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# Landslide Hazard Zonation Mapping Using Statistical Approach

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**Abstract**

Numerous research projects on slope stability hazards have been done over the last thirty years. Initially the investigations were mainly oriented to solving instability problems on site and techniques were developed by engineers to appropriately design a planned structure, to prevent slope failure. In order to solve this problem and considering that hazard assessment has to be based on careful study of the natural conditions of an area and an analysis of all the possible parameters involved in the slope stability processes, several types of landslide hazard analysis techniques have been developed. The statistical approach is a well known methodology and has been used worldwide. The results of slope stability investigations using the Information Value Method and Weight of Evidence approach delineated the most hazardous zones. Most of these zones are located along the east of the mapsheet and situated on the hilly areas. These are Dengkil, Serdang Lama, Sg. Besi and part of the Keramat and Melawati areas.

## Pemetaan Zon Bencana Tanah Runtuh Menggunakan Pendekatan Statistik

**Abstrak**

Banyak kajian tentang bencana kestabilan cerun telah dilakukan sejak 30 tahun yang lepas. Kebanyakan penyiasatan yang dilakukan bertujuan untuk menyelesaikan masalah ketidakstabilan di lapangan dan teknik-teknik ini telah dibangunkan oleh jurutera sehingga sampai ke peringkat rekabentuk pelan struktur, bagi menghalang kegagalan cerun. Dalam usaha menangani masalah ini dan mempertimbangkan kehadiran bencana ia harus dilakukan melalui kajian terperinci tentang keadaan tabii kawasan dan analisis sebanyak mungkin parameter yang terlibat dalam proses ketakstabilan, beberapa jenis teknik analisis bencana tanah runtuh telah dibangunkan. Pendekatan Statistik boleh dianggap sebagai pelopor dan kaedahnya sangat dikenali dan digunakan dengan meluas di seluruh dunia. Hasil kajian ketakstabilan cerun mengunakan pendekatan Kaedah Nilai Maklumat dan Kadar pemberat bukti telah dapat mengenalpasti kawasan yang paling berpotensi dari segi bencana. Kebanyakan kawasan ini menjajar sepanjang Timur syit peta dan terletak di kawasan perbukitan. Kawasan ini terdiri daripada Dengkil, Serdang Lama, Sungai Besi dan sebahagian daripada Keramat dan Melawati.

## INTRODUCTION

Slope stability hazard zonation is defined as the mapping of areas with an equal probability of occurrence of landslides within a specified period of time (Varnes, 1984). Landslide hazard zonation consists of two different aspects:

i) The assessment of the susceptibility of the terrain for a slope failure, in which the susceptibility of the terrain for a hazardous process expresses the likelihood that such a phenomenon occurs under the given terrain conditions or parameters.
ii) The determination of the probability that a triggering event occurs.

Prediction of hazard in areas presently free of landslides is based on the assumption that hazardous phenomena that have occurred in the past can provide useful information for the prediction of occurrences in the future. Therefore, mapping these phenomena and the factors thought to be of influence is very important in hazard zonation.

In statistical landslide hazard analysis, the combination of factors that have led to landslides in the past, are determined statistically and quantitative predictions are made for landslide free areas with similar conditions. Two different statistical approaches are used in landslide hazard analysis:

i) Bivariate statistical analysis. In this method, each factor map (slope, geology, distance map, etc) is combined with the landslide distribution map, and then weight values, based on landslide densities are calculated for each parameter class (slope class, lithological unit, distance from road or fault, etc). The first example of such an analysis was given by Brabb (1984), who performed a simple combination of a landslide distribution map with a lithological map and a slope map. Several statistical methods can be applied to calculate weight values, such as landslide susceptibility (Brabb, 1984; Van Westen, 1993), the information value method (Yin and Yan, 1988), weights of evidence modelling (Bonham -Carter, 1994;), Bayesian combination rules, certainty factors, Dempster – Shafer method and fuzzy logic.
ii) The use of multivariate statistical models for landslide hazard zonation has mainly been developed in Italy.

