from the high-resolution DTM LiDAR using Spatial Analyst Tools. The study area contains more than 10 streams which are closely related to the geological structure in the study area. The drainage of the study area was analysed from the DTM LiDAR data using hydrology in the Spatial Analyst Tools. Most of the
stream networks are parallel to each other and only the stream network in the southern part of the study area eventually merges together. The buffers were created, using 3D Analyst, around each of the drainages in the following increments in meters, 0-25, 25-50, 50-75, 75-100 and >100. The ranges for the buffers were chosen in part because these ranges were typical in similar studies and due to how close the drainage channels were to each other.

3.2.7. Topographic Wetness Index. TWI describes how do topographical and hydrological features influence the location and size of saturated areas which act as initiation points for the runoff. Wood et al. [9] predict that steady-state conditions and uniform soil properties for their equation (4) to calculate TWI,

\[ TWI = \ln (\frac{A}{\tan \beta}) \]  

A represents the flow accumulation raster and the slope gradient is \( \beta \) (in degrees).

Wood et al. [9] explains that steady state and uniform soil properties can be assumed because the variation of topography often far exceeds soil transitivity.

3.3. Satellite Image and Field Derived Parameters

3.3.1. Soil. The soil map of the study area was extracted from the 1:50,000 scales which might not be very accurate in comparison with the study that used the high-resolution LiDAR data to develop Landslide Susceptibility Map. However, eight (8) soil series were used to analyse whether this factor contributed to the stability of the slopes which led to landslides in the study area (Figure 7). The soil series were Tatau, Similajau, Rajang, Nyalau, Merit, Miri1, Miri and Igan.

3.3.2. Lithology. The study area is underlain by two (2) geological formations, namely: The Tukau Formation and Miri Formation, and alluvium of the quaternary deposit. However, the lithology is crucial as the types of rocks are one of the factors that influence the stability of the slope. A total of five (5) different lithological were extracted from the previous studies.

3.3.3. Landuse. The land cover of the area is a thematic classification of the Spot 5 images which is also counter check on the ground. Spot 5 images with resolution 2.5 m are used to identify the high vegetation, low vegetation, built up and barren. Field checking is important in order to demarcate the extent of the land cover to be digitized to vector format for analysis.

3.3.4. Biomass. The plot mapping of biomass together with Canopy Height Model (CHM) LiDAR data and Spot 5 images have made the study possible. The plot mapping and spot 5 with a resolution of 2.5 m are successful in delineating the biomass based on the spot 5 images.

4. Result and Discussion

4.1. Landslide Susceptibility Analyses

For calculation of the landslide susceptibility index (LSI) of the study area, the frequency ratios of the each of the class or type of each factor (Table 1, Figure 8 & Figure 9) are calculated based on the formula (1).

The overall Landslide Susceptibility Index (LSI) of the area is calculated as follows;
LSI = Fr (Aspect) + Fr (Curvature) + Fr (Slope) + Fr (LS Factor) + Fr (Lineament Density) + Fr (Lithology) + Fr (Soil) + Fr (Distance to Drainage) + Fr (Topographic Wetness Index) + Fr (Land use) + Fr (Biomass).

**Figure 6.** The causative factor maps derived from LiDAR (Slope, Aspect, Curvature, LS Factor, Lineament Density, Distance to Drainage and Topographic Wetness Index).

**Figure 7.** The causative factor maps derived from satellite image and field mapping. (Lithology, Soil, Biomass and Land Use)

| Parameters | Pixel of Occurrences | % Pixel of Occurrences | Pixel of Landslides | % pixel of Landslides | Frequency Ratio |
|------------|----------------------|------------------------|---------------------|-----------------------|-----------------|
| Aspect     |                      |                        |                     |                       |                 |
| Flat       | 139                  | 0.0002                 | 0                   | 0.0000                | 0.0000          |
| North      | 8341842              | 12.7558                | 47944               | 19.1472               | 1.5011          |
| Northeast  | 7678637              | 11.7416                | 15356               | 6.1327                | 0.5223          |
| Location     | East          | Southeast     | South         | Southwest     | West          | Northwest     |
|--------------|---------------|---------------|---------------|---------------|---------------|---------------|
|              | 8238603       | 8236733       | 8227661       | 7549745       | 8252807       | 8870433       |
|              | 12.5979       | 12.5950       | 12.5812       | 11.5446       | 12.6196       | 13.5641       |
|              | 18625         | 18095         | 19463         | 24197         | 35555         | 71162         |
|              | 7.4382        | 7.2265        | 7.7729        | 9.6635        | 14.1995       | 28.4197       |
|              | 0.5904        | 0.5738        | 0.6178        | 0.8371        | 1.1252        | 2.0952        |

