CHAPTER 8

DISCUSSION AND CONCLUSIONS

8.1 DISCUSSION

Rapid urbanization and development in hilly areas has underlined the importance of understanding the geological factors promoting instability. This requires careful and comprehensive assessment of factors that lead to initial and subsequent failure. Assessments involve detailed field investigations for geology, soils, hydrology, topography, rainfall, and human factors which collectively cause slope instability. Assessments may conclude with recommendations for methods and procedures for mitigation of existing landslides, immediate landslide hazards, as well as the identification of more detailed geotechnical analysis and monitoring of selected landslides.

Landslides and other forms of mass wasting have posed major challenges to the mountainous terrains of the country. It is a natural hazard of significant impact worldwide, and affects at least 15 percent of the land surface of India, an area that exceeds 0.49 million km² (National Institute of Disaster Management, 2009). Landslides may occur almost anywhere, from manmade slopes to natural, pristine ground. It occurs independently or aided by human activity. They typically result from extreme natural events such as heavy rainfall, volcanic eruptions, earthquakes, etc. which can be combined with factors related to human activities such as deforestation and intensive exploitation of land for agricultural use and other developmental activities. Landslides have caused large numbers of casualties and huge economic losses in hilly and mountainous areas.

Geological investigations of land instability have been attempted to derive the spatial variation and distribution of slope instability in the study area. Geomorphology, geological features, lithology, land use / land cover, groundwater, and rainfall are important initiators of landslides. Human interventions such as haphazard and
unscientific developmental activities worsen existing stability conditions. The present study is carried out to evaluate the factors responsible for land instability and to generate a LHZ map for the study area as developmental activities and expansion of Kohima town are taking place or are being proposed in this area. In addition risk analyses has been carried out along the NH 2 and the approach road to the NU campus, which are being widened, to provide mitigation measures against possible landslides and those areas along the highway that are affected by landslides.

More than 90 percent of the surface area of Nagaland state is hilly. Due to under-thrusting of the Indian plate below that of the Burmese, most rocks of the region is highly deformed. The deformation is primarily in the form of large scale folding, faulting, and shearing. Large scale jointing has also affected the rocks; due to stresses along various directions the rocks are commonly fractured. The region receives abundant rainfall which has aided rapid weathering of the already weakened rocks. All these processes together have played a very significant role in causing much surface instability in the study area and region as a whole.

The study area represents high denudational hills made up of rocks belonging to the Disang and Barail groups. The Disang make up the bulk of the rocks of the study area. They are very weak, being made up primarily of shale with thin alternations of sandstone and siltstone. These are overlain by the younger Barail made up dominantly of sandstone with minor intercalations of shale. The unmappable Barail are confined to the upper ridges as irregular blocks along the flanks of some slopes due to faulting. The rocks of this area are commonly affected by two to four sets of joints. Faults too are fairly common in the study area, though most are of local extent. The weak Disang are jointed, fractured, and crumpled to varying extents and have been affected by the weathering processes aided by prolonged monsoonal rains.

Studies have been carried out for landslide hazard microzonation mapping of the study area. Data on geoenvironmental parameters such as slope, structural features, lithology, groundwater, and land use / land cover are derived from various sources through the analysis of SoI toposheet and satellite imagery and extensive fieldwork. These parameters are converted into digital format in ArcGIS 9.2 and databases are generated for road network, facet, slope morphometry, land use / land cover, drainage
network, groundwater, lithology, structure, and landslide incidences employing visual interpretation and digital techniques.