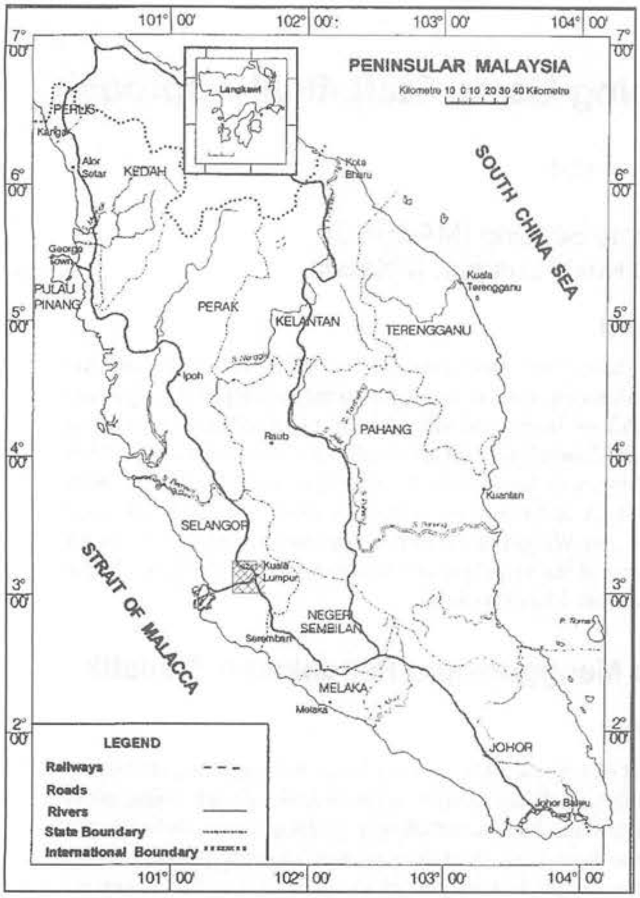


Figure 1: Location of the study area.

For the purpose of this study, two statistical analysis approaches were used namely Information Value Method and Weight of Evidence Modelling.

## STUDY AREA

The study area, which is covered by map sheet 3757 is located within two states, Federal Territory of Kuala Lumpur and part of Selangor (Figure 1). Both Kuala Lumpur and Shah Alam are within this map sheet. Geographically, this area is bounded by the coordinates of 330,000 N to 360,000 N and 390,000 E to 420,000 E. The physical relief of this area can be considered as undulating to moderately rough with altitudes ranging from mean sea level to 575m. Lagong Hill is the highest peak in the area.

## GEOLOGY

The geology of this area comprises granitoid and metamorphic rocks with lesser sedimentary rock (Figure 2). The granitoid are mainly of acidic intrusives consisting of porphyritic biotite granite, muscovite-biotite granite and microgranite. The metamorphosed rocks on the other hand, comprises the Kenny Hill Formation, Hawthornden Schist and Kuala Lumpur Limestone. The Kenny Hill Formation, which is the least metamorphosed, consists of quartzite and phyllite, with lesser shale and sandstone. The age of this formation is probably Early to Middle Permian (Abdullah Sani, 1983). Hawthornden Schist, which is probably of Silurian age, comprises medium-grained, massive, dark green to black, and well foliated quartz-mica schist and graphitic quartz-mica schist (Gobbett, 1964).

