4 CHARACTERISTICS OF SOIL AND ITS EFFECT ON LANDUSE

CHAPTER OUTLINE

4.1. Introduction

4.2. Outcrop vs soil cover of the western and eastern slope of Gangtok ridge

4.3. Soil thickness study

4.4. Pedogenesis

4.5. Organic carbon content and soil pH of Gangtok town and surroundings

4.6. Land use and Land cover

4.7. Conclusion
Chapter – 4
CHARACTERISTICS OF SOIL AND ITS EFFECT ON LANDUSE

4.1. Introduction

The physical and chemical properties, development of soil profile, soil thickness and changing land use/and cover have been discussed in details in this chapter, based on data mostly collected from the field and analysed in the laboratory.

The soil type of Gangtok is brown forest soil (Sehgal, J. 2002). The soils of the study region are moderate to slightly acidic with pH varying from 4 to 6. The soils have moderate to high accumulation of humus at their surfaces with organic matter content varying from 1 to 3 percent. The cation exchange capacity of the soils varied from 15 to 20 cmol (P+) kg⁻¹ soil and the base saturation percent varied from 60 to 90. The soils showed high biological activity. Some parts of the study area are under Tropical Climate zone and rests of areas are covered by Temperate zone. As a result the organic carbon content varied from place to place. From the extensive field survey it has been concluded that the maximum eastern part of the study area had distinct soil horizons. The depth of the soils varied from 0.5 metre to 7 metre. Due to high elevation the upper convex hill slopes continuously causes soil erosion by raindrop splash. Simultaneously the clay particles are being removed from the surface soils. As a result the soils become looser in texture. It has been noticed that the maximum active, old, reactivated and fossil slides are driven with the debris due to liquefaction at the high elevation. In this study effort has been made to find out the various characteristics of soils, profile development and the soil thickness of the Gangtok town and the surrounding for the better understanding of the study of landslide.

4.2. Outcrop vs soil cover of the western and eastern slope of Gangtok ridge

4.2.1. Eastern slope:

Due to mechanical and chemical weathering, thick to moderate soils have been developed irregularly in the eastern part of the Gangtok ridge but almost 50% surface are covered by rock exposure, boulders, slide dump materials,
OUTCROP & SOIL COVER MAP OF THE EASTERN PART OF GANGTOK RIDGE

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- RIVER
- GANGTOK RIDGE
- ROAD
- THRUST
- SURFACE AND SUB-SURFACE SOIL COVER
- LANDSLIDE AREA
  - OUT CROP OF GRANITE BEARING MICA SCHIST INTERBANDED WITH QUARTZITE
  - OUT CROP OF LINGTSE GRANITE GNEISS
  - OUT CROP OF GARNET STAUROLITE BEARING MICA SCHIST - DATING GROUP
  - OUT CROP OF BIOTITE BEARING QUARTZO-ILESPHATIC BANDED GNEISS - DARULING GNEISS

AREA COVERED BY VARIOUS OUTCROPS AND SOIL

- 49.7%
- 5.4%
- 33.6%
- 2.8%
- 7.9%
- 0.8%

Fig 4.1
old and new slide sears, anthropogenic cover and mixture of soil and big boulders. The outcrops boundary have been demarcated and depicted through the help of GPS and somewhere due to inaccessible tracts, the surface soil are marked on the basis of vegetation covered through RS techniques. In the eastern part, the four major lithological units are situated and these rocks are exposed as outcrops. Landslide scars and its dumping materials with big boulders are also prominently standing on the surface at few places. In the upper part, the maximum outcrops which are basically Darjiling gneiss are exposed as outcrops, but the valley sides (mostly gentle sloping sides) are characterised by thin sandy to silty soil covered (table 4.1). The thickness of soil varies drastically over ridges and valleys. In steep slopes and scarp faces as seen in the Chanmari, North Tathangchen, Rongyek and upper Bhurtuk, the soil formation is almost negligible. However, cover as thick as 5 metre is exposed a long the road cutting between T.V. tower and V.V.I.P. enclaves. Along the gentle slopes, the cover consists primarily of heterogeneous sandy to silty material with sub angular exotic boulders and dislodged blocks of underlying rock masses.

The lingtse granite gneiss and Daling schists near the valleys have been excessively converted into a thick to moderately deep silty to clayey soils. At all the places, debris slides, debris with rock slide and big boulders have been found on the Lingtse granite and schistose country during the extensive field survey. But the maximum numbers of out cropping big boulders have been located near Ranipool. Along the ridge tops, where in situ residual soil is preserved, mostly sandy to silty soil have been found over gneissic country and silty to clayey soil is developed over schistose rockmass. A detailed account of the location, rock type, slide dump material and outcrop zones are given separately in the fig.4.1 & table 4.2.
### Table 4.1. Percentage of outcrop & soil cover of eastern part

<table>
<thead>
<tr>
<th>Sl.</th>
<th>Various outcrop &amp; mica schist</th>
<th>Area in percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Garnet bearing mica schist</td>
<td>6.24</td>
</tr>
<tr>
<td>2</td>
<td>Lingtse granite gneiss</td>
<td>0.67</td>
</tr>
<tr>
<td>3</td>
<td>Garnet stuarolite bearing mica schist</td>
<td>2.32</td>
</tr>
<tr>
<td>4</td>
<td>Biotite bearing quartzo-feldspathic banded gneiss</td>
<td>27.78</td>
</tr>
<tr>
<td>5</td>
<td>Surface &amp; sub-surface soil cover</td>
<td>58.50</td>
</tr>
<tr>
<td>6</td>
<td>Landslide area</td>
<td>4.48</td>
</tr>
</tbody>
</table>

