Chapter 9

SUMMARY AND CONCLUSIONS

Kolli hills located in part of Eastern Ghats and one of the major tourist spots in Tamil Nadu. The mountain forms a plateau like landform, mainly covered by charnockitic formation. The plateau region is connected through Ghat road from foot hills. The Ghat road section is covered by 70 hairpin bends, mostly vulnerable for landslides, particularly during monsoon season. The average annual rainfall at Kolli hills is 1497 mm, which is almost more than 50% of State average annual rainfall. The landslide inventory conducted for last twenty years indicates that atleast 74 landslide events at 54 locations occurred in different dimensions and intensity. This has indicated that the necessity of conducting a detailed landslide hazard zonation mapping and geotechnical studies to prevent or minimize the further hazards. With this background, landslide study has been carried out through integrated remote sensing, GIS, geotechnical and field investigations.

The Bureau of Indian Standard (BIS) code IS: 14496 (Part 2) 1998 guidelines is followed for landslide hazard zonation mapping. In order to carryout hazard zonation study, the Ghat road section is divided into 7 facets. For each facet, the various evaluation factors such as lithology, structure, slope morphometry, relative relief, land use and land cover, hydrogeological conditions, density of hairpin bends were assessed. In addition the triggering factors like rainfall and seismicity were added. Ratings were assigned based on LHEF rating scheme and the Total Estimated Hazard (TEHD) was calculated for each facet.

Remote sensing technique was adopted for terrain mapping, which include drainage pattern, geomorphology, land use and land cover, structure and lineaments. The Ghat road section is mostly covered by structural hill system. The area is criss-crossed by minor lineaments at various sectors. Land use and land cover is an important parameter in assessing landslide hazard zones along Ghat road section, interpreted from satellite data. The
major land cover units along the ghat road sections are dense forest, fairly dense forest, and forest plantation.

The resistant of rocks, the weathering and subsequent erosion are the important causative factors in hazard mapping. The Ghat road section mainly covered by charnockites and gneisses. It is observed that at many places these rocks are significantly weathered and fractured condition. The geometry of structural discontinuities were measured for all facets for atleast two to four locations. The orientation of discontinuities and joint pattern in the Ghat road disposed atleast in three directions. The structural discontinuities were plotted in the stereonet to infer direction and angle of plunge. Based on the total estimated hazard of causative factors, the hazard zones were classified under low hazard, moderate hazard and high hazard zone.

Apart from heuristic landslide hazard zonation mapping, the various statistical methods such as frequency ratio, fuzzy logic, and relative effect models were used to prepare landslide susceptibility maps. The relationship between causative factors and landslide inventory data were derived using the statistical models. The slope curvature, slope aspect, relief, proximity to road, drainage and lineaments are the additional factors incorporated in the statistical analyses. The results are comparable with all three statistical models.

The LHEF and statistical methods followed by a detailed slope stability analyses were carried out at selected locations. The Rock Mass Rating (RMR) system was carried out using Bieniawski (1989) and IS 13365 (part 1) (1998) classification system for the facets 2, 3, and 4. In this method, the condition of discontinuities, spacing of discontinuities, groundwater condition, point load strength were assessed and used as input data. Based on output of RMR values, the rock mass along the slope is classified as good and fair categories. In addition Slope Mass Rating (SMR) was estimated on detailed scale by following Romana (1985) classification system. In this method, the result of RMR values, orientation of discontinuities and method of excavation were used as input for estimation of SMR. The factor of safety of
critical sections were determined for planar and wedge failure cases using Hoek and Bray (1981) method.

Similarly, soil slope stability analyses were carried out at five locations in the facets 1, 2, 3, and 5. In the analyses, the circular failure chart and limit equilibrium methods were adopted and estimated the factor of safety under various slope saturation conditions. The results obtained from LHEF and statistical methods, rock slope stability analyses, and soil slope stability analyses are validated through landslide inventory data. Finally, remedial measures were suggested for moderate and high landslide hazard zones. It is recommended based on the controlling terrain parameters and results of slope stability analyses.

The following conclusions were drawn from the present study.

- The landslide inventory data here shown that the occurrence of landslides along Ghat road section of Kolli hills is inevitable. Further, the data have shown the frequency of landslide occurrences are once in 8 years and mostly associated with torrential rainfall during NE monsoon (Oct-Dec).

- It is evident that the structural discontinuities and weathering are the major causative factors for occurrence of landslides.

- The output of landslide hazard zonation mapping carried out through LHEF rating scheme (BIS 1998) has indicated that, the facet 1, 2, and 5 are categorized under moderate hazard zones and the facet 3 and 4 classified under high landslide hazard zones.

- In statistical analysis, the frequency ratio model (87.93%) has slightly higher accuracy than fuzzy gamma operator (87.33%) and relative effect (85.26%) models in prediction accuracy of landslide susceptibility zones.

- The results of rock mass rating system has indicated that the rock sections RS-1 (facet 2), RS-2 (facet 3) and RS-6 (facet 4) fall in good rock category and rock section RS-3 & 4 (facet 3), and RS-5 (facet 4) fall in fair rock type.
• The results of slope mass rating indicated that the rock sections RS-1, RS-2, and RS-6 classified as stable, rock sections RS-3 and RS-5 categorized as partially stable and rock section RS-4 under very bad condition and categorized as completely unstable. The results have indicated that the rock sections RS-1, RS-2 & RS-6 required occasional support, RS-3 and RS-5 require systematic support, and the RS-4 identified as unstable section, which needs re-excavation.

• The results obtained from RMR and SMR are comparable with the landslide inventory data and landslide hazard zonation mapping and validated.

• The mode of failure at various sections in the Ghat road is inferred from the Hoek and Bray method as follows;
  
  Rock Section 3 : Planar Failure
  Rock Section 1, 4, and 6 : Wedge Failure
  Rock Section 2 : Planar & Wedge Failure

• The factor of safety for planar failure case indicates that RS-3 (0.22) is more unstable.

• In limit equilibrium method, the soil sections SS-3 and SS-4 are unsafe under partially or completely saturated (natural slope) condition. In average slope condition, all the soil sections are unsafe under partially or completely saturated conditions.

• Remedial measures such as reinforcement, drainage control, and modification of slope geometry are suggested for unstable slope sections located in moderate and high hazard zones.

• Overall, the study has provided a detailed information on the sections and locations of landslide hazards along Ghat road of Kolli hills. The landslide zonation maps are useful for decision makers, planners, and engineers. The output is useful to carry out proper preventative and restorative measures to avoid occurrence of landslides in future.