LANDSLIDE HAZARD ZONATION MAPPING USING LIDAR DATA

GEOSMART ASIA
1st October 2015

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  • MODEL DEVELOPMENT
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BACKGROUND

• The increasing population and expansion of settlements over hilly areas has greatly increased the impact of natural disasters such as landslide.
• Over the years, various techniques and models have been developed to predict landslide hazard zones.
• The development of these models are based on nine different landslide inducing parameters i.e. slope, land use, lithology, soil properties, geomorphology, flow accumulation, aspect, proximity to river and proximity to road.
• Rank sum, rating, pairwise comparison and AHP techniques are used to determine the weights for each of the parameters used. Four Criteria considered
  • The need for accurate DEM
  • LiDAR technology
  • Models - MCDM
BACKGROUND

• The increasing population and expansion of settlements over hilly areas has greatly increased the impact of natural disasters such as landslide.

• Over the years, various techniques and models have been developed to predict landslide hazard zones.

• The development of these models are based on different landslide inducing factors such as:

<table>
<thead>
<tr>
<th>Main Groups</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground Condition</td>
<td>Geomorphology</td>
</tr>
<tr>
<td></td>
<td>Geology</td>
</tr>
<tr>
<td></td>
<td>Soil</td>
</tr>
<tr>
<td></td>
<td>Land use</td>
</tr>
<tr>
<td>Distance Related</td>
<td>Roads</td>
</tr>
<tr>
<td></td>
<td>River</td>
</tr>
<tr>
<td></td>
<td>Drainage density</td>
</tr>
<tr>
<td></td>
<td>Faults</td>
</tr>
<tr>
<td>Geomorphometry</td>
<td>DEM</td>
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<tr>
<td></td>
<td>Slope</td>
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<tr>
<td></td>
<td>Aspect</td>
</tr>
<tr>
<td></td>
<td>Elevation</td>
</tr>
<tr>
<td>Triggering</td>
<td>Rainfall</td>
</tr>
<tr>
<td></td>
<td>Earth quakes</td>
</tr>
</tbody>
</table>
BACKGROUND

- Slope is one of the most important factor in assessing landslide hazard areas – need high accuracy and high resolution DEM

- LiDAR technology and Geographical Information System (GIS) are important tools in assessing landslide hazards

- Multi-criteria Decision Making (MCDM) Multi-criteria decision making approach also play important role in determining relative importance of landslide factors

Source: Sight Power
Phase 1 - Selection of Study Area
Cheras and Kajang (5 x 5 km)

Phase 2 - Landslide Model Development
• Expert opinion to rank factors
• Modify previously developed models based on only slope, land use, lithology and soil properties factors (Othman, W. Mohd. N. Surip, 2013)

Phase 3 - Data Acquisition

Phase 4 - Data Processing/analysis in GIS
Rank Criteria
Calculate Weight and Standardize Score for the criteria used
Generate Landslide Hazard Zone Maps using different models

Phase 5 - Validation of Models
STUDY AREA – PART OF CHERAS AND KAJANG

Area Coverage
- Size: 5 x 5 km
- From Cheras to Kajang
- Elevation Range: 20 – 321 m above MSL
- Mukim: Kajang, Semenyih and Cheras
DATA COLLECTION

- Digital Terrain Model (DTM) – from LiDAR
- Digital Surface Model (DSM) – from LiDAR
- Orthoimage
- Digital Elevation Model from SRTM – from USGS website
- Soil Properties - derived from soil map
- Land use – Digitised from Orthoimage
- Lithology
DATA ACQUISITION FROM LiDAR

- Data acquisition - Hazard and Slope Risk Mapping Project at Cheras Selatan-Kajang-Bangi-Putrajaya, Selangor for RS & GIS Consultancy Sdn Bhd and Department of Mineral & Geoscience.

EQUIPMENT DETAILS:

- LiDAR System is LiteMapper 6800-400 (Riegl 680i-400kHz)
- This Laser Scanner is Full Waveform which has unlimited number of return echoes.
- This System comes with high resolution RGB Camera System 60 Mega Pixel and automatic geo-correction system which is equipped with 512kHz Fiber Optic IMU.

