Identification of temporary evacuation sites and relocation of dangerous settlements in the Dolakha District: An approach by hazard mapping

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J-RAPID Workshop, 21-22 June 2016
## Members

<table>
<thead>
<tr>
<th>HU Team</th>
<th>TU Team</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teiji Watanabe</td>
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<td>Graduate School of Environmental Science</td>
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</table>
Study area

- Dolakha District = eastern part of the damaged area of the country
- Tama Koshi = hydropower dam
- Trekking destination of Rolwaling

source: Government of Nepal
Objectives

1. To identify potentially dangerous sites in the Dolakha region through landslide susceptibility mapping.
2. To identify potentially dangerous sites in the case of future earthquakes and other hazards.
3. To map GLOF inundation along the main river.
4. To propose temporal evacuation sites in the case of future hazards.
EARTHQUAKE FACT SHEET

Dolakha was the epicentre of the 12 May earthquake, while the 25 April earthquake caused widespread damage to the area.

KEY FIGURES

280,874  total population
87%    houses fully or partially damaged
50,284   houses fully damaged
305                       houses partially damaged
134    dead
304    injured
2,037   people in nine sites
       (Temporary settlements)

(Source: Tamakoshi Hydropower 2014, 2 District Development Committee 03/07/2015, 3 IOM/CCCM 20/07/2015)
Many People are still living in temporary houses in temporary settlement sites
Flow of research

Remote sensing & GIS
- Base maps (Land use and land cover map, etc.)

Baseline survey
- Damage, dearth toll, etc.

Field survey
- Distribution of landslides/rockfalls/other hazards

UAV survey
- Photography for 3D mapping at seriously damaged sites

Modeling
- HEC-RAS analysis for GLOF hazard

Field survey
- Distribution of damages; social survey

Labo. analysis
- Base-mapping for hazard map
- 3D-mapping (Structure from Motion)

Labo. analysis
- Identifying evacuation sites

Labo. analysis
- Identifying evacuation sites

Training seminars for students
- Recommendation to local communities/government

HEC-RAS analysis for GLOF hazard
- Identifying evacuation sites

Landslide & GLOF hazard map
- 3D-mapping (Structure from Motion)
Methodology

Data Sources
- Topographic Maps
  - Contour line
  - DEM
  - Drainage line
  - Landuse
- Satellite Image
  - IR & R Band
  - Road map
- Field survey: Geology
  - Geological unit
- Google earth Image
  - Landslide Inventory
  - Predictive rate evaluation

Input layer
- Slope
- Aspect
- Relative relief
- Curvature

Analysis
- Reclassification
- Reclassification
- Reclassification
- Reclassification
- Feature class
- Crosstabulation
- Bivariate analysis

Landslide Susceptibility
- Weighted value
Procedure

• Landslide (both pre and post Earthquake) were inventoried from Google Earth Image and Field Survey
• Causative parameters were developed in Arc GIS Environment
• Inventoried pre earth quake landslide and the parameters were cross tabulated
• Landslide index was calculated by using formula (Van Westen, 1979)

\[
\ln W_i = \ln \left( \frac{Density_{class}}{Density_{map}} \right) = \ln \left( \frac{A(Si)}{A(Ni)} \right) \sum \frac{A(Si)}{A(Ni)}
\]

• A (Si) = Number of evidence in a certain parameter class.
• A (Ni) = Total area, in a certain parameter class.
Landslide susceptibility was determined by summation of each factor’s ratings using equation:

\[ LHI = \sum_{i}^{n} Wi \]

Where,

\( Wi \) = Weight assigned to each parameter

\( N \) = Total number of parameters
Field Survey was carried out for Geological mapping of the area

Legend:
- Sub-himalaya
- Lesser Himalaya
- Miocene Granites
- Tethyan Himalaya
- Greater Himalaya
- Lower Greater
  Upper Lesser

MFT = Main Frontal thrust
MBT = Main Boundary thrust
RT = Ramgarh thrust
MCT = Main Central thrust
STDS = South Tibetan detachment system
MHT = Main Himalayan thrust

Study area

Map Legend:
- Pokhara
- Kathmandu
- NEPAL
- India
- Nepal
- Pakistan
- Bangladesh
- Sri Lanka