### Table 4.2. Location [GPS] of different outcrops on the eastern slope

<table>
<thead>
<tr>
<th>GPS way point</th>
<th>Latitude (N)</th>
<th>Longitude (E)</th>
<th>Nature of outcrop</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27°21'51&quot;</td>
<td>88°38'32&quot;</td>
<td>Biotite bearing banded gneiss</td>
</tr>
<tr>
<td>2</td>
<td>27°21'28&quot;</td>
<td>88°38'36&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>3</td>
<td>27°21'20&quot;</td>
<td>88°30'08&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>4</td>
<td>27°21'02&quot;</td>
<td>88°38'18&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>5</td>
<td>27°20'49&quot;</td>
<td>88°36'47&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>6</td>
<td>27°20'28&quot;</td>
<td>88°39'13&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>7</td>
<td>27°20'16&quot;</td>
<td>88°38'52&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>8</td>
<td>27°20'25&quot;</td>
<td>88°38'51&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>9</td>
<td>27°20'27&quot;</td>
<td>88°38'12&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>10</td>
<td>27°20'15&quot;</td>
<td>88°37'36&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>11</td>
<td>27°20'22&quot;</td>
<td>88°37'28&quot;</td>
<td>Landslide scarp</td>
</tr>
<tr>
<td>12</td>
<td>27°20'22&quot;</td>
<td>88°37'16&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>13</td>
<td>27°20'06&quot;</td>
<td>88°37'19&quot;</td>
<td>&quot;</td>
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<tr>
<td>14</td>
<td>27°20'07&quot;</td>
<td>88°37'30&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>15</td>
<td>27°20'10&quot;</td>
<td>88°37'14&quot;</td>
<td>Quartzo-feldspathic banded gneiss</td>
</tr>
<tr>
<td>16</td>
<td>27°19'47&quot;</td>
<td>88°37'27&quot;</td>
<td>Landslide scarp</td>
</tr>
<tr>
<td>17</td>
<td>27°19'47&quot;</td>
<td>88°37'27&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>18</td>
<td>27°19'53&quot;</td>
<td>88°37'57&quot;</td>
<td>Quartzo-feldspathic banded gneiss</td>
</tr>
<tr>
<td>19</td>
<td>27°19'41&quot;</td>
<td>88°37'09&quot;</td>
<td>Mica schist</td>
</tr>
<tr>
<td>20</td>
<td>27°19'29&quot;</td>
<td>88°37'42&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>21</td>
<td>27°19'23&quot;</td>
<td>88°37'21&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>22</td>
<td>27°19'18&quot;</td>
<td>88°37'29&quot;</td>
<td>Landslide scarp</td>
</tr>
<tr>
<td>23</td>
<td>27°19'21&quot;</td>
<td>88°37'14&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>24</td>
<td>27°19'07&quot;</td>
<td>88°37'05&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>25</td>
<td>27°19'13&quot;</td>
<td>88°37'01&quot;</td>
<td>Lingtse granite gneiss</td>
</tr>
<tr>
<td>26</td>
<td>27°19'03&quot;</td>
<td>88°37'15&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>27</td>
<td>27°18'59&quot;</td>
<td>88°37'11&quot;</td>
<td>Landslide scarp</td>
</tr>
</tbody>
</table>

Contd.
OUTCROP & SOIL COVER MAP OF THE WESTERN PART OF GANGTOK RIDGE

INDEX

- RIVER
- GANGTOK RIDGE
- ROAD
- THRUST
- SURFACE AND SUB-SURFACE SOIL COVER
- GARNET BEARING MICA SCHIST INTERBANDED WITH QUARTZITE
- LINGTSE GRANITE GNEISS
- GARNET STAUROLITE BEARING MICA SCHIST - DALING GROUP
- BIOTITE BEARING QUARTZO-FELDSPATIC BANDED GNEISS - DARJILING GNEISS
- LANDSLIDE AREA

Fig 4.2
4.2.2. Western slope:

In the western part of the Gangtok ridge line, 82% surface area is covered with thick to moderate surface and sub-surface soils which are developed from Darjiling gneiss. Lingtse gneiss and Daling schists, are the products of in situ weathering, the 70%, 9%, 1% and 5.5% area are covered by outcrops of Darjiling gneiss, Darjiling Schist, Lingtse granite gneiss and granite-quartzite schist respectively (table 4.3). Rest of the area (3.6%) is covered by old and new landslides scars.

<table>
<thead>
<tr>
<th>SI</th>
<th>Various outcrop &amp; soil cover</th>
<th>Area in percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Garnet bearing mica schist</td>
<td>5.5</td>
</tr>
<tr>
<td>2</td>
<td>Lingtse granite gneiss</td>
<td>1.0</td>
</tr>
<tr>
<td>3</td>
<td>Garnet stuarolite bearing mica schist</td>
<td>0.9</td>
</tr>
<tr>
<td>4</td>
<td>Biotite bearing quartzo-feldspathic banded gneiss</td>
<td>7.0</td>
</tr>
<tr>
<td>5</td>
<td>Surface &amp; sub-surface soil cover</td>
<td>82.0</td>
</tr>
<tr>
<td>6</td>
<td>Landslide area</td>
<td>3.6</td>
</tr>
</tbody>
</table>

