REMOTE SENSING BASED REGOLITH THICKNESS MODELING AND EVALUATING ITS IMPACT OF EARTHQUAKE INDUCED BUILDING DAMAGES

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Earthquake ground shaking

- **Surface**
  - Site effects
- **Bed rock**
  - Medium effects
  - Seismic waves
  - Causative fault
  - Hypocenter

- **Source effects**
- **Site effects**
  - Topographic effects
  - Regolith thickness effects
  - Geologic effects
Why amplification of seismic response in regolith?
Regolith thickness prediction, existing methods

- Physically-based modeling (Dietrich et al, 1995)
- Interpolation (Kuriakose et al. (2009))
- Statistical environmental correlations
Regolith thickness influenced by ..... 

- Topography
- Geomorphology
- Geology
- Landuse

Factors addressed following a Remote Sensing & GIS based approach
Kashmir earthquake

Date: 8th October 2005
Magnitude: 7.6
Depth: 10 Km
Epicenter: 34.43ºN, 73.53ºE
Death Toll: 80,000
Economic Loss: 5 billion US$
Regolith thickness predictors used

**Landforms**
- Erosional Landscape
- Alluvial Fan
- Flood Plain
- River Bed
- River Terrace

**Elevation (ASTER DEM)**

**Distance from stream**
- Distance (m)
- Elevation (m)
Regolith thickness samples and resistivity profiles
Geophysics for regolith thickness estimation

• Measuring regolith thickness to greater depth laborious and expensive

• Electrical resistivity is an efficient choice
  - Electrical resistivity of soil is much less than bedrock
  - Deep penetration
  - Capable of recording long profiles
Electrical resistivity profiles for regolith thickness estimation

(a) 0.00 8 16 24 32 40 Distance (m)
Depth (m) 0.84 1.68 2.52 3.36 4.20

(b) 0 24 48 72 96 120 Depth (m) 0 13 25 38 50

(c) 0 24 48 72 96 120 Depth (m) 0 13 25 38 50
### Collected data

#### Number of regolith thickness samples and resistivity profiles

<table>
<thead>
<tr>
<th>Samples at exposed bedrock</th>
<th>Resistivity Profiles (R.P)</th>
<th>Interpreted regolith thickness from R.P</th>
<th>Total regolith thickness samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>169</td>
</tr>
<tr>
<td></td>
<td>109</td>
<td>24</td>
<td>60</td>
</tr>
</tbody>
</table>

#### Distribution of regolith thickness samples in different landforms

<table>
<thead>
<tr>
<th>Landforms</th>
<th>Outcrop samples</th>
<th>Samples from R.P</th>
<th>Total</th>
<th>% of Samples</th>
<th>% of covered area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alluvial Fan</td>
<td>31</td>
<td>25</td>
<td>56</td>
<td>33.1</td>
<td>30.5</td>
</tr>
<tr>
<td>Flood Plain</td>
<td>39</td>
<td>20</td>
<td>59</td>
<td>34.9</td>
<td>32.4</td>
</tr>
<tr>
<td>River Terrace</td>
<td>39</td>
<td>15</td>
<td>54</td>
<td>32.0</td>
<td>20.8</td>
</tr>
<tr>
<td>River Bed</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>16.3</td>
</tr>
</tbody>
</table>
Impact of landforms on regolith thickness

![Diagram showing regolith thickness for different landforms](image)
Impact of elevation and distance from stream on regolith thickness

River Terrace

Alluvial Fan

Flood Plain
Regression analysis

- A statistical technique used to find relationships between variables for the purpose of predicting future values.

- Multiple linear regression attempts to model the relationship between two or more explanatory variables and a response variable by fitting a linear equation to observed data.

\[ Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n \]
Regression model for regolith thickness prediction

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>43.897</td>
</tr>
<tr>
<td>Flood Plain</td>
<td>-32.207</td>
</tr>
<tr>
<td>River Terrace</td>
<td>-21.798</td>
</tr>
<tr>
<td>Alluvial Fan (elevation)</td>
<td>-0.031</td>
</tr>
<tr>
<td>Flood Plain (elevation)</td>
<td>-0.009</td>
</tr>
<tr>
<td>River Terrace (elevation)</td>
<td>-0.008</td>
</tr>
<tr>
<td>Alluvial Fan (d.stream)</td>
<td>-0.001</td>
</tr>
<tr>
<td>Flood Plain (d.stream)</td>
<td>0.008</td>
</tr>
<tr>
<td>River Terrace (d.stream)</td>
<td>-0.010</td>
</tr>
</tbody>
</table>

Adjusted $R^2 = 92.3$
Modeled regolith thickness

regolith thickness variation along landform boundaries
Validation of the predicted regolith thickness

RMSE = 0.26 m
Regolith thickness modeling in erosional landscape
Regolith thickness samples
Predictors used for modeling the regolith thickness
Impact of geology on regolith thickness
Modeled regolith thickness in erosional landscape of the area
Validation of the predicted regolith depth
Integrated regolith thickness
Kashmir earthquake damages and correlation with regolith depth

(a)

(b)

\[ R^2 = 0.38 \]

\[ R^2 = 0.46 \]
Conclusions

- In a depositional landscape, landforms are the major controlling factors for regolith depth prediction.

- Regression modeling allows for analysis of regolith depth samples and make prediction at unsampled sites.

- Remote sensing derived data are an added value in providing spatial coverage for regolith depth prediction at regional scale.

- The derived regolith thickness model showed a strong positive correlation with seismic induced building damage.
Regolith thickness prediction and its influence on earthquake induced building damages