In the study area surface instability is noted even in gentle slopes. This is due to local steepness of these slopes and the weak rocks and soils that make up the area. Hence, it was felt justifiable to raise the rating of lithology for this area to 2.5 from the recommended 2.0 of the Bureau of Indian Standards (1998). Similarly the rating for land use / land cover is reduced to 1.5 from 2.0 as the relative effect of this parameter is not as significant as that of lithology. Relative relief as a factor in instability studies in this area is insignificant. It is therefore proposed not to use relative relief, as this parameter bears no impact in this study. The TEHD value is therefore reduced to 9.0 from the 10.0 proposed by the Bureau of Indian Standards (1998). However, the total value for the different zones is preserved as percentages of the original value of 10.0. Based on computed TEHD values the hazard zones of the study may be classified under four categories, viz. low, moderate, high, and very high. Slopes are generally gentle to moderate in this area. Most steep and very steep slopes are confined to the north. The rocks are commonly partially weathered, crumpled, and weathered shale which are responsible for the general weakness of the slopes. Landslide incidences maps generated in ArcGIS are laid over the thematic and LHZ maps to ascertain their relationship with the various categories of the themes and hazard zones.

All five categories of slopes are noted in the study area. A large number of slopes are mapped as gentle but much of these are locally moderate to steep along stream channels, being areally too small to be categorized as individual facets. Hence, in the overall analyses these slopes are given the ratings of the general slope in that facet. Slides normally occur in areas of locally steep slopes. With relation to slope, 2.33% of slides occur on very steep slopes, 6.98% on steep slopes, 44.19% on moderately steep slopes, and 46.50% on gentle slopes. Very gentle slopes constitute a small portion of the area, these slopes being more or less stable. The frequency of landslides in the very steep slopes is naturally high while that of the steep slopes is also high. The moderately steep slopes also show reasonably high values. The frequency of landslides on the gentle slopes is appreciably low. However, the reason that landslides have affected this category as well, besides locally steepness of slopes, is attributed to the weak lithology, faulting in the area, and erosive activity of streams.
The lithological map of the study area shows the distribution of the various litho-units. Here, 34.88% of the slides occur in weathered shale and the same in loose debris, 25.58% in crumpled shale, and 4.65% in partially weathered shale. The other litho-units, being more stable are not affected by landslides. Another reason is that the slopes of some of these areas are gentler. The frequency of slide distribution indicates that the loose debris areas are most prone to landslides. This is natural as debris slopes possess very low shearing strengths, being mixed with clays and hence, collapse easily in the presence of water. The high frequency of slides in the weathered horizons is due to the abundance of water from rainfall during the monsoon when the shearing strengths of clays are reduced. The 2.21 frequency of the crumpled shale also point to the same reasons, besides rampant slope cutting.

Most of the surface area in this study is dry. The largest percentage of slides has occurred in wet areas (46.51) followed by the dry areas (34.88). The damp areas show negligible percentages (18.60) of landslides. However, the frequency of landslides in wet areas (9.30) is high while damp areas also show relatively higher values (2.24) compared to the dry areas.

The area has been classified under five categories of land use / land cover. The populated areas made up of some small villages are located in geologically more stable areas and as such do not suffer from landslide activity. Moreover, indiscriminate earth cutting and unscientific land use practices such as construction of large and heavy structures is not resorted to in such areas. Most wet cultivation for paddy is confined to old landslides. In these areas the water retention during the growing season increases the pore-water pressure tremendously leading to continued subsidence and/or damage of hill slopes and roads. The moderately and sparsely vegetated areas are usually geologically weak with unfavorable slopes and hence, have been affected by 18.60% and 16.28% of landslides respectively. Densely vegetated areas also are affected by landslides which are ascribed to structural disturbances and weak lithology. Hence, the frequency of landslides is also high.

The LHZ map delineates the study area into four classes comprising low, moderate, high, and very high hazard zones. The low hazard zones are free of landslides. 11.63% slides occur in moderate hazard zones, 51.16% in high hazard zones, and 37.21% in
very high hazard zones. The very high hazard zones have a frequency of 12.31 and high hazard zones 3.17. The moderate hazard zones have a comparatively low frequency of 1.01%. Results indicate that the very high hazard zones are highly unstable. The high hazard zones too are unstable. Much of the areas identified as moderate hazard zones are more or less stable as long as external factors such as large earthquakes, cloudbursts, excessive anthropogenic activity, etc. do not disturb the equilibrium.