Occasionally in the upper part of the Ranikhola stream, big size boulders have been identified but not to mapable scale. Out crops locations map (fig. 4.2) has been prepared through GPS survey. In details the location of the rock exposures, old and new landslide scars, boulders and mixture of soil and slide dump materials are given in the table 4.4.
### Table 4.4. Location [GPS] of different outcrops on the western slope

<table>
<thead>
<tr>
<th>GPS way point</th>
<th>Latitude (N)</th>
<th>Longitude (E)</th>
<th>Nature of outcrop</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27°18'06''</td>
<td>88°35'11''</td>
<td>Garnet bearing mica schist</td>
</tr>
<tr>
<td>2</td>
<td>27°18'50''</td>
<td>88°35'11''</td>
<td>Landslide scarp</td>
</tr>
<tr>
<td>3</td>
<td>27°18'52''</td>
<td>88°35'12''</td>
<td>&quot;</td>
</tr>
<tr>
<td>4</td>
<td>27°19'14''</td>
<td>88°35'13''</td>
<td>&quot;</td>
</tr>
<tr>
<td>5</td>
<td>27°19'16''</td>
<td>88°35'13''</td>
<td>&quot;</td>
</tr>
<tr>
<td>6</td>
<td>27°19'20''</td>
<td>88°35'14''</td>
<td>Mica schist</td>
</tr>
<tr>
<td>7</td>
<td>27°19'33''</td>
<td>88°35'15''</td>
<td>Landslide scarp</td>
</tr>
<tr>
<td>8</td>
<td>27°19'40''</td>
<td>88°35'16''</td>
<td>&quot;</td>
</tr>
<tr>
<td>9</td>
<td>27°20'02''</td>
<td>88°35'15''</td>
<td>&quot;</td>
</tr>
<tr>
<td>10</td>
<td>27°20'07''</td>
<td>88°35'36''</td>
<td>&quot;</td>
</tr>
<tr>
<td>11</td>
<td>27°20'03''</td>
<td>88°35'17''</td>
<td>&quot;</td>
</tr>
<tr>
<td>12</td>
<td>27°20'06''</td>
<td>88°35'17''</td>
<td>&quot;</td>
</tr>
<tr>
<td>13</td>
<td>27°20'17''</td>
<td>88°35'16''</td>
<td>Lingtse granite gneiss</td>
</tr>
<tr>
<td>14</td>
<td>27°20'19''</td>
<td>88°35'17''</td>
<td>Landslide scarp</td>
</tr>
<tr>
<td>15</td>
<td>27°20'24''</td>
<td>88°35'16''</td>
<td>&quot;</td>
</tr>
<tr>
<td>16</td>
<td>27°20'26''</td>
<td>88°35'17''</td>
<td>Mica schist</td>
</tr>
<tr>
<td>17</td>
<td>27°20'25''</td>
<td>88°35'14''</td>
<td>Granite bearing mica schist</td>
</tr>
<tr>
<td>18</td>
<td>27°20'27''</td>
<td>88°35'17''</td>
<td>Biotite bearing banded gneiss</td>
</tr>
<tr>
<td>19</td>
<td>27°20'33''</td>
<td>88°35'17''</td>
<td>Landslide scarp</td>
</tr>
<tr>
<td>20</td>
<td>27°20'34''</td>
<td>88°35'16''</td>
<td>&quot;</td>
</tr>
<tr>
<td>21</td>
<td>27°20'37''</td>
<td>88°35'17''</td>
<td>Biotite bearing banded gneiss</td>
</tr>
<tr>
<td>22</td>
<td>27°20'45''</td>
<td>88°35'16''</td>
<td>Mica schist</td>
</tr>
<tr>
<td>23</td>
<td>27°20'43''</td>
<td>88°35'15''</td>
<td>Landslide scarp</td>
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<td>24</td>
<td>27°20'48''</td>
<td>88°35'19''</td>
<td>&quot;</td>
</tr>
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<td>25</td>
<td>27°20'47''</td>
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<td>&quot;</td>
</tr>
<tr>
<td>26</td>
<td>27°20'51''</td>
<td>88°35'17''</td>
<td>Biotite bearing banded gneiss</td>
</tr>
<tr>
<td>27</td>
<td>27°20'56''</td>
<td>88°35'19''</td>
<td>Landslide scarp</td>
</tr>
<tr>
<td>28</td>
<td>27°20'54''</td>
<td>88°35'18''</td>
<td>&quot;</td>
</tr>
<tr>
<td>29</td>
<td>27°21'02''</td>
<td>88°35'17''</td>
<td>&quot;</td>
</tr>
<tr>
<td>30</td>
<td>27°21'07''</td>
<td>88°35'18''</td>
<td>&quot;</td>
</tr>
<tr>
<td>31</td>
<td>27°21'09''</td>
<td>88°35'20''</td>
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<td>32</td>
<td>27°21'06''</td>
<td>88°35'21''</td>
<td>&quot;</td>
</tr>
<tr>
<td>33</td>
<td>27°21'08''</td>
<td>88°35'21''</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

Contd.
The maximum numbers of outcrops have been found on the biotite bearing quartzofeldspathic banded gneiss and garnet bearing mica schist interbanded with quartzite and rest of the portions are covered with soil. The western part is gentler than the eastern part. In the gentle sloping western sides, spurs and valley are characterised by silty and clayey soil but cliff faces and escarpments are characterised by sandy soil. The terrace cultivations are dominant in the gentle valley sides slopes. Along the ridge tops the residual soil is preserved in situ and along the valley sides the transported landslide materials are dumped but somewhere [Sichey and Lingding] fine soils with boulders have been found.