Geology
Geological map of the area

<table>
<thead>
<tr>
<th>Geology</th>
<th>Area (Sq Km)</th>
<th>Landslide (Sq Km)</th>
<th>Wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher Himalaya (Gneiss)</td>
<td>632.56</td>
<td>1.10</td>
<td>0.02</td>
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<tr>
<td>Graphitic Schist</td>
<td>102.21</td>
<td>0.33</td>
<td>0.40</td>
</tr>
<tr>
<td>Garnet Schist</td>
<td>85.91</td>
<td>0.36</td>
<td>0.60</td>
</tr>
<tr>
<td>Chlorite-Biotite Schist</td>
<td>55.35</td>
<td>0.26</td>
<td>0.70</td>
</tr>
<tr>
<td>Gneiss (Orthogneiss)</td>
<td>41.42</td>
<td>0.09</td>
<td>-0.05</td>
</tr>
</tbody>
</table>

Legend
- River
- VDCs/Municipality
- Chlorite-Biotite Schist
- Garnet Schist
- Gneiss
- Graphitic Schist
- Higher Himalaya
Landslide Inventory

Landslide inventory was prepared using Google Image, topomap and field survey.
Identification of earthquake induced landslides
Earthquake-Induced
Jointed rocks at Olitar
Debris flow at Charnawoti area
Debris flow at Buma Village
Rockfall at Wosimpa village
Jointed rocks at Olitar
Debris flow at Charnawoti area
Identification of unstable slopes

Unstable jointed slope at Sigati bazar

Cracks near Kalinchwok temple
Landslide Inventory Map

Legend
- VDCs/Municipality
- River
- Pre-earthquake landslide
- Post-earthquake landslide
<table>
<thead>
<tr>
<th>Slope Class</th>
<th>Area (Sq Km)</th>
<th>Landslide (Sq Km)</th>
<th>Wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;15</td>
<td>65.69</td>
<td>0.04</td>
<td>-1.34</td>
</tr>
<tr>
<td>15-25</td>
<td>199.54</td>
<td>0.25</td>
<td>-0.64</td>
</tr>
<tr>
<td>25-35</td>
<td>295.66</td>
<td>0.67</td>
<td>-0.04</td>
</tr>
<tr>
<td>25-45</td>
<td>230.11</td>
<td>0.63</td>
<td>0.16</td>
</tr>
<tr>
<td>&gt;45</td>
<td>126.61</td>
<td>0.56</td>
<td>0.64</td>
</tr>
</tbody>
</table>