| Curvature    | -5,760.2 - -29.3 | 3999042 | 6.1151 | 31833 | 12.7130 | 2.0790 |
|--------------|------------------|---------|--------|-------|---------|--------|
|              | -29.3 - 49.1     | 59321009 | 90.7096 | 202703 | 80.9526 | 0.8924 |
|              | 49.1 - 4,249.1   | 2076549 | 3.1753 | 15861 | 6.3343 | 1.9949 |

| Slope        | 0 – 5            | 25892944 | 39.5933 | 19439 | 7.7633 | 0.1961 |
|--------------|------------------|----------|---------|-------|--------|--------|
|              | 5 – 15           | 20726345 | 31.6930 | 39643 | 15.8231 | 0.4995 |
|              | 15 – 25          | 9723458  | 14.8683 | 77129 | 30.8027 | 2.0717 |
|              | 25 – 35          | 5664446  | 8.6616  | 71218 | 28.4420 | 3.2837 |
|              | 35 – 60          | 3266853  | 4.9954  | 42041 | 16.7897 | 3.3610 |
|              | 60 – 90          | 122554   | 0.1874  | 927   | 0.3702  | 1.9755 |

| Ls_Factor    | 0 - 1.07         | 43008030 | 65.7642 | 36192 | 14.4538 | 0.2198 |
|--------------|------------------|----------|---------|-------|---------|--------|
|              | 1.07 - 3.22      | 11805779 | 18.0524 | 65023 | 25.9680 | 1.4385 |
|              | 3.22 - 6.45      | 7985592  | 12.2109 | 103900| 41.4941 | 3.3981 |
|              | 6.45 - 12.37     | 2417637  | 3.6968  | 41668 | 16.6408 | 4.5013 |
|              | 12.37 - 137.15   | 179562   | 0.2746  | 3614  | 1.4433  | 5.2566 |

| Lineament    | 0-1.38           | 24369949 | 37.2644 | 9923  | 3.9629  | 0.1063 |
|--------------|------------------|----------|---------|-------|---------|--------|
|              | 1.38 - 3.60      | 23762902 | 36.3362 | 40996 | 16.3724 | 0.4506 |
|              | 3.60 - 5.56      | 8303470  | 12.6970 | 57878 | 23.1145 | 1.8205 |
|              | 5.56 - 7.83      | 5278734  | 8.0718  | 70853 | 28.2963 | 3.5056 |
|              | 7.83 - 13.50     | 3681545  | 5.6295  | 70747 | 28.2539 | 5.0189 |

| Lithology    | Mainly sand      | 29052537 | 44.4278 | 27479 | 10.9751 | 0.2470 |
|--------------|------------------|----------|---------|-------|---------|--------|
|              | with some gravel |         |         |       |         |        |
|              | and silt.        |          |         |       |         |        |
|              | Mainly sand,     | 3746517  | 5.7293  |       | 0       | 0.0000 |
|              | silt and clay.   |          |         |       |         | 0.0000 |
|              | Interbedded      |          |         |       |         | 0.0000 |
|              | sandstone and    |          |         |       |         | 0.0000 |
|              | shale. Poorly    |          |         |       |         | 0.0000 |
|              | consolidated     |          |         |       |         | 0.0000 |
|              | sandstone with   |          |         |       |         | 0.0000 |
|              | clay. Thick      |          |         |       |         | 0.0000 |
|              | sandstone bed    |          |         |       |         | 0.0000 |
|              | with thinly      |          |         |       |         | 0.0000 |
|              | bedded shale.    |          |         |       |         | 0.0000 |