4.3. Soil thickness study

Soil thickness means the depth of the soil (Biswas, T.D & Mukherjee, and S.K. 2006). It can be measured by electrical resistivity survey, soil cuttings and bore whole method (Sehgal, J.L., 1990). In this part of the work effort has been given to measure the soil thickness and depicted those data on the map.

4.3.1. Methodology:
SOIL THICKNESS WITH OUTCROP MAP OF THE WESTERN PART OF GANGTOK RIDGE

INDEX

- RIVER
- GANGTOK RIDGE
- ROAD
- THRUST
- SOIL THICKNESS BELOW 3 METRE
- SURFACE AND SUB-SURFACE SOIL COVER
- SOIL THICKNESS ABOVE 3 METRE
- GARNET BEARING MICA SCHIST INTERBANDED WITH QUARTZITE
- LINGTSE GRANITE GNEISS
- GARNET STUAROLITE BEARING MICA SCHIST - DALING GROUP
- BIOTITE BEARING QUARTZO-FELDSPATHIC BANDED GNEISS - DARJILING GNEISS
- LANDSLIDE AREA

Fig 4.3
GPS marking of the rock exposures have been done at the beginning of the work. Electrical Registivity Survey (table 4.7 & 4.8), bore hole and soil cuttings in some particular places have been conducted by CGWB and NBSS & LUP [Central Ground water Board & National Bureau of Soil Science and Landuse Planning]( D.C. Nayak, D. Sarkar and M.Velanyutham, 2001). Above 3 metre and below 3 metre deep soil zones were found at cultivated, dense forest and light forest covered areas respectively.

**4.3.2. Soil thickness of the western part of the Gangtok ridge:**

In the western part of the Gangtok ridge, 11.9% areas have come under below 3 metres soil thickness zone. Mainly upper Bhurtuk, upper Sichey, some part of the Lingding and Tadong are included in this particular zone. The below 3 metres depth is mainly found in Quartzo-feldspathic banded gneiss and mica-schist interbanded with Quartzite and dense forest. Cultivated land and built up area are the dominant land use/land cover in this area.

**Table 4.5. Percentage of outcrop and soil thickness of western part**

<table>
<thead>
<tr>
<th>Various outcrop &amp; soil cover</th>
<th>Area in percentage</th>
<th>Soil thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garnet bearing mica schist</td>
<td>5.5</td>
<td>&lt;3 m 72.2 11.9</td>
</tr>
<tr>
<td>Lingtse granite gneiss</td>
<td>1.0</td>
<td>&gt;3 m 82.0</td>
</tr>
<tr>
<td>Garnet stuarolite bearing mica schist</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>Biotite bearing quartzo-feldspathic banded gneiss</td>
<td>7.0</td>
<td></td>
</tr>
<tr>
<td>Landslide area</td>
<td>3.6</td>
<td></td>
</tr>
<tr>
<td>Soil thickness(&gt;3m &amp; &lt;3 m)</td>
<td>82.0</td>
<td></td>
</tr>
</tbody>
</table>

In the western part 72.2% area is included under above 3 metres depth zone (table 4.5). The maximum area of Lingding, Lower Tadong, Development area, Lower Sichey, Hospital and Palace are in the above 3 metres soil depth zone. Lithologically, this zone is characterised by Mica schist and Darjiling Gneiss and it is situated near Ranikhola valley and flat surface of the central part of the town. The land use/landcover of these areas are mainly dense forest, isolated pockets of rice and maize cultivated land. The soil thickness with outcrop map is shown in the fig. 4.3
4.3.3. Soil thickness of the eastern part of the Gangtok ridge:

In the eastern part, 41.5% area is covered by rock exposures and landslide scars. Very high degree of slope, rugged and dissected topography does not allow the settlement in this area. Rest of the area is characterised by open mixed jungle and dense forest. Agricultural activities were prominent in the river valley side particularly lower Shari, Rongyek, Near Ranipool and lower Tathangchen etc. The soil thickness map (fig. 4.4) has been depicted through land use / landcover, lithological characteristics and electrical registivity survey. Above 3 metres soil thickness [17.4% areas] zone has been occupied in the lower part of the Gangtok ridge line or near the river (Rorachu) valley. 41.4% includes below 3 metres thickness zones which have been restricted upper and middle parts of the western slope. During field survey, the maximum soil thickness (above 3 metres) has been observed on the Darjiling gneiss and mica schist. The soil thickness with outcrop map and electrical registivity survey data are given in the table 4.6. & 4.7.

Table 4.6. Percentage of outcrop and soil thickness of eastern part

<table>
<thead>
<tr>
<th>Various outcrop &amp; soil cover</th>
<th>Area in percentage</th>
<th>Soil thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landslide area</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>Garnet bearing mica schist</td>
<td>6.2</td>
<td></td>
</tr>
<tr>
<td>Lingtse granite gneiss</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>Garnet stuarolite bearing mica schist</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>Biotite bearing quartzo-feldspathic banded gneiss</td>
<td>27.8</td>
<td></td>
</tr>
<tr>
<td>Soil thickness(&gt;3m &amp; &lt;3 m)</td>
<td>58.5 41.1 17.4</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.7. ERS DATA with landuse characteristics along different GPS way points [eastern slope]