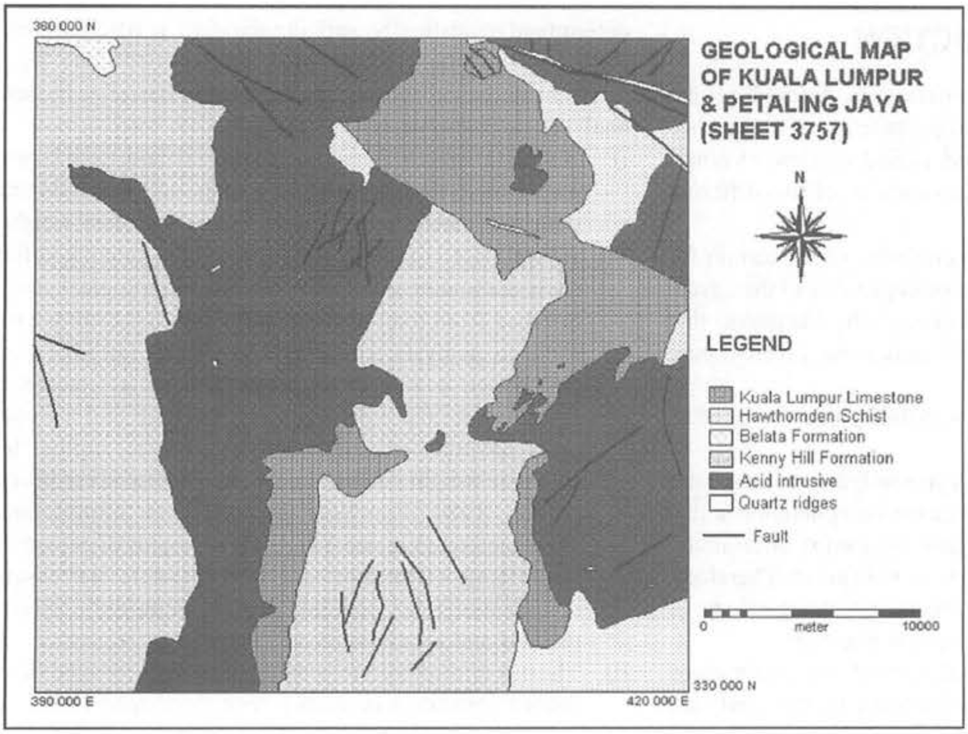


Figure 2: Geological map of the study area.

The Kuala Lumpur Limestone, which is crystalline and fine to medium grained, is normally massive and interbedded with lenses of dolomite and marble. The exposure of this rock unit can be found in a few localities, largest being Batu Caves. The only sedimentary rock unit is the Belata Formation with limited exposure in the north-eastern section of the map sheet. This formation consists mainly of argilleous and arenaceous rock.

The Kuala Lumpur Fault Zone, which passes through the Kuala Lumpur area is considered the major structure. This fault zone generally trends northwest to west-northwest. In addition to this, there are other fault zones within the study area, trending north-northeast.

## GEOMORPHOLOGY

The area comprises denudational, fluvial and karstic landforms. The geomorphological unit of the denudational landform consists of residual hill, scarp zone and denudational hill, whereas the fluvial landform is represented by fluvial terrace and valley fill.

Landslide features were found and recorded at several localites especially at the newly developed hilly area. The most tragic landslide occurred at the Highland Towers, which resulted in the collapse of one apartment block and claimed 48 lives. Recently, several landslides have occurred in the surrounding areas, for example the occurrence of landslides at Bukit Antarabangsa.

## MATERIAL AND METHODOLOGY

The procedures of the methodology is shown in the flow-chart in Figure 3. The layers or parameter maps were prepared using either ILWIS or ARC-INFO softwares and the analysis was done using ILWIS only.

The data used are as follows:

i) Topographic map and digital elevation data, which was later used for DTM generation. The slope map was generated by classifing the slope into 7 classes; $0^0 - 10^0$, $10^0 - 20^0$, $20^0 - 30^0$, $30^0 - 40^0$, $40^0 - 50^0$, $50^0 - 60^0$ and more $60^0$.
ii) Geological map ( 6 classes of lithological units)
iii) Geomorphological map ( 7 classes)
iv) Landuse map (31 classes)
v) Distance map that was generated from faults and road maps respectively
   a) Distance from road was classified into two parameter maps;
      Distance from highways (3 classes; 0 – 30m, 30m – 60m and 60m – 90m) and Distance from main roads (3 classes; 0 – 20m, 20m – 40m and 40m – 60m).
   b) Distance from faults were classified into three parameter maps;
      Distance from major faults (3 classes; 0 – 30m, 30m – 60m and 60m – 90m)
      Distance from minor faults (3 classes; 0 – 20m, 20m – 40m and 40m – 60m)
      Distance from quartz ridges (3 classes; 0 – 10m, 10m – 20m and 20m – 30m).
vi) Remotely sensed data: satellite data and aerial photographs were used for producing the landslide distribution map.
vii) Rainfall map (3 classes).