| Soil         | Nyalau           | 37575484 | 57.4572 | 109938| 43.9055 | 0.7641 |
|--------------|------------------|----------|---------|-------|---------|--------|
|              | Igan             | 1696396  | 2.5940  |       | 0       | 0.0000 |
|              | Miri             | 5156964  | 7.8856  | 105765| 42.2389 | 5.3565 |

| Density      | 1.38 - 3.60      | 23762902 | 36.3362 | 40996 | 16.3724 | 0.4506 |
|--------------|------------------|----------|---------|-------|---------|--------|
|              | 3.60 - 5.56      | 8303470  | 12.6970 | 57878 | 23.1145 | 1.8205 |
|              | 5.56 - 7.83      | 5278734  | 8.0718  | 70853 | 28.2963 | 3.5056 |
|              | 7.83 - 13.50     | 3681545  | 5.6295  | 70747 | 28.2539 | 5.0189 |
| Location | Index | Distance to 0 - 25m | Drainage 25 – 50 | Drainage 50 – 75 | Drainage 75 – 100 | Drainage > 100m |
|----------|-------|---------------------|------------------|------------------|------------------|----------------|
| Similajau | 192284 | 0.2940 | 0 | 0.0000 | 0.0000 |
| Rajang   | 2128122 | 3.2541 | 0 | 0.0000 | 0.0000 |
| Merit    | 1186455 | 1.8142 | 0 | 0.0000 | 0.0000 |
| Miri1    | 16846362 | 25.7600 | 29638 | 11.8364 | 0.4595 |
| Tatau    | 614533 | 0.9397 | 5056 | 2.0192 | 2.1488 |

| Distance to | 0 - 25m | 25 – 50 | 50 – 75 | 75 – 100 | > 100m |
|-------------|---------|---------|---------|----------|--------|
| Topographic | -3.77 - 2.52 | 30.7285 | 103676 | 41.4046 | 1.3474 |
| Wetness     | 2.52 - 4.70 | 33.7682 | 95003 | 37.9409 | 1.1236 |
| Index       | 4.70 - 7.17 | 22.2158 | 39299 | 15.6947 | 0.7065 |
|             | 7.17 - 10.89 | 10.6067 | 10947 | 4.3719 | 0.4122 |
|             | 10.89 - 22.56 | 2.6796 | 1472 | 0.5879 | 0.2194 |

| Land Use | Barren | Build-Up | High Vegetation | Low Vegetation |
|----------|--------|----------|-----------------|----------------|
| Biomass  | 0 - 16.43 | 16.43 - 51.33 | 51.33 - 86.92 | 86.92 - 117.04 | 117.04 - 173.85 |
|          | 42841417 | 3949365 | 4100837 | 5696373 | 8808608 |

| Biomass | 0 - 16.43 | 16.43 - 51.33 | 51.33 - 86.92 | 86.92 - 117.04 | 117.04 - 173.85 |
|---------|-----------|---------------|---------------|---------------|---------------|
|         | 42841417  | 3949365       | 4100837       | 5696373       | 8808608       |
|         | 65.5360   | 6.0415        | 6.2732        | 8.7139        | 13.4748       |
|         | 107192    | 34595         | 31599         | 39264         | 37747         |
|         | 42.8128   | 13.8173       | 12.6207       | 15.6821       | 15.0762       |
|         | 0.6533    | 2.2871        | 2.0119        | 1.7997        | 1.1188        |

**Figure 8.** Conceptual Framework of data capture, processing, and validation of the study.
The calculation was carried out by using the raster calculator in Spatial Analyst Tool in ArcGIS (Figure 10). The LSI then was classified using the natural breaks methods because it allows to gather similar values and to maximize the differences between classes (Figure 11).

Figure 9. Frequency ratio maps of all the causative factor.

Figure 10. The Model Builder of calculating LSI using raster calculator in spatial analyst tool.

Figure 11. Landslide Susceptibility Map of the study area overlay on Miri City.
4.2. Validation.

To check susceptibility model developed by the probabilistic frequency ratio of bivariate statistical, the randomly assigned landslide inventory was plotted on LSM for validation.