<table>
<thead>
<tr>
<th>GPS way point</th>
<th>Locality/landmark</th>
<th>Latitude (N)</th>
<th>Longitude (E)</th>
<th>Electrical registivity survey data</th>
<th>Land use/landcover</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ranipool</td>
<td>27°17'36''</td>
<td>88°36'06''</td>
<td>3.20</td>
<td>Agricultural land</td>
</tr>
<tr>
<td>2</td>
<td>Ranipool</td>
<td>27°17'37''</td>
<td>88°36'02''</td>
<td>4.10</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>27°17'56''</td>
<td>88°36'24''</td>
<td>3.90</td>
<td>Habitation with sparse forest</td>
</tr>
</tbody>
</table>

Contd.
Table 4.8. ERS data with landuse characteristics along different GPS way points [western slope]

<table>
<thead>
<tr>
<th>GPS way point</th>
<th>Locality/landmark</th>
<th>Latitude (N)</th>
<th>Longitude (E)</th>
<th>Electrical resistivity survey data</th>
<th>Land use/landcover</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Soil thickness &lt;3 mt.</td>
<td>Soil thickness &gt;3 mt.</td>
</tr>
<tr>
<td>1</td>
<td>Ranipool</td>
<td>27°17'24''</td>
<td>88°35'41''</td>
<td>2.30</td>
<td>Urban settlement</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>27°18'07''</td>
<td>88°36'19''</td>
<td>1.80</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>27°18'31''</td>
<td>88°35'51''</td>
<td>2.10</td>
<td>Agricultural land</td>
</tr>
<tr>
<td>4</td>
<td>Tadong</td>
<td>27°18'30''</td>
<td>88°36'17''</td>
<td>2.70</td>
<td>Urban</td>
</tr>
</tbody>
</table>

Contd.
4.4. Pedogenesis:

Soils are developed from rocks through the intermediate stage of formation of regolith which is the result of weathering (Sehgal, J. 2002). The sequence of soil formations are involved e.g. first the formation of regolith by the breaking down of the bedrocks and the second the addition or organic matter through the decomposition of plant and animal tissues and recoganisation of these components by soil forming processes to form soil. There are three important

<table>
<thead>
<tr>
<th></th>
<th>Latitude</th>
<th>Longitude</th>
<th>Area (Ha)</th>
<th>Land Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>27°18'43&quot;</td>
<td>88°36'14&quot;</td>
<td>4.70</td>
<td>Agricultural land</td>
</tr>
<tr>
<td>6</td>
<td>27°19'04&quot;</td>
<td>88°35'56&quot;</td>
<td>5.30</td>
<td>&quot;</td>
</tr>
<tr>
<td>7</td>
<td>Deorali</td>
<td>27°18'48&quot;</td>
<td>2.30</td>
<td>Habitation with sparse forest</td>
</tr>
<tr>
<td>8</td>
<td>Lingding</td>
<td>27°19'09&quot;</td>
<td>6.10</td>
<td>Urban settlement</td>
</tr>
<tr>
<td>9</td>
<td>Palace</td>
<td>27°19'12&quot;</td>
<td>1.90</td>
<td>Dense forest</td>
</tr>
<tr>
<td>10</td>
<td>Hospital</td>
<td>27°19'21&quot;</td>
<td>3.50</td>
<td>Urban settlement</td>
</tr>
<tr>
<td>11</td>
<td>Development area</td>
<td>27°19'44&quot;</td>
<td>4.80</td>
<td>Habitation with sparse forest</td>
</tr>
<tr>
<td>12</td>
<td>Sichey</td>
<td>27°20'09&quot;</td>
<td>2.60</td>
<td>Rural settlement</td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>27°20'05&quot;</td>
<td>3.70</td>
<td>Habitation with sparse forest</td>
</tr>
<tr>
<td>14</td>
<td></td>
<td>27°20'10&quot;</td>
<td>2.10</td>
<td>Urban settlement</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>27°20'59&quot;</td>
<td>4.20</td>
<td>Dense forest</td>
</tr>
<tr>
<td>16</td>
<td></td>
<td>27°20'27&quot;</td>
<td>3.20</td>
<td>&quot;</td>
</tr>
<tr>
<td>17</td>
<td></td>
<td>27°21'14&quot;</td>
<td>2.40</td>
<td>Habitation with sparse forest</td>
</tr>
</tbody>
</table>

Pedogenesis refers to the process by which soil is developed from rock through weathering.
Plate 4.1 & 4.2. Field measurement of well developed soil profile at Road side near Hospital

Plate 4.3. terrace cultivation is dominating landuse pattern at Near valley side
factors which are influencing the weathering of minerals. These are climatic conditions, physical characteristics, chemical and structural characteristics of rocks.

The pedogenic processes are interacting in some area during soil formation because those are very dynamic, complex and involve in many biological and chemical reactions (Sehgal, J. 1992). In case of Gangtok town and surrounding, it has been noticed that, due to active and passive soil forming factors and some pedogenic processes are being influencing for the development of soil and soil profile. In the western part of the Gangtok ridge line good soil have been developed varying the depth from 2 to 7 metres (D.C. Nayak, Dipak Sarkar and M.Velanyutham 2001). But in the eastern part of the study area some specific isolated soil patches have been found due to the presence of rock exposure. With the help of field manual (Soil Survey Staff, 1981 & Sehgal, J.L. and R.K. Saxena and S. Vadivelu, 1995) two selected soil profiles had been studied at the road sites near Sikkim Manipal Hospital (Plate 4.1 & 4.2).

