Landslide Hazard Analysis using Landsat-8 OLI and AHP Technique in Tanjung Bungah, Penang

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Abstract. Various technique and application have been used in determining the hazard analysis. AHP technique was chosen for this study in effort to find the most factors cause the landslide in the study area. The aim of this study is to determine the factors of landslide hazard using satellite imagery Landsat-8 OLI and Analytic Hierarchy Technique (AHP) in Tanjung Bungah, Penang. This study embarks on three objectives which are to identify the parameter involved in landslide hazard based on surface characteristics, to derive topographical surface from satellite image Landsat 8 OLI in relation of landslide hazard and to determine the correlation of identified parameter and derived topographical information for landslide hazard using AHP technique in Tanjung Bungah, Penang. There are 6 parameters used which are slope, aspect, lithology, rainfall, land surface temperature (LST), and soil-adjusted vegetation index (SAVI). Landsat 8 has been processed to provide the secondary data used in GIS platform. All the processed data are then overlaid using weighted overlay analysis. The output of the analysis shown is spatially visualized to examine the location of the landslide hazards risk. The map produced help in better understanding of nature impact of past, current and future development decision making.

1. Introduction
Landslide is where geologist use to depict the downslope development and known as one of the regular procedures that shape the surface of the Earth. Landslide can only be said as hazard when it threatens the mankind and make loss of life. Landslide can happen due to a few factors, for example, high force of precipitation, sideways or soak inclines, thick enduring, different rocks and geologic structure, and land use that is not in accordance with its characteristics [1], but mostly is triggered by rainfall, earthquake or the joint of the two [2].

In Malaysia, landslide might be one of the serious threats especially in coastal cities such as Melaka, Kota Kinabalu, Johor Bahru, Kuching and low-lying state such as Penang and Kedah. Recently, one of the landslides happened in Tanjung Bungah, Penang which caused of the death of 11 people at a construction site [3,4]. This landslide hazard might cause from improper planning, deforestation, inconsistency of nowadays weather, structure of soil etc.

Therefore, advancement in remote sensing with the development of high spatial resolution imagery has been used for topography, mapping and analysis purposes. Landsat 8 is chosen because it have the ability to help produce the parameters and this is proved by the various researchers [2, 5-6, 1, 7].
Therefore, this study used AHP technique from Multi Criteria Decision Making (MCDM) method which develop by previous researcher, Thomas L. Saaty [8, 9]. This technique will combine the several parameters to identify the most parameters which contribute to the landslide hazard. The parameter chosen AHP will generate a weight for each of the parameters that are used in this study, the higher the weight is, the more vital the corresponding criteria. AHP technique enables quick and realistic analysis of landslides based on data collection and manipulation [10]. By finding out the causes of the landslide hazard, there is a benefit that can provide an effective medium or method to identify the parameters of landslide hazard using satellite imagery and AHP technique.

2. Background of Study Area

Tanjung Bungah was chosen for the study area in this project. Tanjung Bungah is a suburb of Georgetown in Penang, Malaysia. It is situated at 5°27'54.36" N 100°16'55.92" E along the northern shore of Penang Island between Batu Feringgi and Tanjung Tokong. The aggregate territory at Tanjung Bungah is around 7.73 km². Other than that, it is additionally situated about 6.5km northwest of the downtown area. Tanjung Bungah is outstanding spot as a shoreline goal, there are a few inns and resorts covering the shorelines inside the zone. The decades of urbanization have likewise prompted the ascent of local location cost and popularity at Tanjung Bungah. In 2004 Tanjung Bungah was hard hit by the 2004 Indian Ocean Tsunami since it is situated along the northern bank of Penang Island.

![Figure 1. Study Area of Tanjung Bungah (Sources: Google Earth)](image)

3. Datasets and Methodology

3.1. Data Collection

The data which have been collected are Landsat 8, DEM, lithology and rainfall. During data collection, data was prepared either downloaded from open sources, online digitized, or gathered from related official department. The satellite imagery which is Landsat-8 was downloaded from open source, USGS Global Visualization Viewer (GloVis) (https://glovis.usgs.gov/). The image was analysed for pre-processing procedure and has been projected to Malayan Rectified Skew Orthomorphic (MRSO) and Kertau 48 as the datum. Meanwhile, rainfall data were collected from meteorological department which consist of three (3) rainfall stations surrounding Tanjung Bungah and was used for interpolation process. Lithology map of Tanjung Bungah obtained from secondary data sources.
3.2. Data Processing
The brief workflow for this study was shown in Figure 2. The data processing for all the parameters produced by using ArcGIS software which are Land Surface Temperature (LST), lithology, rainfall, Soil-Adjusted Vegetation Index (SAVI), slope and aspect map. The parameters are processed since from the start until the final map for the parameters using ArcGIS. AHP technique also involved to all the parameters to calculate start from rating the features, weighting the parameter including doing the pairwise comparison matrix, normalized matrix, and consistency checking. The last step involved in AHP is doing the overlay analysis for all the parameters.