Slope Map

Legend
- River
- VDCs/Municipality
- Slope gradient (Degree)
- <15
- 15-25
- 25-35
- 35-45
- >45
<table>
<thead>
<tr>
<th>Relative Relief</th>
<th>Area (Sq Km)</th>
<th>Landslide (Sq Km)</th>
<th>Wi</th>
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</thead>
<tbody>
<tr>
<td>0-160.9</td>
<td>197.6</td>
<td>0.2</td>
<td>0.77</td>
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<tr>
<td>161-234.6</td>
<td>305.7</td>
<td>0.6</td>
<td>0.34</td>
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<td>234.7-308.4</td>
<td>246.8</td>
<td>0.5</td>
<td>0.55</td>
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<tr>
<td>308.5-405.5</td>
<td>137.0</td>
<td>0.4</td>
<td>1.14</td>
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<td>405.7-851.4</td>
<td>30.5</td>
<td>0.3</td>
<td>2.64</td>
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<td>Drainage distance</td>
<td>Area (Sq Km)</td>
<td>Landslide (Sq Km)</td>
<td>Wi</td>
</tr>
<tr>
<td>-------------------</td>
<td>--------------</td>
<td>-------------------</td>
<td>----</td>
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<tr>
<td>&lt;50</td>
<td>286.49</td>
<td>0.89</td>
<td>0.28</td>
</tr>
<tr>
<td>50-100</td>
<td>222.66</td>
<td>0.64</td>
<td>0.20</td>
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<tr>
<td>100-150</td>
<td>129.21</td>
<td>0.29</td>
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<tr>
<td>150-200</td>
<td>99.67</td>
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<td>&gt;200</td>
<td>179.60</td>
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<td>Landuse</td>
<td>Area (Sq Km)</td>
<td>Landslide (Sq Km)</td>
<td>Wi</td>
</tr>
<tr>
<td>--------------------</td>
<td>--------------</td>
<td>-------------------</td>
<td>-----</td>
</tr>
<tr>
<td>Barren Land</td>
<td>3.2</td>
<td>0.07</td>
<td>0.49</td>
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<tr>
<td>Cultivated Land</td>
<td>200.9</td>
<td>0.58</td>
<td>0.21</td>
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<tr>
<td>Exposed Rock</td>
<td>103.9</td>
<td>0.44</td>
<td>0.40</td>
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<tr>
<td>Forest</td>
<td>361.8</td>
<td>0.59</td>
<td>-0.36</td>
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<td>Grassland</td>
<td>8.0</td>
<td>0</td>
<td>0.00</td>
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<tr>
<td>Lake</td>
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<td>0</td>
<td>0.00</td>
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<td>Landslide/Erosion</td>
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<td>0.15</td>
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<td>Riverbed</td>
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<td>0.00</td>
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<tr>
<td>Settlement</td>
<td>0.9</td>
<td>0</td>
<td>0.00</td>
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<tr>
<td>Shrub/Bushes</td>
<td>92.4</td>
<td>0.23</td>
<td>0.06</td>
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<td>Snow</td>
<td>33.5</td>
<td>0</td>
<td>0.00</td>
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<tr>
<td>Sparse Forest</td>
<td>108.3</td>
<td>0.08</td>
<td>-1.15</td>
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<td>Aspect</td>
<td>Area (Sq Km)</td>
<td>Landslide (Sq Km)</td>
<td>Wi</td>
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<tr>
<td>--------</td>
<td>-------------</td>
<td>------------------</td>
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<tr>
<td>North</td>
<td>223.88</td>
<td>0.25</td>
<td>-0.75</td>
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<tr>
<td>East</td>
<td>217.65</td>
<td>0.60</td>
<td>0.17</td>
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<tr>
<td>South</td>
<td>237.81</td>
<td>0.67</td>
<td>0.19</td>
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<tr>
<td>West</td>
<td>238.21</td>
<td>0.62</td>
<td>0.11</td>
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<tr>
<td>Curvature</td>
<td>Area (Sq Km)</td>
<td>Landslide (Sq Km)</td>
<td>Wi</td>
</tr>
<tr>
<td>-----------</td>
<td>--------------</td>
<td>-------------------</td>
<td>-----</td>
</tr>
<tr>
<td>Concave</td>
<td>426.77</td>
<td>1.13</td>
<td>0.12</td>
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<tr>
<td>Straight</td>
<td>44.18</td>
<td>0.06</td>
<td>-0.53</td>
</tr>
<tr>
<td>Convex</td>
<td>446.66</td>
<td>0.96</td>
<td>-0.09</td>
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<tr>
<td>Road Distance</td>
<td>Area (Sq Km)</td>
<td>Landslide (Sq Km)</td>
<td>Wi</td>
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<tr>
<td>--------------</td>
<td>--------------</td>
<td>-------------------</td>
<td>-----</td>
</tr>
<tr>
<td>&lt;50</td>
<td>35.24</td>
<td>0.18</td>
<td>0.80</td>
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<td>50-100</td>
<td>29.03</td>
<td>0.10</td>
<td>0.39</td>
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<tr>
<td>100-150</td>
<td>25.75</td>
<td>0.06</td>
<td>-0.06</td>
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<tr>
<td>150-200</td>
<td>23.32</td>
<td>0.04</td>
<td>-0.29</td>
</tr>
<tr>
<td>&gt;200</td>
<td>804.28</td>
<td>1.76</td>
<td>-0.06</td>
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</table>
### Normalized Vegetation Index (NDVI)

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<tr>
<th>NDVI</th>
<th>Area (Sq Km)</th>
<th>Landslide (Sq Km)</th>
<th>Wi</th>
</tr>
</thead>
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<tr>
<td>-0.2 - 0.059</td>
<td>102.68</td>
<td>0.29</td>
<td>0.19</td>
</tr>
<tr>
<td>0.06 - 0.16</td>
<td>148.11</td>
<td>0.61</td>
<td>0.57</td>
</tr>
<tr>
<td>0.17 - 0.25</td>
<td>211.87</td>
<td>0.48</td>
<td>-0.02</td>
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<td>0.26 - 0.34</td>
<td>252.09</td>
<td>0.47</td>
<td>-0.22</td>
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<tr>
<td>0.35 - 0.55</td>
<td>202.88</td>
<td>0.28</td>
<td>-0.51</td>
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### Landslide Susceptibility Map

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<th>Susceptibility</th>
<th>Area (sq Km)</th>
<th>Percentage (%)</th>
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<tbody>
<tr>
<td>Low</td>
<td>426.2</td>
<td>46.5</td>
</tr>
<tr>
<td>Moderate</td>
<td>331.8</td>
<td>36.2</td>
</tr>
<tr>
<td>High</td>
<td>158.5</td>
<td>17.3</td>
</tr>
</tbody>
</table>
Flow of research

Remote sensing & GIS
- Base maps (Land use and land cover map, etc.)
  - Landslide hazard map
  - Training seminars for students
  - Recommendation to local communities/government

Baseline survey
- Damage, dearth toll, etc.