Structure and lithology are the main geologic factors contributing to slope instability in the area. These rocks are commonly affected by local folds (Plate 8.1) and are cut across by two to four sets of joints. Thrusts too are probably present in the Disang. However, due to the monotonous nature of the Disang sediments it is difficult to map such thrusts. Joints, shear zones, fault planes, and weathered horizons in this area facilitate erosion, particularly with the aid of surface runoff. Surface runoff is responsible for removal of most top soil. The joints are responsible for imparting the splintery nature to some of the Disang shales (Plate 8.2). The shales in this area are highly fissile, which is another cause of their weakness. The fissile nature of the shales coupled with the joint planes have made this terrain highly susceptible to mass wasting. Folding and faulting in the area have crumpled and fractured the shales to a great extent (Plate 8.3). These crushed zones comprise debris of various materials that are thoroughly mixed with clayey and sandy soils.

Numerous well-defined lineaments are very prominent in satellite imagery of the area. Some streams have cut deep channels along such planes. Steep gullies have formed due to base erosion by streams flowing along fault planes. Trellis drainage patterns are common in the study area. Other drainage patterns include parallel, some dendritic, and intermediate forms. Most of these patterns indicate structural control. The lower order streams generally follow major joint patterns. These channels meet larger streams at various angles forming irregular branches. Toe erosion by streams is active along the lower flanks of the hills of this area. This has facilitated well developed tension cracks.
Plate 8.1. Folding in shale

Plate 8.2. Splintery Disang shale
Joint data obtained from the field are plotted to generate a rose diagram (Fig. 1.4). The rosette shows concentration of one set of plots along NE-SW, which is parallel to the regional trend that is related to F₂ movements. Another set of joints trend NW-SE. These joints are due to tensile or shear stresses that are concentrated around the regional NW-SE compression corresponding to F₃ movements. As a consequence hybrid fractures have developed in the terrain due to the interplay of these stresses causing extensive deformation of the rocks. Jointing and fracturing have considerably weakened the rock masses thereby initiating extensive weathering to produce thick mantles of waste, making the area susceptible to sliding, particularly during the monsoon.

Studies reveal that the major triggering factors of landslides in the area are anthropogenic activity and excessive rainfall received during the monsoon. One of the factors for slope destabilization in the terrain is the removal of slope support for widening of roads. This is particularly true in areas where topographic slopes and dips of beds are in conformity, with beds dipping at equal or lesser amounts than hill slopes. The overloading of slopes or removal of lateral support by human interference is a prime concern for slope failure in many areas. Soil cover in the area permits luxuriant growth of vegetation but urbanisation and other human activities have disturbed the natural processes thereby exposing the soil to water action which ultimately results in extensive surface erosion and slope instability. Terrace cultivation for paddy is commonly practiced in old landslide areas rich in silt and clay. In such areas water is trapped in the terraces during the planting season whereby extreme pore pressure is generated. Such terraces are found in patches along the NH 2. On either side of the highway water logging leads to continuous subsidence and damage of the road during the monsoon (Plate 8.4). The area experiences high monsoon precipitation which causes abundant percolation of rainwater through the porous soils and highly jointed and fractured rocks. With the high saturation due to excess water the weathered and crumpled shales become unstable leading to mud and debris flows. However, the area is generally dry after the monsoon. During this period landslide activity is not known in Nagaland. Most landslides take place during the peak of monsoon. This is because the highly porous rocks due to large scale jointing and fracturing does not retain water, but rapid water seepage takes place into the subsurface during the monsoon.
Plate 8.3. Crumpled and fractured shales

Plate 8.4. Damage of road due to terrace cultivation
The abundance and action of water in soils is the major factor for initiation of landslides. However, this is frequently overlooked in soil exploration and safety calculations. Dry surfaces also are not indications of favourable groundwater conditions as groundwater evaporates rapidly during the dry season. It often takes many years until water becomes active (Bishop, 1957; Skempton, 1977; Bauer et al., 1980). Its control and removal are thus very important in the stabilization of slopes. The stabilization of active landslides by controlling drainage has been carried out with full success at numerous landslide zones (Veder and Hilbert, 1980). However size, permeability, and transmissivity of pervious zones and orientation of discontinuities will determine the effectiveness of drains.

