CONTENTS

- An brief overview of physiography, geology & landslide occurrence in the Nepal Himalaya

- 3D geological modelling of central Nepal

- Landslide hazard modelling of central Nepal

- Integration of model3D & landslide hazard/susceptibility

- Concluding remarks
Physiography and geology of Nepal Himalaya

Extreme vertical variation of topography with respect to geolocal subdivisions

Nelson et al. 1980
Occurrence of landslides & tectonostratigraphy of Nepal Himalaya
Extreme weather event and landslide occurrences (July 1993, central Nepal)
Extreme weather event of 19–21 July 1993; rainfall measured at Tistung, central Nepal (source: Department of Soil Conservation & Watershed Management)
Modelling site (latitudes 27°37' to 27°45' N & longitudes 84°57'38" to 85°08'2" E)

Lesser Himalaya, central Nepal
19-21 July 1993 Cloudburst & landslide damages

20 July 1993 - Site of bridge destroyed

Upstream extensive landslides

Huge sediment transport along river course

To Kathmandu
Failure of thin soils along the dip-slopes is the most occurrences
3D geological modelling: IMPLICIT APPROACH (after Caumon et al. 2007)

Using following GOCAD research plugins:
- GeolToolbx
- GRGLib
- IsoSurf
- SolidExplorer
- Stereonet
- StructuralLab

The coordinate system will be in meters, with Z positive upwards.
3D model configuration using GOCAD
Orientation vector ($\mathbf{v}$)

$$\mathbf{v} = \begin{bmatrix} \sin(\theta) \cdot \cos(\phi) \\ \cos(\theta) \cdot \cos(\phi) \\ \cos(\phi) \end{bmatrix}$$

where, dip direction $\theta$ (azimuth) and dip $\phi$ angles

**DSI** (Mallet 2002)

$$R^*(\varphi) = \sum_{\alpha \in \Omega} \mu(\alpha) \cdot R(\varphi|\alpha) + (\phi \cdot \mathbf{\omega}) \cdot \sum_{c \in C} \mathbf{\omega}_c \cdot \rho(\varphi|c)$$

where, $R(\varphi|\alpha)$ is the local roughness at node $\alpha$, $\rho(\varphi|c)$ is a constraint defined for node $\alpha$, $\mu$ is a stiffness coefficient, and $\mathbf{\omega}_c, \phi, \mathbf{\omega}$ are weight coefficients
Computed stratigraphic surfaces for Model3D

Rock strata geometry
3D geological model of Lesser Himalaya, central Nepal
If the probability of presence (1) of a phenomenon is \( P_a \), then \( P_b \) represents the absence (0).

\[
\text{(i.e. } P_a + P_b = 1) \]

\[
P(Y) = \frac{1}{1 + e^{-z}}
\]

Where \( P(Y) \) is the probability of an event occurring.

\[ Z = b_0 + b_1A_1 + \ldots + b_nA_n \]

Where, \( b_i \) (\( i=0,1, \ldots, n \)) is coefficient estimated from sample data, and \( A_i \) (\( i=1,2, \ldots, n \)) is independent variables (i.e. landslide related physical parameters)
Thematic Raster Summary

Integer variable matrix

\[
\begin{pmatrix}
0 & 541 & 4 & 0 & 0 & 0 & 0 \\
1 & 349 & 677 & 0 & 0 & 0 & 0 \\
2 & 0 & 535 & 0 & 0 & 0 & 0 \\
3 & 0 & 574 & 0 & 0 & 0 & 0 \\
4 & 0 & 375 & 0 & 0 & 0 & 0 \\
5 & 75 & 579 & 0 & 0 & 0 & 0 \\
6 & 0 & 341 & 0 & 0 & 0 & 0 \\
7 & 0 & 292 & 0 & 0 & 0 & 0 \\
8 & 0 & 25 & 0 & 0 & 0 & 0 \\
9 & 0 & 190 & 0 & 0 & 0 & 0 \\
10 & 0 & 452 & 0 & 0 & 0 & 0 \\
11 & 0 & 196 & 0 & 0 & 0 & 0 \\
12 & 0 & 889 & 0 & 0 & 0 & 0 \\
13 & 0 & 662 & 0 & 0 & 0 & 0
\end{pmatrix}
\]