4. Result and Discussion

4.1. Land Surface Temperature (LST) and Soil Adjusted Vegetation Index Extraction (SAVI)
Figure 3 indicates the LST map and the classification of LST in Tanjung Bungah, Penang. The lowest temperature at the area is 23°C while the highest temperature at that area is 29°C. The temperature values have been classified into 5 respective classes starting from 23-24, 24^-25, 25^-26, 26^-27 and 27^-29.

![Figure 2. Flowchart of Methodology](image_url)

![Figure 3. Classified LST and SAVI Map of Tanjung Bungah](image_url)
Meanwhile, SAVI map shows the output of green vegetation percentages in 5 classes starting from the highest amount which is 1.1%-0.9%, 0.9%-0.8, 0.8%-0.7%, 0.7%-0.6%, and 0.6%-0.4%. Class 1 indicates higher value of green vegetation while class 5 indicates the lowest value of green vegetation extracted using SAVI. This classifications are important as it has been used as indicator in obtaining the pairwise comparison matrix and to determine the weightage in AHP analyst. According to the figure, the connection of LST and SAVI is obviously related to one another. The area with high green vegetation index reflect to lower value of temperature especially in east and southern region of the study area.

4.2. Surface Analysis: Slope and Aspect Classification

Figure 4 shows the slope and aspect classification of study area. The lowest slope in that area is shown in the green colour which is 0° - 5° while the highest slope in that area were shown in the red colour which is 25° - 39°. The slopes have been categorized into 5 classes. High degree of slope contribute to higher risk of landslide as the slope angle and landslide are directly related to each other. Increment of slope angle frequently contribute to the increases in the shear stress in the unconsolidated ground [11].

![Figure 4. Slope and Aspect Map of Tanjung Bungah](image)

The Figure represents the aspect map and its classification where it identifies the downslope direction of the maximum rate of elevation change in Tanjung Bungah, Penang and is expressed in degrees from North and clockwise, ranging from 0° to 360°. For -1° – 57° showing the Northeast, East and Southeast direction. While 57° – 129° showing the flat surface, North and Northeast direction. The 129° – 213° showing the Southeast, South and Southwest direction. Then, 213° – 292° showing the Southwest and West direction while 292° - 360° showing the West, Northwest and North direction. These aspect value is important as the rate of elevation changes play a part in landslide hazard risk estimation. Based on these output, East region shows the sloppiest area while the middle region is less affected by the topographic characteristic. The relationship of slope and aspect is based on the variation of elevation model. The visual effect seen in aspect classification indicates the area whether it is hilly or flat surface where for landslide risk evaluation, hilly area contribute to higher risk of the phenomena.

4.3. Inverse Distance Weightage Assessment for Rainfall data and Lithology Map

Rainfall data tabulations for a year which has been obtained from meteorology department, later has been interpolated using kriging techniques. At least three rain gauge stations used in inverse distance weightage analysis. The following figure 5 shows the result from the rainfall which is the dark blue indicate the result from 212.15 mm to 236.41 mm while the bright blue indicate the result from 236.41 mm to 271.18 mm. Basically, there is not much different for both class, as Tanjung Bungah is only a part of Penang Island region. The rainfall tabulation is quite similar for all the region in study area.
Therefore, it is not to be seen as impactful parameters to be measured. However, it is still crucial as it have the impact in pairwise comparison matrix values for the whole process of landslide hazards risk identification.

4.4. Pairwise Comparison Matrix Calculation
Each of the parameters used was categorized into several classes and weights were assigned to each class to rate the class. The individual class weights and map scores was assesses based on Satty’s AHP where a pair-wise comparison matrix prepared for each map using a nine point important scale as shown in Table 1 (Pairwise Comparison Matrix) where A presented slope, B presented Aspect, C presented Lithology, D presented Rainfall, E presented LST while F presented SAVI.

|       | A   | B   | C     | D     | E     | F     |
|-------|-----|-----|-------|-------|-------|-------|
| A     | 1   | 5   | 2     | 0.333 | 2     | 2     |
| B     | 0.2 | 1   | 0.333 | 0.2   | 0.2   | 0.333 |
| C     | 0.5 | 3   | 1     | 0.143 | 0.333 | 0.333 |
| D     | 3   | 5   | 7     | 1     | 3     | 3     |
| E     | 0.5 | 5   | 3     | 0.333 | 1     | 0.5   |
| F     | 0.5 | 3   | 3     | 0.333 | 2     | 1     |
| SUM   | 5.700 | 22.000 | 16.333 | 2.342 | 8.533 | 7.166 |

Table 2 (Normalized Matrix) shows the normalized matrix where it is calculated to gain criteria weight. The result for criteria weight then used to do the overlay analysis in ArcGIS. If the value of CR calculated is less than 0.1, it shows that the rankings were consistent and did not have any of combinations of pairs that would end up not making sense. The weight can be used for overlay analysis.
However, if the value of CR calculated is more than 0.1, the pairwise comparisons matrix should be recalculated.