Selected soil profile study

Profile 1

Site characteristics:

1. Profile No. – P₁
2. Location – Sikkim Manipal Hospital
3. Physiography
   i) Micro-relief-spur with terraces (Mountainous region)
   ii) Surface condition – vegetal cover
4. Parent Material – Mica schist
5. Climate – Humid tropic
6. Hydrogeology – Damp
7. Drainage – Nil
8. Human influence – Less
9. Land use / landcover – Natural vegetation
10. Altitude – 1160 metres
11. Date of study – 02.02.04

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (Feet)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>P₁</td>
<td>0-1.3</td>
<td>Very dark grayish brown (10 YR 3/2) sandy loamy,</td>
</tr>
</tbody>
</table>
A Geo-Technical Investigation into the Causes and Management of Landslides in Gangtok Town of Sikkim Himalayas
Chapter - 4 Characteristics of Soil and Its Effect on Landuse

Profile 2

Site characteristics:

1. Profile No. - P
2. Location - Sikkim Manipal Hospital
3. Physiography - i) Micro-relief-spur with terraces (Mountainous region)
   ii) Surface condition - unknown grass with light forest cover
4. Parent Material - Garnetiferous Mica schist
5. Climate - Humid tropic
6. Hydrogeology - Wet and damp
7. Drainage - Near non perennial stream
8. Human influence - Non active
9. Land use / landcover - Natural vegetation near NH31A and lower slope is used by agriculture
10. Altitude - 1162 metres
11. Date of study - 02.02.04

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (Feet)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>0 - 1.4</td>
<td>Dark brown (10 YR 3/3); moderately coarse sandy loam; very coarse granular; hard when dry, moist friable, wet slightly sticky and slightly plastic; very fine roots, common fine pores; no cracks</td>
</tr>
<tr>
<td>P2</td>
<td>1.4 - 3.7</td>
<td>Grayish brown (2.5 Y 3/2); moderately coarse single grain, slightly hard when dry, very friable when moist, fine roots, medium</td>
</tr>
<tr>
<td>P3</td>
<td>3.7 - 4.4</td>
<td>Yellowish brown (10 YR 5/4); moderately coarse sandy loam, coarse moderately angular blocky, sticky, very hard, no roots</td>
</tr>
</tbody>
</table>
slightly plastic, firm when moist slightly hard when dry; fine roots, few fine pores; no cracks
Yellowish red (5 YR 5/8); moderately coarse sandy loam; medium weak blocky, friable when moist, slightly hard when dry with plastic, common few pores; no roots

Number of soil samples were collected on the basis of the soil survey norms (Sehgal, J.L., 1992.) from different horizons of the selected soil profiles and different sites of the Gangtok town and surroundings and investigated in the laboratory to determine the characteristics (appendix 12-23) of the existing soils of the area under study.

4.4.1. Soil Profile development

From the above studied profile it has been found that, good soil horizons have been developed and the surface of the soil profiles are covered by vegetation and unknown grasses. The moderate to gentle slopes are receiving high amount of rainfall and the process of leaching and illuviation are more active on the selected sites. Consequently, the finer particles of clay and silt move downward and subsequently these elements are deposited or more concentrated in the lower horizons due to fine pores and fine roots. There are clear evident that, clay, silt, iron percentages are more in the lower horizons at a depth of 60-90 cm.

Due to the presence of tropical and temperate deciduous forest with considerable undergrowth, the accumulation of organic matter in the upper (P₁) and middle (P₂) horizons are higher than the P₃ and P₄ horizons. The soil organic carbon percentages in both the soil profiles, particularly in the P₁, P₂ horizons, are 3.88%, 2.97% and 2.68%, 3.12% respectively. The organic carbon percentages were lower in the P₃ and P₄ horizons.

The higher rainfall on coarse-textured (mainly sandy, sandy loam, clay) soils of the profiles helps to remove the organic matter and iron through leaching to a depth of 20-70 cm and forming dark brown, yellowish, brown colour at P₂, P₃, P₄ horizons. As a result, mature to semi matured soil develops with well defined horizons. Due to continuous anthropogenic activities [construction of settlement
A Geo-Technical Investigation Into the Causes and Management of Landslides in Gangtok Town of Sikkim Himalayas
and the deforestation accumulation of organic matter in the sub surface soils are gradually decreasing. Therefore the formation of a well defined B or C horizons in the soil profiles in the municipality area are hindering.

The different tones of brown colour within the range of dark brown to very dark yellowish brown are found in the upper horizons in both the soil profiles between 1 to 30 cm due to the presence of high organic matter.

The reddish tint in the middle ($P_2$ and $P_3$) or lowest layer ($P_4$) is due to the presence of iron and it varies from 8.57 to 10.26 ft.

Soils of all the horizons of both the soil profiles are slight to moderate acidic in reaction. The soil pH ranges from 5.4 to 6.1 in the $P_1$ and $P_2$ horizons and in the lower horizons it varied from 5.4 to 5.7.

4.5. Land use and Land cover

4.5.1. Introduction:

Land use can be defined as the use of land by human with emphasis on the functional role of land in economic activities. Land use forms an abstraction, not always directly observable even by the closest inspection (Brady, N.C. & Weil, R.R. 2004).

In contrast, land cover, in its narrowest sense, often designates only the vegetation either natural or man made, on the earth's surface. In broader sense, land cover designates the visible evidence of land use to include both vegetative and non vegetative features. In this meaning, dense forest, plowed land, urban structures and paved parking areas all constitute land cove, whereas land use is abstract, land cover is concrete and therefore is subject to direct observation (Brady, N.C. & Weil, R.R. 2004).