DATA ACQUISITION:

- Date: 19 December 2014, 30 December 2014 – 3 January 2015
- Requirement RSGIS & JMG for data acquisition:
- Helicopter type: Eurocopter EC 120B
- Helicopter Speed: 60 knot
- Flying Altitude: 600 m AGL
- Laser Scan Angle: 60°
- PRR laser: 400 kHz (maximum range)
LiDAR Project Area

225 km²
(22500 Ha)
DTM derived from LiDAR
DEM – Shuttle Radar Topographic Mission (SRTM) – 30 x 30 m
Orthoimage of Study Area
Slope map derived from LiDAR

Slope map derived from SRTM
DEVELOPMENT OF LANDSLIDE HAZARD ZONATION MODELS

• Based on earlier studies by Ainon Nisa, Wan Mohd and Noraini Surip
• Study Areas - Ampang Jaya and Hulu Langat
• Technique used – GIS-based Multicriteria Decision Making (MCDM)
## Landslide Hazard Models Tested

<table>
<thead>
<tr>
<th>Model No</th>
<th>Technique/ Criteria</th>
<th>Slp</th>
<th>Lu</th>
<th>Litho</th>
<th>SP</th>
<th>Geomor</th>
<th>Asp</th>
<th>Elev</th>
<th>Rf</th>
<th>Priv</th>
<th>Prd</th>
<th>Facc</th>
<th>Drg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ranking (Rank Sum)</td>
<td>0.333</td>
<td>0.133</td>
<td>0.267</td>
<td>0.2</td>
<td>0.067</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Ranking (Rank Reciprocal)</td>
<td>0.438</td>
<td>0.109</td>
<td>0.219</td>
<td>0.146</td>
<td>0.088</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Ranking (Rank Exponential)</td>
<td>0.454</td>
<td>0.073</td>
<td>0.291</td>
<td>0.164</td>
<td>0.018</td>
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<tr>
<td>4</td>
<td>Rating</td>
<td>0.335</td>
<td>0.168</td>
<td>0.252</td>
<td>0.211</td>
<td>0.034</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>AHP (Expert Opinion)</td>
<td>0.162</td>
<td>0.082</td>
<td>0.116</td>
<td>0.277</td>
<td>0.023</td>
<td>0.061</td>
<td>0.21</td>
<td>0.041</td>
<td>0.032</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Pairwise Comparison (Expert Opinion)</td>
<td>0.5</td>
<td>0.036</td>
<td>0.143</td>
<td>0.214</td>
<td>0.107</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Pairwise Comparison (Expert Opinion)</td>
<td>0.294</td>
<td>0.088</td>
<td>0.236</td>
<td>0.265</td>
<td>0.029</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.088</td>
</tr>
<tr>
<td>8</td>
<td>AHP (Expert Opinion)</td>
<td>0.361</td>
<td>0.113</td>
<td>0.091</td>
<td>0.199</td>
<td>0.141</td>
<td>0.051</td>
<td>0.044</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>9</td>
<td>AHP (Expert Opinion)</td>
<td>0.301</td>
<td>0.089</td>
<td>0.073</td>
<td>0.152</td>
<td>0.108</td>
<td>0.045</td>
<td>0.037</td>
<td>0.195</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FACTORS CONSIDERED:**

- Slope (slp)
- Land use (Lu)
- Lithology (Litho)
- Soil Properties (SP)
- Geomorphology (Geomor)
- Aspect (Asp)
- Elevation (Elev)
- Rainfall (Rf)
- Proximity to river (Priv)
- Proximity to road (Prd)
- Flow Accumulation (Facc)
- Drainage Pattern (Drg)
## Developed Models