**Table 2. Normalized Matrix**

|     | A     | B     | C     | D     | E     | F     | Criteria Weight (W) |
|-----|-------|-------|-------|-------|-------|-------|---------------------|
| A   | 0.18  | 0.23  | 0.12  | 0.14  | 0.23  | 0.28  | 0.197               |
| B   | 0.004 | 0.05  | 0.02  | 0.09  | 0.02  | 0.05  | 0.043               |
| C   | 0.09  | 0.14  | 0.06  | 0.06  | 0.04  | 0.05  | 0.072               |
| D   | 0.53  | 0.23  | 0.43  | 0.43  | 0.35  | 0.42  | 0.397               |
| E   | 0.09  | 0.23  | 0.18  | 0.14  | 0.12  | 0.07  | 0.138               |
| F   | 0.09  | 0.14  | 0.18  | 0.14  | 0.23  | 0.14  | 0.154               |
| SUM | 1.00  | 1.00  | 1.00  | 1.00  | 1.00  | 1.00  | 1.00                |

Meanwhile, Table 3 shows the result from the calculation that have been done where it shown the result of the consistency ratio was 0.062 which is below 0.1 thus all the weightage for 6 parameters were ranked consistently.

**Table 3. Accuracy of Criteria Weight**

|     | A     | B     | C     | D     | E     | F     | Consistency Measure |
|-----|-------|-------|-------|-------|-------|-------|---------------------|
| A   | 0.17  | 0.18  | 0.12  | 0.11  | 0.24  | 0.26  | 6.454               |
| B   | 0.03  | 0.04  | 0.02  | 0.07  | 0.02  | 0.04  | 6.187               |
| C   | 0.08  | 0.11  | 0.06  | 0.05  | 0.04  | 0.04  | 6.286               |
| D   | 0.51  | 0.18  | 0.43  | 0.34  | 0.36  | 0.40  | 6.506               |
| E   | 0.08  | 0.18  | 0.19  | 0.11  | 0.12  | 0.07  | 6.341               |
| F   | 0.08  | 0.11  | 0.19  | 0.11  | 0.24  | 0.13  | 6.523               |
| Average | 6.383 | CI     | 0.077 | RI    | 1.240 | CR    | 0.062               |

4.5. Landslide Risk Evaluation using Overlay Analysis

Figure 6 indicate the result from the overlay analysis that have been done for all the six parameters. As shown only some of the places in Tanjung Bungah were considered as high risk, while more than half of the place were categorized as moderate risk and some of the place were categorized as low risk. The highlighted areas in Figure 6 are the area which landslide had occurred in past. After the output overlaid on the study area, the risk area for landslide hazard and actual event on the location can be said coincide to one another. Therefore, the six parameters used in this study are sufficient to support the output of weightage analysis to identify the risk of landslide hazard. There are approximately 30% of the total area in Tanjung Bungah has high risk of landslide, where the other 65% were medium risk and 5% low risk. Most of the area in Tanjung Bungah has been developed into housing scheme, industrial and commercial area. Despite of the unique hilly topography characteristic in the study area, the development still take place tremendously. This has obviously gave negative impact towards the sustainability of the environment itself. As most of the medium and high risk area located in developing area. The 5% of low risk area was contributed by the area with less construction or buildings and greener area.
5. Conclusion

This study shows the integration of spatial analyst tools and Landsat-8 imageries have good prospective and accomplishment. Landslide hazard can be evaluated and monitored using Landsat-8. The techniques of AHP suitable to be used as an assessment method to identify the risk area of landslide hazard. The potential of this techniques may be developed to an extensive rank by optimizing the parameters used in its pairwise comparison matrices. In order to enhance the risk evaluation, other parameter such as humidity, fault line, and soil types may also contribute to landslide hazard. Moreover, the reflection and refraction method in seismic survey may also contribute to better output for the landslide risk assessment. However, this study has indicates even with the limitations of the parameters used, the outcome are reasonable and applicable. Hence, the use of AHP techniques with the support from satellite imagery suggest low cost whereas contribute to rapid and highly relevant output. The outcome from this study may easily ease the process of environmental impact assessment before any development can be done. It is important to understand the ecology of nature so that human does not breach the limits and cause nature to strike back.

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