For the validation of the output from our analysis, the receiver operating characteristics (ROC) curve was drawn, and the area under curve (AUC) value was calculated for the proposed model (Figure 12). The AUC value ranges from 0.5 to 1.0 where an AUC value close to 1.0 reflect model fitness and a value below 0.5 indicates model’s inaccuracy and unacceptability. The ROC plot assessment results of the validation data set (Figure 8) show that the AUC for the landslide susceptibility map using the frequency ratio model is 0.971, which corresponds to a prediction accuracy of 97.1% (Table 2). According to the decision rules suggested by [10] when the susceptibility value of 0.5 is taken into consideration as the cut-off value, 97.1% of observed landslides are located on the areas having high susceptibility values. Therefore, the landslide susceptibility maps produced using these sets are considered as spatial effective.

Another method to validate the landslide susceptibility map is to check using the landslide data from the study area. The validation process posits that an active landslide must be triggered in those areas showing at least moderate values of susceptibility (≥14.665 and <20.573, class 3 in Table 3), and will be more probable for higher susceptibility values (Class 4 and 5 in Table 3). Most of the landslides in the entire study area (90.02%) are included in the areas showing susceptibility values higher than 20.574 or class 4 and 5.

![Figure 12. Prediction rate curve for the landslide potential maps using the Frequency Ratio model.](image)

**Table 2.** Result of the ROC for the LSI using Frequency Ratio model

| Area Under the Curve | Test Result Variable(s); Value | Asymptotic 95% Confidence Interval |
|----------------------|-------------------------------|----------------------------------|
|                      | Area                          | Std. Error^a                      | Lower Bound | Upper Bound |
|                      | .971                          | .006                             | .960        | .982        |

^a Under the nonparametric assumption

^b Null hypothesis: true area = 0.5
### Table 3. Validation of susceptibility zones

| Reclassified Value | Susceptibility Class | Pixel Number | % Area Covered | Landslide Pixel | % Landslide area covered |
|--------------------|----------------------|--------------|----------------|-----------------|--------------------------|
| 4.738 – 10.016     | Very Low             | 16598211     | 25.41          | 1               | 0.00                     |
| 10.016 – 14.655    | Low                  | 23612456     | 36.14          | 8804            | 0.62                     |
| 14.655 – 20.574    | Medium               | 13339317     | 20.42          | 12228           | 9.36                     |
| 20.574 – 27.612    | High                 | 8254028      | 12.63          | 66357           | 50.81                    |
| 27.612 – 45.525    | Very High            | 3523620      | 5.39           | 51202           | 39.21                    |
| TOTAL              |                      | 65327632     |                | 130592          |                          |

### 4.3. Discussion

In the calculation of frequency ratio of the causative factors that influence the slope stability in the study area, a number of the frequency ratio is greater than 1 which means that the respective frequency ratio has a higher correlation. The aspect with the slope facing west, northwest has the FR value of 1.125, 2.09, and 2.02 respectively. The slope aspect has a significant impact on landsliding because it controls the exposure to sunlight, winds, rainfall [11] and vegetation cover [12]. However, in this particular case, the aspect is controlled by the bedding plane as it covers a total area of 32.8%. As in curvature the concave accounts for 6.1%, while convex which covers 3.2% have higher correlations with FR values of 2.07 and 1.9. Slope gradient plays significant factors to slope stability with any slopes more than 35° are considered steep and could cause the slope to be unstable, but in this case slope of more than 15° are having FR of more than 1. These slopes covered 28% of the total area. The LS Factor, which controls by slope length and steepness are having 34.3% of the area with FR more than 1. This is due to the long stretch of slopes, especially to the western flank.

Different lithologic units have different sensitivities to landslides [13]. As a result, the wide variation of the lithological types from different geological formation in the Canada Hill area makes the lithology as a major predictive factor, which controls the landslide occurrences. The more stable units are the quaternary alluvium and Tukau Fm. These consist of mainly poorly consolidated sand, silt and clay, underlying the flat area, mostly on top of the ridges. Thick bedded sandstone exhibit FR nearly 1 as the outcrops are found along the ridges and the slopes at Tanjong Lobang. The interbedded shale and sandstone exhibit FR of 7.26 which cover 8.8% of the area. These beds are dipping to the west and northwest causing FR of aspect and slopes having greater FR. The present soil series of Miri and Tatau which are comprised of fine sand and sandy loem with poorly drained conditioned are the reason that it has FR more than 1. Beside the lithology which greatly shaped the geomorphology of Canada Hill, the presence of the few sets of lineaments also detrimental in affecting the slope stability. The lineament density with FR 3.6 to 13.50 covered 26.5% of the study area.