Dummy variable matrix

\[
\begin{pmatrix}
0 & 1 & 1 & 0 & 0 & 0 & 0 \\
1 & 1 & 1 & 0 & 0 & 0 & 0 \\
1 & 0 & 1 & 0 & 0 & 0 & 0 \\
1 & 0 & 1 & 0 & 0 & 0 & 0 \\
1 & 1 & 1 & 0 & 0 & 0 & 0 \\
1 & 0 & 1 & 0 & 0 & 0 & 0 \\
1 & 0 & 1 & 0 & 0 & 0 & 0 \\
1 & 0 & 1 & 0 & 0 & 0 & 0 \\
1 & 0 & 1 & 0 & 0 & 0 & 0 \\
1 & 0 & 1 & 0 & 0 & 0 & 0
\end{pmatrix}
\]
### Logistic Regression Coefficients

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coef.</th>
<th>Variables</th>
<th>Coef.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Slope angle</strong></td>
<td></td>
<td><strong>Slope complexity</strong></td>
<td></td>
</tr>
<tr>
<td>&lt;15°</td>
<td>-0.217</td>
<td>Granite slope (GS)</td>
<td>-1.662</td>
</tr>
<tr>
<td>15°-25°</td>
<td>0.074</td>
<td>Oblique slope (OS)</td>
<td>-0.349</td>
</tr>
<tr>
<td>25°-35°</td>
<td>0.778</td>
<td>Dip-slope ≥ slope (DS-EL)</td>
<td>1.357</td>
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<tr>
<td>35°-45°</td>
<td>0.417</td>
<td>Dip-slope &gt; slope (DS-G)</td>
<td>-0.023</td>
</tr>
<tr>
<td>&gt;45°</td>
<td>-0.145</td>
<td>Counter dip-slope (CDS)</td>
<td>-0.163</td>
</tr>
<tr>
<td><strong>Slope aspect</strong></td>
<td></td>
<td>Fractured zone (FZ)</td>
<td>-1.030</td>
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<tr>
<td>Flat</td>
<td>-0.385</td>
<td>Forest (Fo)</td>
<td>1.536</td>
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<tr>
<td>North (N)</td>
<td>0.117</td>
<td>Shrub land (SrL)</td>
<td>-0.124</td>
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<tr>
<td>North East (NE)</td>
<td>0.253</td>
<td>Grassland (GrL)</td>
<td>0.880</td>
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<tr>
<td>East (E)</td>
<td>0.590</td>
<td>Cultivated land (CuL)</td>
<td>0.657</td>
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<tr>
<td>South East (SE)</td>
<td>-0.177</td>
<td>Barren land (BnL)</td>
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</tr>
<tr>
<td>South (S)</td>
<td>0.195</td>
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<tr>
<td>South West (SW)</td>
<td>-0.348</td>
<td>Constant</td>
<td>-3.640</td>
</tr>
<tr>
<td>West (W)</td>
<td>-0.027</td>
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</tr>
<tr>
<td>North West (NW)</td>
<td>0.333</td>
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<tr>
<td><strong>Engineering geology</strong></td>
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<tr>
<td>Thin soil [1-3 m] (TnSl)</td>
<td>-0.203</td>
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<tr>
<td>Thick soil [&gt;3 m] (TkSl)</td>
<td>-0.272</td>
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<td>Colluvium (Clv)</td>
<td>-0.876</td>
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<td>Alluvium (Alv)</td>
<td>0.240</td>
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<tr>
<td>High Rock Mass Strength (HRMS)</td>
<td>-0.868</td>
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<tr>
<td>Medium Rock Mass Strength (MRMS)</td>
<td>0.222</td>
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<tr>
<td>Low Rock Mass Strength (LRMS)</td>
<td><strong>1.420</strong></td>
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</tr>
</tbody>
</table>
Probability calculation using logistic regression

For example:

\[ p(Y) = \frac{1}{1 + e^{-(\beta_0 + \beta_1 \text{quartzite} + \beta_2 \text{Forest} + \beta_3 \text{Slope} \times (15-25) + \beta_4 \text{AspectNW})}} \]

- Intercept
- Regression value
- Present = 1
- Absent = 0
Predicted Landslide Hazard/susceptibility Map
AUC = 90-94%  
(with prediction accuracy of 0.5 to 1)
Integration of 3D geomodel & Landslide hazard/susceptibility

Geological unit:
1. Granite
2. Limestone
3. Calc. shale or slate
4. Meta-sandstone, phyllite
5. Marble, schist
6. Quartzite, schist

Landslide hazard:
VH Very High  H High  M Medium  L Low  VL Very Low

Feature:
Road
Buildings
CONCLUDING REMARKS

Implicit approach of “sparse data” modelling quite illustrative to compute geologic-boundary surfaces.

Statistical modelling of landslide hazard is particularly suited in regional terrain of central Nepal.

3D geomodel and landslide hazard has provided interactive evaluation of integrated scenarios.
Thank you very much !!!!