<table>
<thead>
<tr>
<th>Model No</th>
<th>Technique</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rank Sum</td>
<td>$0.333(s_{slp}) + 0.133(s_{lu}) + 0.267(s_{lit}) + 0.2(s_{sp}) + 0.067(s_{geomorf})$</td>
</tr>
<tr>
<td>2</td>
<td>Rank Reciprocal</td>
<td>$0.438(s_{slp}) + 0.109(s_{lu}) + 0.219(s_{lit}) + 0.146(s_{sp}) + 0.088(s_{geomorf})$</td>
</tr>
<tr>
<td>3</td>
<td>Rank Exponent</td>
<td>$0.454(s_{slp}) + 0.073(s_{lu}) + 0.291(s_{lit}) + 0.164(s_{sp}) + 0.018(s_{geomorf})$</td>
</tr>
<tr>
<td>4</td>
<td>Rating</td>
<td>$0.335(s_{slp}) + 0.168(s_{lu}) + 0.252(s_{lit}) + 0.211(s_{sp}) + 0.034(s_{geomorf})$</td>
</tr>
<tr>
<td>5</td>
<td>AHP</td>
<td>$0.162(s_{slp}) + 0.082(s_{lu}) + 0.116(s_{lit}) + 0.277(s_{sp}) + 0.023(s_{asp}) + 0.061(s_{elev}) + 0.207(s_{rfal}) + 0.041(s_{priv}) + 0.032(s_{prd})$</td>
</tr>
<tr>
<td>6</td>
<td>Pairwise Comparison</td>
<td>$0.5(s_{slp}) + 0.036(s_{lu}) + 0.143(s_{lit}) + 0.214(s_{sp}) + 0.107(s_{asp})$</td>
</tr>
<tr>
<td>7</td>
<td>Pairwise Comparison</td>
<td>$0.294(s_{slp}) + 0.088(s_{lu}) + 0.029(s_{geomorf}) + 0.265(s_{sp}) + 0.236(s_{lit}) + 0.088(s_{flowacc})$</td>
</tr>
<tr>
<td>8</td>
<td>AHP</td>
<td>$0.361(s_{slp}) + 0.141(s_{asp}) + 0.091(s_{lit}) + 0.113(s_{lu}) + 0.199(s_{sp}) + 0.051(s_{priv}) + 0.044(s_{prd})$</td>
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<td>9</td>
<td>AHP</td>
<td>$0.301(s_{slp}) + 0.108(s_{asp}) + 0.073(s_{lit}) + 0.089(s_{lu}) + 0.152(s_{sp}) + 0.045(s_{priv}) + 0.037(s_{prd}) + 0.195(s_{drg})$</td>
</tr>
</tbody>
</table>
Landslide Hazard Zonation Maps Generated from Model 1, 2 and 3
Landslide Hazard Maps Generated from Model 1, 2 and 3
Landslide Hazard Maps Generated from Model 7, 8 and 9
Comparison between landslide hazard class and landslide historical data – Area Hulu Kelang
Models Used – For this study

Criteria Considered

• Slope
• Lithology
• Land use
• Soil Properties

\[ LHZ \text{ (Model 1)} = (0.400 \times s_{slp}) + (0.100 \times s_{lu}) + (0.300 \times s_{litho}) + (0.200 \times s_{sp}) \]  
\[ \text{------------------------(1)} \]

\[ LHZ \text{ (Model 2)} = (0.347 \times s_{slp}) + (0.219 \times s_{lu}) + (0.218 \times s_{litho}) + (0.174 \times s_{sp}) \]  
\[ \text{--------------------------(2)} \]

\[ LHZ \text{ (Model 3)} = (0.481 \times s_{slp}) + (0.240 \times s_{lu}) + (0.159 \times s_{litho}) + (0.120 \times s_{sp}) \]  
\[ \text{-------------------------------(3)} \]
RESULT – LHZ MAP BASED ON MODEL 1

LHZ based on LiDAR data

LHZ based on SRTM data
RESULT – LHZ MAP BASED ON MODEL 2

LHZ based on LiDAR data

DTM_Model 2

LHZ based on SRTM data

Legend
Hazard Class
- Low Hazard
- Medium Hazard
- High Hazard
- Very High Hazard
RESULT – LHZ MAP BASED ON MODEL 3

LHZ based on LiDAR data

LHZ based on SRTM data

Legend
Hazard Class
- Low Hazard
- Medium Hazard
- High Hazard
- Very High Hazard
SITE 1

Legend

Hazard Class
- Low Hazard
- Medium Hazard
- High Hazard
- Very High Hazard
SITE 4

Legend
Hazard Class
- Low Hazard
- Medium Hazard
- High Hazard
- Very High Hazard
SITE 5

Legend
Hazard Class
- Low Hazard
- Medium Hazard
- High Hazard
- Very High Hazard
SITE 6

Legend

Hazard Class
- Low Hazard
- Medium Hazard
- High Hazard
- Very High Hazard
SITE 7

Legend

Hazard Class
- Low Hazard
- Medium Hazard
- High Hazard
- Very High Hazard
CONCLUSIONS

• MCDM techniques is used to calculate the relative importance of the factors
• Accuracy of model largely depend on the quality and resolution of DTM
• LiDAR provide high resolution/high accuracy height information
• GIS is an important tools to integrate and model landslide hazard zones