## ANALYSIS

The calculation applied for the Information Value Method is based on the following formula, to calculate the information value $I_i$ for the variable $X_i$:

$$I_i = \log \frac{S_i / N_i}{S / N}$$

In which:

$S_i$ = the number of pixels with mass movements and the presence of variable $X_i$
$N_i$ = the number of pixels with variable $X_i$
$S$ = the total number of pixels with mass movements
$N$ = the total number of pixels

The degree of hazard for a pixel $j$ is calculated by the total information value $I_j$:

$$I_j = \sum_{i=0}^{m} X_{ij} I_i$$

In which:

$m$ = number of variables
$X_{ij}$ = 0 if the variable $X_i$ is not present in the pixel $j$ and 1 if the variable is present

The larger the $I_j$ value the more unstable is pixel $j$ within the slope.

The calculation applied for the Weight of Evidence is based on the assumption given below. The resultant cross table from a simple crossing of a binary landslide map with a binary variable map can be summarized as follows:

| Landslides | Variable class represent as binary pattern | |
|---|---|---|
| | 1 (present) | 0 (absent) |
| Present - 1 | Npix1 | Npix2 |
| Absent - 0 | Npix3 | Npix4 |

The weights can be expressed as:

$$W_i^+ = \ln \frac{\text{Npix1} / (\text{Npix1} + \text{Npix2})}{\text{Npix3} / (\text{Npix3} + \text{Npix4})} \quad \text{and}$$

$$W_i^- = \ln \frac{\text{Npix2} / (\text{Npix1} + \text{Npix2})}{\text{Npix4} / (\text{Npix3} + \text{Npix4})}$$

The weight calculation for all classes of a thematic map require the following columns in the modified cross table.

nmap = total number of pixels in the map
nslide = total number of landslide pixels in the map
nclass = number of pixels in the class
nslclass = number of pixels with landslides in a class