Another distinction is that land cover lacks the emphasis on economic function that is essential to the concept of land use and landuse planning (F.A.o., 1991). Hydrologists can focus solely on land cover because of their concern with only the physical components of the landscape that pertain to the movement of moisture. But a traffic engineer must consider land use a component of a traffic flow model and must address the economic function of each parcel of land as a
LANDUSE MAP (1974)

INDEX

- ARABLE LAND
- HABITATION WITH LIGHT FOREST
- DENSE FOREST
- OPEN SCRUB
- RURAL SETTLEMENT
- URBAN SETTLEMENT

Fig 4.5

SOURCE: Topographical sheet of S.O.I

GRAPH OF AREA COVERED BY DIFFERENT LANDUSE
LANDUSE MAP (1990)

INDEX

- BUILT-UP AREA
- FOREST
- AGRICULTURAL LAND
- VACANT LAND WITH LIght FOREST

0 1 2
kilometres

Source: LISS III DATA

SOURCE: IRS IC LISS III DATA

GRAPH OF AREA COVERED BY DIFFERENT LANDUSE

- 27.5%
- 41.1%
- 15.9%
- 15.4%

Fig 4.6
LANDUSE / LANDCOVER MAP OF GANGTOK AND SURROUNDINGS

DATA SOURCE: IRS 1C LISS III + PAN
DATE OF ACQUISITION: 19TH JANUARY 2002
contributor of automobile traffic to the region's highways. Usually the distinction between land use and land cover becomes more important as the scale of a study becomes larger and detail becomes finer.

Land use patterns reflect the character of a society's interaction with its physical environment, a fact that becomes obvious when it is possible to see different economic and social systems occupying the same or similar environments (Dent, D. and S.B. Despande, (eds.), 1993).

4.5.2. Changing land use and land cover scenario of the study area

To study the changing land use and land cover scenario four RS and GIS based map were prepared on the basis of topographical map (Survey of India,1974), LISS-III satellite data (1990), LISS-III + PAN data (2002) and LISS-III + PAN (2006) of the study area respectively.

The first map (Fig.4.5 ) has been classified into a six broad classes e.g. arable land, habitation with light forest, dense forest, open scrub, rural settlement and urban settlement which have been covered by 28.7%, 23.0%, 8.7%, 24.2%, 3.7% and 11.7% of the total area respectively.

The second map (Fig.4.6) has been prepared by LISS-III satellite data and some modification has been done by GPS in 1990. Here, it has been further divided into a four major classes such as built up area, forest cover, agricultural land (Plate 4.3) and vacant land with light forest. Form the comparative study; it has been observed that the total forest land and agricultural land in 1974 were 84.6% where as in 1990 it was 68% (table 4.9). The percent reduction in forest and cultivated area in 1990 than 1974 was 16.6%. In case of built up area (rural + urban settlement) in 1974 it was 15.4% but in 1999 it has increased to 16.6%.

The third map (Fig. 4.7) has been prepared with the help of LISS-III + PAN data in 2002. In 2002 the forest cover was also reduced 7% (table 4.9) and the built up area had been also increased 10% then 1990. In case of vacant land the area has been reduced due to urban and rural construction. The population density and number of house holds are being increased day to day.

From the above discussion, it has been noticed that, the percentage of forest cover and vacant area are being reducing by recent years in the Gangtok
A Geo-Technical Investigation into the Causes and Management of Landslides in Gangtok Town of Sikkim Himalayas
LANDUSE MAP OF GANGTOK MUNICIPALITY
(2002)

INDEX

FOREST
CULTIVATED LAND
RESIDENTIAL AREA
COMMERCIAL AREA
PLAY GROUND
INDUSTRIAL / INSTITUTIONAL AREA
OFFICES
PARKING
NH-31A
MASTER PLAN BOUNDARY

AREA UNDER DIFFERENT LANDUSE TYPES

Fig 4.8

Source: satellite image (2002)
field verification through GPS
LANDUSE MAP ALONG THE NH-31A

INDEX

- DENSE FOREST
- RESIDENTIAL AREA
- GOVT.OFFICE
- SCHOOL/HOSTEL
- INDUSTRIAL AREA
- MIXED
- VACANT LAND
- ACTIVE SLIDE

AREA UNDER DIFFERENT LANDUSE TYPES

- DENSE FOREST: 36.90%
- RESIDENTIAL AREA: 15.27%
- GOVT.OFFICE: 9.89%
- SCHOOL/HOSTEL: 31.69%
- INDUSTRIAL AREA: 3.60%
- MIXED: 2.65%
- VACANT LAND: 0.35%
- ACTIVE SLIDE: 0.00%

Fig 4.9
LANDUSE MAP ALONG THE WESTERN BY-PASS

INDEX
- DENSE FOREST
- LIGHT FOREST
- RESIDENCIAL AREA
- ROCK EXPOSURE
- BARREN LAND
- LANDSLIDE

AREA UNDER DIFFERENT LANDUSE TYPES

Fig 4.10
GRAPH OF AREA COVERED UNDER DIFFERENT LANDUSE

Fig 4.12
Simultaneously the urban field and rural construction have been encroached in the forest cover and vacant land. Many multistoried hotels, lodges and guest houses have been constructed on the unstable (high, very high landslide prone zone and high risk prone zone) and steep slope side in the western and eastern part of the Gangtok town. As a result the devastating landslides are being happened frequently. It is stated that, frequency of landslides have been tremendously increased in the recent years. But before 1980, Geological Survey of India reported that there was very little existence of landslides. After 1990 to till now, the Environmental Scientists, Geologist and Geographers have agreed that, unscientific landuse is the major triggering factor of the landslide in Gangtok.