In any slope failure, runoff plays an important role as that of a triggering factor for a landslide. Surface water flows and accumulates to form a network of stream which was once a fault plane. In hydrologic factor, distance to stream and Topographic Wetness Index (TWI) are taken into account as the causative factors in a landslide susceptibility index. A distance of landslides more than 25 m to drainage shows that the value of the FR is more than 1 and the values decrease in cases where the distance is more than 100 m. This covers a total area of 64.5%. TWI on the other hand, shows high FR in the class of 1 and 2 with FR values 1.34 and 1.12 respectively with 64.4% coverage. TWI is predicting areas which are susceptible to saturation and are prone to overflows. FR values are lower along the stream channel indicating that lower FR values are the opposite of TWI.

Causative factors such as Land use, which has four categorical classes shows the classes of barren and high vegetation have FR values greater than 1 indicating that high vegetation (FR value 1.60) is also prone to landslides beside the barren area (FR value 1.12) with a coverage area for both classes is 49.4%. The recent landslides body is without vegetation cover while the relict landslides are mostly found in
the area with biomass of more than 16.43 Kg/Ha. Two classes of biomass showing FR values more than 2; class 2 and 3 with FR values of 2.28 and 2.01 respectively. Relict of landslides is having trees of height lower than surrounding after being disturbed by movement. Landslides with FR values below 2 but with biomass nearly 100Kg/Ha indicate that the relics are much older. The soil condition in the landslide area is not compacted and loosely colluvium with high water content and this causes the plants to grow rapidly.

Landslide distribution is mapped via DTM and fieldwork shows that it varies depending on the location and types of debris. Landslides of planar failure are found only in the south-west slopes whereas, toppling and circular failures are in the southeast. These data are not mentioned in the previous study by [14] and only manage to outline three (3) landslide without considering the past landslide hidden under the canopy. Moreover, little were covered during the field mapping, especially, under the forest cover which geological formation is the key to the slope stability in the study area. This was due to geological factors that contribute to the types of failure. The role of topographic factor is also closely related to geology because thick massive sandstone that shaped the slope aspect and slope gradient especially in the southwest. Similarly, the LS factor and curvature formed as a result of the weathering effect of shale and sandstone beds. JKR [14] also failed to mention and relate the geological factors such as lithology and lineament in the developing landslide susceptibility map, hazard map and risk map.

5. Conclusion

There are eleven (11) factors generated that are associated with the distribution of landslides in order to produce the landslide susceptibility map. The factors were selected based on the previous studies in which it is mentioned that these factors are main causative factors of landslides. Landslide inventory is significant in this study as the distribution of the landslides are related to the causative factor, especially the topographic and geologic factor. The delineation of topographic factors is also appropriate as it is closely related to the geological structure, especially the bedding plane which has similarities with the slope aspect. Anthropogenic factors of biomass are taken into account for the analyses of frequency ratio (FR), however the value is not substantial to prove that it greatly affected the stability of the slopes. This is due to the geological conditions of the study area as well as other causative factors. Geological factors of lithology and lineament density is a major factor that affects stability in the region other than the influence of human on the environment especially the vegetation cover.

This study proved the geological factor acted as one of the main causative factors in the stability of slopes. Mapping of landslide inventory was crucial in using the frequency ratio method as it was related to the landslide and the causative factors. The geomorphology of Canada Hill was formed by the geological structure, especially the anticline and the main Miri fault. These geological structures also shaped the topographical features such as the aspect and slope gradient which in turn also cause the failures in the western flank of Bukit Canada. The Landslide Susceptibility Map produced can be used for optimum management by decision makers and land use planners, and also avoidance of landslide susceptible regions in the study area.

6. References

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