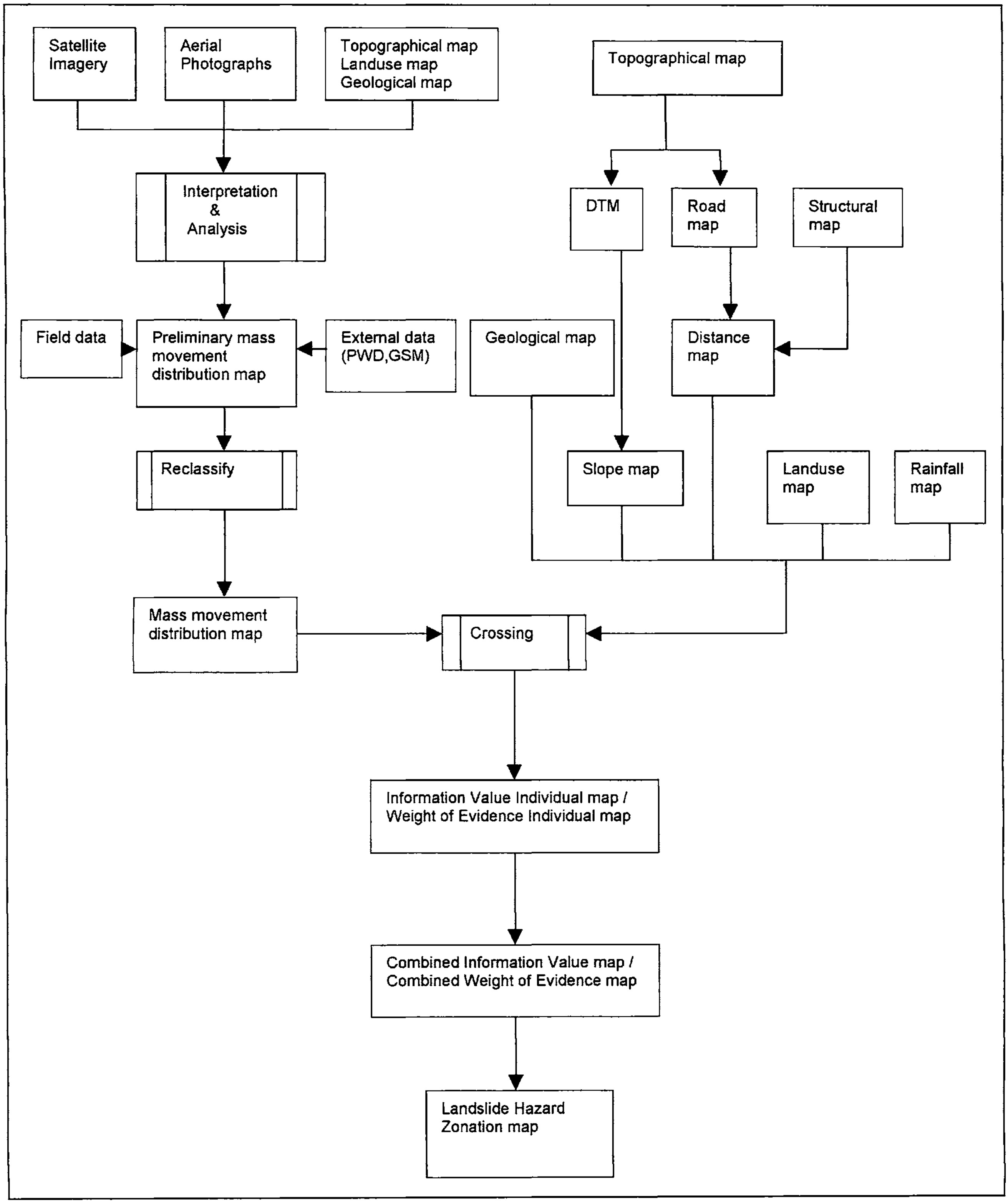


Figure 3: Flowchart of methodology.

The parameters required for the above formula ($W_i^+$ and $W_i^-$) can be derived as:

Npix1 = nslclass

Npix2 = nslide – nslclass

Npix3 = nclass – nslclass

Npix4 = nmap – nslide – nclass + nslclass

To quantify the spatial association between a map class and the occurrence of landslides, the contrast factor calculation as mentioned in Bonham-Carter (1994) is defined as:

$$C_w = W_i^+ - W_i^-$$

The final weight can be calculated as the sum of positive weight of the class in consideration and negative weights for all other classes:

Final weight = positive weight + sum (negative weight) – negative weight.

## RESULT AND DISCUSSION

The analysis and calculation processes in the modelling part were the same for all the parameter maps. To shorten the process of calculation and redundant tasks, the scripts or batch files as shown in the annexure were used in the analysis.

The weight value calculated from either the Information Value Method or the Weight of Evidence, shows that the most causative factor influencing the landslide occurrences in this area are slope influences. Table 1 below shows the most positive weight values calculated from both methodologies. Table 2 shows the weight values calculated for lithological units for comparative.

Reclassification of the total information value map was conducted to generate the landslide hazard zonation map as shown in Figure 4. The landslide hazard zonation map was reclassified into three arbitrary classes, which are low, moderate and high hazards. The low hazard zone can be described as an area where the probability of occurrences of landslides are very limited, even with strong triggering factors, such as heavy rainfall and tremendous landuse changes. The medium hazard zone represents an area where some mass movements will be generated under the influence of intense triggering factors. Within the high hazard zones, a considerable number of mass movements can be expected even with the presence of weak triggering factors.

## CONCLUSION

Based on landslide hazard zonation and prediction, some of the areas need much more careful consideration taken of their stability, especially the areas where lives and properties are involved. Most of these areas are along the eastern section of the mapsheet and are situated on hilly terrain. These include Dengkil, Serdang Lama, Sg. Besi and part of the Keramat and Melawati areas.

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Table 1: The weight value based on Information Value and Weight of Evidence for slope classes.