Modeling
- HEC-RAS analysis for GLOF hazard

Field survey
- Distribution of landslides/rockfalls/other hazards
  - Landslide & GLOF hazard map
  - Identifying evacuation sites

UAV survey
- Photography for 3D mapping at seriously damaged sites
  - 3D-mapping (Structure from Motion)
  - Identifying evacuation sites

Labo. analysis
- Base-mapping for hazard map
- Landslide & GLOF hazard map

Field survey
- Distribution of damages; social survey
  - Identifying evacuation sites

HEC-RAS analysis for GLOF hazard

Photography for 3D mapping at seriously damaged sites
UAV survey (Singati and Gongar only)


UAV: DJI Phantom 2
Camera: RICOH GR

Attached to UAV

GPS logs & flight sites → Gave dimensions

SfM:
DSM, Ortho-map
Social survey: 13 settlements

Tamakosi 6
Kattike 17
Charikot 98
Dolakha 22
Singati 66
Olital 4
Bohle 10
Suri Doban 4
Jamune 3
Purano Jagat 28
Jagat 5
Manthali 10
Gongar 10

The number of interviewed households in Nov. 2015:

Face-to-face questionnaire survey

25 questions:
- Income
- Length of residence
- Damage
- Knowledge about evacuation site and hazard map

Socio economic Information:
1. How many years have you lived in this site?
2. Are you migrant or Local....? If migrants ..... a.How did you find this place? 
   b.Why did you choose this place? 
   c.What is the main purpose of choose this place? 
   d.Who suggested you to migrant this place? 
   e.What kind of problems did you face in previous place? 
3. What are the income sources in your family and estimate how much you earned per month?
(1) Landslide hazard map

(2) GLOF hazard map
One of the dangerous glacial lakes, Tsho Rolpa: potential source of future GLOF

Local residents, hydropower-related workers, and international trekkers to Rolwaling Himal (>3,000 per year).

Tsho Rolpa (ICIMOD, 2011):
Length=3.7 km
Area=1.54 km²
Vol=86 million m³
Max depth=135.5 m
Where,

\[ Q = \frac{1}{n} AR^{2/3} S^{1/2} \]

Where,

- \( Q \) = discharge (m\(^3\)/s)
- \( A \) = cross-section area (m\(^2\))
- \( R \) = hydraulic radius (m)
- \( S \) = friction slope and
- \( n \) = Manning’s roughness coefficient

Manning’s \( n \) for different land use (Chow et al., 2010)

<table>
<thead>
<tr>
<th>Land use type</th>
<th>Manning’s n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barren</td>
<td>0.03</td>
</tr>
<tr>
<td>Bush</td>
<td>0.05</td>
</tr>
<tr>
<td>Cultivation area</td>
<td>0.035</td>
</tr>
<tr>
<td>Cutting area</td>
<td>0.04</td>
</tr>
<tr>
<td>Forest</td>
<td>0.1</td>
</tr>
<tr>
<td>Grassland</td>
<td>0.035</td>
</tr>
<tr>
<td>Orchard</td>
<td>0.055</td>
</tr>
<tr>
<td>River</td>
<td>0.04</td>
</tr>
<tr>
<td>Sand</td>
<td>0.03</td>
</tr>
</tbody>
</table>

HEC-RAS model for mapping inundation area along the river
GLOF hazard and landslide hazard map

Legend:
- Temple
- School
- Other Houses
- River
- Police camp
- Interviewed houses
- Hydropower houses
- Post earthquake landslides
- Pre earthquake landslides

Flood inundation level:
- High: 21.0024
- Low: 0.143066

Landslide susceptibility:
- Low susceptibility
- Medium susceptibility
- High susceptibility

Regions:
- Gongar
- Singati
GLOF hazard and landslide hazard map: Dolakha, Charikot, Kattike, Tamakoshi
GLOF hazard and landslide hazard map: Purano Jagat, Jagat, Manthali
GLOF hazard and landslide hazard map: Jamune, Suri Dobhan, Bhorle, Olitar
GLOF hazard and landslide hazard map (Detailed): Singati
GLOF hazard and landslide hazard in Gongar
Nov. 2015:
Interviewed household number: 66
Feb. 2016:
Drone coverage: 16 households
June 2016:
More interviewed & drone covered all settlement area

Singati:
Population=1,618
Households=338
Earthquake damage survey in Singati

116 houses:
33 collapsed
5 partly damaged
4 emigrated to KTM (no use)
Damaged houses by the earthquake (by questionnaire survey)