### Table 4.9. Landuse/landcover category [in percentage] in different years

<table>
<thead>
<tr>
<th>SI</th>
<th>Landuse/landcover category</th>
<th>Area in percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1974</td>
</tr>
<tr>
<td>1</td>
<td>Arable land</td>
<td>28.7</td>
</tr>
<tr>
<td>2</td>
<td>Habitation with light forest</td>
<td>23.0</td>
</tr>
<tr>
<td>3</td>
<td>Dense forest</td>
<td>8.7</td>
</tr>
<tr>
<td>4</td>
<td>Open scrub</td>
<td>24.2</td>
</tr>
<tr>
<td>5</td>
<td>Rural settlements</td>
<td>3.7</td>
</tr>
<tr>
<td>6</td>
<td>Urban settlements</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Vacant land</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Vacant land with light forest</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Forest (open, dense, light)</td>
<td></td>
</tr>
</tbody>
</table>

The forth map (Fig. 4.8) of Gangtok municipality has been prepared from LISS-III + PAN with the help of RS, GIS and GSP techniques. The percentage of built up, parking and playground areas are 61.04 % (table 4.11) whereas the forest cover area is 38.96%. It is expected that after five years the forest cover will be dropped 15 to 20% due to high rate of urban construction. There are four land use / land cover maps (Fig. 4.9 to 4.12) have also been prepared along the different road sections for the assessment of landslide hazard zonation, risk and stability zonation. Along the road sections the different attributes of land use and their percentage have been given on the map and table 4.10.
Table 4.10. Landuse / Landcover percentage along different road sections

<table>
<thead>
<tr>
<th>SI</th>
<th>Landuse / landcover category</th>
<th>Percentage of landuse / landcover</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Along western bypass</td>
</tr>
<tr>
<td>1</td>
<td>Dense forest</td>
<td>32</td>
</tr>
<tr>
<td>2</td>
<td>Residential area</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Govt. Office school / hostel</td>
<td>9.89</td>
</tr>
<tr>
<td>4</td>
<td>Industrial area</td>
<td>2.65</td>
</tr>
<tr>
<td>5</td>
<td>Mixed</td>
<td>3.60</td>
</tr>
<tr>
<td>6</td>
<td>Vacant land</td>
<td>15.27</td>
</tr>
<tr>
<td>7</td>
<td>Agricultural land</td>
<td>32.75</td>
</tr>
<tr>
<td>8</td>
<td>Uninhabited area</td>
<td>15.77</td>
</tr>
<tr>
<td>9</td>
<td>Plantation</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Human agglomeration</td>
<td>37.75</td>
</tr>
<tr>
<td>11</td>
<td>Light forest</td>
<td>12</td>
</tr>
<tr>
<td>12</td>
<td>Rock exposure</td>
<td>2</td>
</tr>
<tr>
<td>13</td>
<td>Barren land</td>
<td>50</td>
</tr>
<tr>
<td>14</td>
<td>Area under forest cover</td>
<td>14.33</td>
</tr>
</tbody>
</table>

Table 4.11. Landuse / landcover percentage of Gangtok municipality (2006)

<table>
<thead>
<tr>
<th>SI</th>
<th>Various landuse / landcover category</th>
<th>Area in percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Forest</td>
<td>38.96</td>
</tr>
<tr>
<td>2</td>
<td>Cultivated land</td>
<td>10.94</td>
</tr>
<tr>
<td>3</td>
<td>Residential area</td>
<td>38.68</td>
</tr>
<tr>
<td>4</td>
<td>Commercial area</td>
<td>2.86</td>
</tr>
<tr>
<td>5</td>
<td>Play ground</td>
<td>0.38</td>
</tr>
<tr>
<td>6</td>
<td>Institutional / industrial</td>
<td>6.23</td>
</tr>
<tr>
<td>7</td>
<td>Offices</td>
<td>1.57</td>
</tr>
<tr>
<td>8</td>
<td>Parking</td>
<td>0.38</td>
</tr>
</tbody>
</table>

4.7. Conclusion

The study of soil thickness, outcrop vs soil cover, Pedogenesis, profile development and changing landuse or landcover scenario are being interacting very important role for the occurrence of mudflow, debris flow and rock-come debris flow in the mountainous terrain like Gangtok. The maximum outcrops are situated on the eastern part of the Gangtok ridge line and good soils have been developed on the Daling Schist [parent material]. The isolated soil pockets [mainly sandy-loam] have been found on the western part of the ridge line. Place to place 3 to 7 metres of soil depth had been determined. According to NBSS & LUP the soil erosion is active in the upper and lower part of the study area where agricultural is a dominating landuse type. High acidic soils are found on the upper Bhurtuk where soils organic carbon concentration is higher. From the above
systematic study it is concluded that the soils of the study area is brown forest soil. Due to unscientific urbanization [high rise multi storied buildings constructed on the unstable] as well as high population explosion, deforestation is continuously happened on the mountainous terrain. As a result, the resisting force is decreasing on the other hand the driving forces are gradually increasing. That is why landslide with debris flow has become a general phenomenon in the Gangtok town and surroundings.

References:


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