| Slope class | Slope range | Information Value | Weight of Evidence | | | | |
|---|---|---|---|---|---|---|---|
| | | Weight | $W_i^+$ | $W_i^-$ | Cw | swmin | wfinal |
| 1 | $0 - 10^0$ | -0.2004 | -0.0869 | 0.2811 | -0.368 | 0.2077 | -0.1603 |
| 2 | $10^0 - 20^0$ | 0.6067 | 0.2642 | -0.0428 | 0.307 | 0.2077 | 0.5147 |
| 3 | $20^0 - 30^0$ | 0.6751 | 0.294 | -0.0215 | 0.3155 | 0.2077 | 0.5232 |
| 4 | $30^0 - 40^0$ | 0.7225 | 0.3146 | -0.0057 | 0.3203 | 0.2077 | 0.528 |
| 5 | $40^0 - 50^0$ | 0.773 | 0.3367 | -0.0013 | 0.338 | 0.2077 | 0.5457 |
| 6 | $50^0 - 60^0$ | 1.1934 | 0.52 | -0.0014 | 0.5214 | 0.2077 | 0.7291 |
| 7 | $> 60^0$ | 0.6775 | 0.2949 | -0.0007 | 0.2956 | 0.2077 | 0.5033 |

Table 2: The weight value based on Information Value and Weight of Evidence for lithological units.

| Lithological unit | Information Value | Weight of Evidence | | | | |
|---|---|---|---|---|---|---|
| | Weight | $W_i^+$ | $W_i^-$ | Cw | swmin | wfinal |
| Limestone (KL Lms) | -0.268 | -0.1165 | 0.0182 | -0.1347 | 0.0008 | -0.1339 |
| Phyllite, Schist (Hw Sch) | 0.6049 | 0.2635 | -0.0255 | 0.289 | 0.0008 | 0.2898 |
| Quartz ridges | -2.2323 | -0.9693 | 0.0011 | -0.9704 | 0.0008 | -0.9696 |
| Acid Intrusive | 0.125 | 0.0544 | -0.0369 | 0.0913 | 0.0008 | 0.0921 |
| Arenaceous, Argilliceous (BF) | -3.7935 | -1.6469 | 0.0014 | -1.6483 | 0.0008 | -1.6475 |
| Quartzite, Phyllite (KHF) | -0.1699 | -0.0736 | 0.0425 | -0.1161 | 0.0008 | -0.1153 |

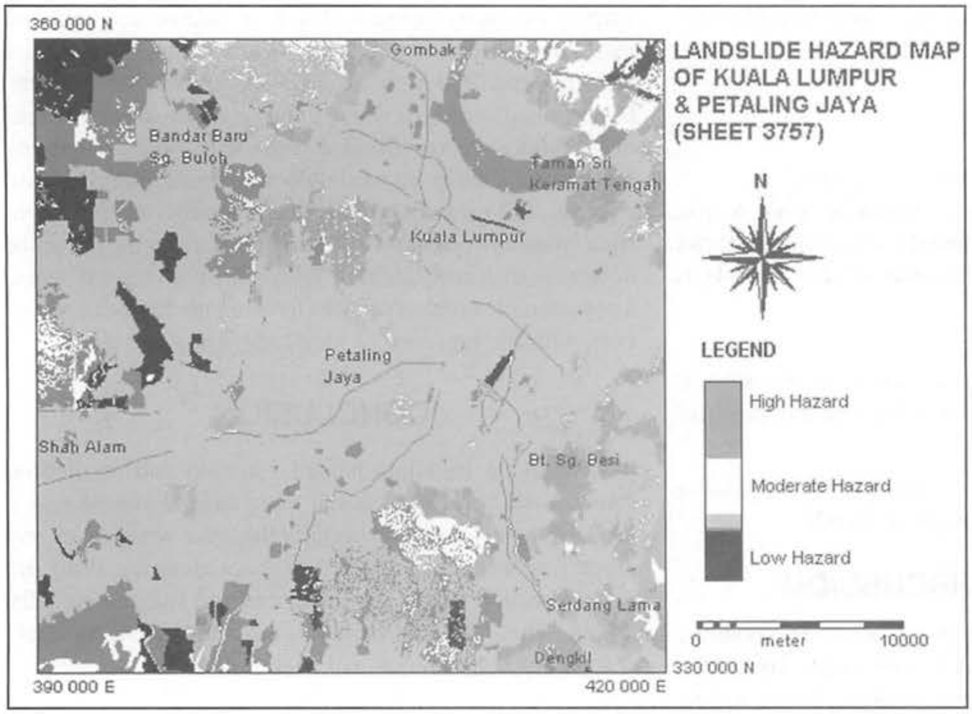


Figure 4: Landslide hazard zonation map of Kuala Lumpur and Petaling Jaya.


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