- **Completely Destroyed**
- **Partly damaged**

- **No. of houses**

<table>
<thead>
<tr>
<th>Location</th>
<th>Completely Destroyed</th>
<th>Partly damaged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gongar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purano Jagat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jagat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manthali</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suri Dobhan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bhorle</td>
<td></td>
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<td>Jamune</td>
<td></td>
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<td>Oltar</td>
<td></td>
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<tr>
<td>Singati</td>
<td></td>
<td></td>
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<tr>
<td>Charikot</td>
<td></td>
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<td>Dolakha</td>
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<tr>
<td>Kattke</td>
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<tr>
<td>Tamakoshi</td>
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</tbody>
</table>
Earthquake damage survey in Singati

River terrace I (higher): quite OK
II (middle): quite OK
III (lower): more collapsed houses
GLOF hazard in Singati estimate by HEC-RAS

Nov. 2015: 33 houses were used on the lower river terrace. The lower river terrace (III) should be avoided to reside: relocation suggested.

Legend
- To be inundated
- Collapsed
- Partly damaged
- Currently used
- Rebuilt
- No use
- Storage

As of Nov. 2015, 4 houses have been rebuilt at the same site at lower river terrace. In June, 2016, there were more rebuilt houses.
Safe site:
1st river terrace → Good for evacuation
Residents’ knowledge on hazard map in Singati

Interviewed 66 households: Yes=1, No=65

*) The entire area: Yes=3, No=280

Only 1.5% of residents know a hazard map
Residents’ knowledge on the safe site for evacuation in Singati

Interviewed 66 households: Yes=2, No=64

Legend
- To be inundated
- Do not know
- Know

Legend:
- To be inundated
- Do not know
- Know

0  50  100(m)
Residents’ knowledge on the evacuation site and safe site

**Evacuate to safe site**

- Yes=7/283

**Safe site near by place**

- Yes=134/283
Evacuation routes in Singati

*) Will work on the lower Singati area
Evacuation routes in Singati

Stone steps: 50 – 90 cm wide (max: 1.8 m)

Existing evacuation routes are not enough
Preparedness for future hazards

Governmental & UNDP’s awareness projects after the earthquake
UAV and questionnaire surveys in Gongar

Nov. 2015:
Interviewed household number: 10

Feb. 2016:
Drone coverage: 10 households
GLOF hazard in Gongar estimate by HEC-RAS

Hydropower facilities

Legend:
- To be inundated
- Collapsed
- Partly damaged
- Currently used
- Rebuilt
- No use
- Storage

0 50 100 (m)
Gongar: some risk of GLOF

To be inundated

Relocation suggested
Conclusions and policy recommendation

Landslide inventory of pre- and post-earthquake event of April 2015 prepared.

Landslide incidences were found to be higher on steep and rectilinear, and south facing slopes, high relative relief, barren, poorly vegetated slopes, closed to roads and small rivers.

High relative relief areas are in high risk of earthquake induced landslides such as rockfall and rock slides.

The susceptibility areas shown in the maps should be considered for relocating the settlements in future.
Conclusions and policy recommendation

HEC-RAS modeling suggests that future GLOF from Tso Rolpa could affect some settlements such as Gongar (16 houses), Kattike (4 houses), Signati (13 houses), and Tamakoshi (6 houses; 100%).

Location of the reconstruction of buildings should avoid lower river terraces.

Evacuation routes in Singati and Gongar were examined to point out the need of their improvement.

Organizing local workshops is suggested to increase awareness of hazard map and to realize evacuation drills.
Transferring the methodology of the hazard mapping to Nepal (students of TU): training seminar will be conducted on 23 and 24 June 2016 and beyond.

Two-day Workshop on ‘Hazard Mapping’
Jointly Organized by
Tribhuvan University (TU), Nepal and Hokkaido University (HU), Japan

Workshop Days: 23rd and 24th June, 2016 (9 and 10 Ashadh, 2073)
Venue: Seminar Hall, Central Department of Physics, TU, Kirtipur
Participants: 40 Master’s students
Contact: Prof. Dr. Lalu Paudel, E-mail: lalupaudel67@yahoo.com

(Day 1) 23rd June

10:45 – 11:00 Introduction
Teiji Watanabe (Faculty of Environmental Earth Science, HU) and Lalu Paudel (Central Department of Geology, TU)
Presentations


26th April 2015
Acknowledgements

We are grateful to the following organizations and persons for their generous helps and support besides the funding support of the J-RAPID project:

- Hokkaido University and Himalayan Research Expedition provided additional funds, and Tribhuvan University provided necessary facilities,
- Mr. Niroj Timilsina, Mr. Kran Dahal, Mr. Shreekrishna Karki, Ms. Alina Karki helped in the field and data analysis.