As part of the objectives of this study, a report with recommended remedial/mitigation measures for five spots including locations 9, 10, 11, 12, and 13 was submitted to the Government of Nagaland on 26th May 2009 and the same of the debris slide along the Nagaland University road (Location 14) was submitted to the Nagaland University on 14th March 2011.

8.2 CONCLUSIONS

The present study attempts to create a landslide hazard database based on field investigations and using topographical maps and satellite data in a GIS environment. GIS is an effective tool that provides for proper planning and policy and decision-making through data integration and modeling. It is suitable to use these models in this rugged terrain which can be analyzed and viewed in 3D perspective. The LHZ map generated for this area using GIS can serve as a useful management tool. This map gives good indications of stability conditions of the area and clearly defines the various hazard zones. The high and very high hazard zones need to be avoided for any developmental projects. Risk analyses for selected locations along the highway and the NU approach road clearly bring out the weaknesses along these roads. Such areas need to be treated with utmost importance and sincerity to prevent any mishap. On this basis landslide management programmes can be planned to check for possible risk to human lives, property, and roads.
Road making techniques are very poor in the state. The debris from these slopes flowing down onto roads erodes the bitumen rapidly and proves to be a costly affair. Hence, it should be seriously considered to implement mitigation measures that have been provided. Other parts of NH 2 beyond the study area that are weak should also be considered for similar appropriate measures. Detailed geotechnical analyses for appropriate mitigation and/or remedial measures need to be taken up in areas proposed for urban expansion in the high hazard zones.

Fresh cut slopes along the roads are apparently stable at the moment. However, at a number of places they can create havoc if left unattended. Under such circumstances top soil or parts of slope should be removed to reduce the driving forces. Barren upper slopes should be afforested with suitable species. Plantation of fast growing, deep rooted trees such as eucalyptus, alder, cedar, willows like *Salix tetrasperma*, *Salix ichnostachya Lindl* and *Salix sitchensis*, and fir like *Pseudotsuga menziessii* in the lower reaches of slide zones will help control slides. Geo-grids, geo-textile, jute mats, etc. will help hold the rock fragments, debris, and loose soil. In some case benching is recommended depending upon the height and slope forming materials. Buttresses and retaining walls are necessary where slope material is weak.

Surface water is one of the major factors that cause landslides. Thus, appropriate drainage facilities should be provided where slope material is susceptible to erosion, particularly under unfavourable groundwater conditions. As far as possible, water should not be allowed to enter landslide zones, old or new. Surface drainage may be necessary around crowns of present slides to prevent sheet wash from entering landslide areas. It is also necessary to remove excess water from the subsurface so as to reduce pore-water pressure below which can cause slope failure.

The potential to susceptibility of landslides can be predicted with adequate weather forecasting and careful analyses of cumulative rainfall patterns to a reasonable degree of accuracy. The threat of an oncoming storm during the monsoon that may be disastrous in terms of landslide susceptibility should be viewed seriously; public warnings of potential danger should be immediately issued. Attempts were made to correlate landslides with rainfall but the exact temporal relation could not be derived due to paucity of landslide as well as rainfall data. Detailed geotechnical investigations
of rocks and soils will be helpful in deriving a threshold rainfall value that triggers landslides in this area.

A strong database is required for the remedy of landslides which involves the determination of appropriate control and preventive measures. Detailed investigations are necessary to assess such factors as the size and shape of unstable masses, the nature and composition of rock types, detailed attitude of joint and bedding planes, and water conditions of the area. Thus, a combination of geologic, geomorphic, and hydrologic studies with soil and rock mechanics is necessary. Mitigation strategies may not be possible in every landslide prone area due to prohibitive costs, engineering and economic feasibility, and social acceptability. However innovations are possible to reduce cost.

The Disaster Management Cell of the Government of Nagaland has recently initiated landslide awareness programs and trainings. Public education and publicity campaigns are also being launched for public awareness on a large scale, for landslide risk and to promote proper understanding of the nature of risk, because public participation in disaster management programs is of utmost importance.