6. SUMMARY AND CONCLUSIONS

Hilly terrain of Mizoram is prone to several types of slope instabilities. Landslides in the state lead to considerable loss of human life and property, disruption in the communication network and severe geo-environmental hazards. The main causes of landslide in the state are young geology, high relief, neo-tectonic activities, heavy rainfall and human interference. The loss of vegetation cover due to shifting cultivation and road construction has adversely affected the absorption and infiltration capacity of the hill slopes. This leads to drying up of the springs and dwindling of water resources, excessive run-off etc. from the slopes of the hilly state of Mizoram. The area receives high rainfall. Rain water increases pore-water pressure of soil and rocks and decreases shearing strength and induces landslides. Neo-tectonic activities mainly due to seismicity and tectonism leading to reactivation of old faults/thrusts etc are quite common in the state. This also accelerates landslides. Besides, the hills and the valleys in the state are composed of soft sedimentary rocks, viz. shale, siltstones, sandstone etc. This in conjunction with high relief further aggravates the situation. Most important aspect of human interference is unscientifically planned and crudely executed road construction. This leads to destabilization of hill slopes and generation of huge amount of debris. It is estimated that construction of just 1 km long road requires removal of 40,000 – 80,000 m³ debris. This debris moves down the slope destroying the vegetation and blocking the mountain streams. Owing to the combined effect of the above, Aizawl city experiences a large number of landslides on the onset of every monsoon season mainly along the highways. It is in this context that a study has been under taken with the aim for preparation of landslide hazard zonation on 1:50,000 scale in GIS environment in and around Aizawl city; detailed investigation of some selected landslides; and finally preparation of landslide disaster management plan.

Mizoram, geologically is a part of Tripura - Mizoram depositional basin and it has been considered as the southern extension of Surma Basin. The entire sedimentary column of the area is a repetitive succession of arenaceous and argillaceous rocks of Palaeogene and Neogene ages. It consists of sandstone, silty-sandstone, siltstone, shale, mudstone and their admixture of varying proportions along with a few pockets
of shell-limestone, calcareous sandstone and intraformational conglomerates. This succession is thrown into a series of approximately N-S trending, longitudinally plunging anticlines and synclines (Ganju, 1975; Ganguly, 1975, 1983). The general strike direction of the rock successions is N-S with dip amount varying from 20°-50° either towards east or west. The study area exposes rocks of Middle and Upper Bhurban Units of Bhurban Formation (Surma Group) and forms both eastern and western limbs of Aizawl Anticline. The area is characterized by alternate succession of argillites and arenites. The Upper Bhurban sediments occur in the southern and southern-eastern extremity of the area along Durtlang-Sihphir road section and along Zemabawk-Tuirial road section. The rest of the area is covered with the underlying Middle Bhurban Unit. The contact between the two units is conformable and transitional. The same is marked in the field by gradual change in the rock facies i.e. argillaceous predominance to arenaceous predominance. The demarcation and correlation of these two units is, however, extremely difficult owing to more or less uniform lithological characters, absence of marker horizons and also index fossils.

Thematic maps have been prepared for creating Landslide Hazard Zonation map. First of all, Digital Elevation Model (DEM) and 3-D map of Aizawl city area has been prepared in GIS (ArcGIS 9.1) environment from the contour map prepared from SOI Topo Sheets (Number 84/9, 10, 13 and 14) at an interval of 20m. Slope map and slope aspect map has been prepared from DEM. Relief map has been prepared with the help of the contours from the SOI Toposheets. Land use map has been prepared from the satellite imageries using ERDAS Imagine (9.1 version) software. Lithological and structural maps have been prepared from the field data and also data extracted from the satellite imagery (IRS 1D, LISS III, FCC geo-coded). Drainage map has been prepared from the SOI Topo Sheets. Microgeohydrological units were delineated from the drainage map and drainage density and drainage frequency maps have been prepared. Landslide population map has also been prepared on the basis of field survey. However, some active and abandoned landslides were also picked up from the satellite imagery. Landslide Hazard Zonation map of the study area has been prepared using data import and Heuristic (knowledge driven) method in which various parameters/thematic layers of GIS database have been incorporated viz. boundary, contours, roads, drainage, faults, lineaments, landslides, landuse types,
lithology, slope, slope-aspect and relief. The thematic layers are integrated after categorizing them into classes with their different respective ranks and the intersection of same ranks from each class are derived by overlaying the thematic maps using ArcCatalog GIS software.

DEM of the study area (Fig. 4.1) shows that highest elevation is 1420m whereas minimum is 480m. Study area has been divided into eight (8) slope percentage classes. Nearly thirty-three per cent of the study area has more than 70 percent slope, 35.136 percent area belongs to 50 – 70 percent slope category and 19.586 per cent of area belongs to 35 – 50 slope class. Thus 88.447 percent of the study area has slope more that 35 percent. Slope map shows that western flank of the northern part of the study area (i.e. Siphir and Durtlang) have steeper slopes as compared to southern part (Kulikawn, Ngaizel, Melthum and Hlimen) where eastern flanks have steeper slopes. Five categories of relative relief have been chosen for landslide hazard evaluation purposes in the study area. These are Very Low (480 – 660m), Low (660 – 800m), Moderate (800 – 980m), High (980 – 1200m), Very High (>1200m) respectively. Nearly 37.18 percent of the study area possesses moderate relief, 29.07 per cent high and very relief whereas 33.75 per cent low and very low relief. Land use/land cover map of the study area is categorized into ten land use classes. It shows that 12.78 sq. km (i.e. 45.28 percent) of the study area is the waste land of one or the other types and, 7.74 sq. km (i.e. 27.42 percent) is under settlement. It is interesting to note that 18.18 percent (9.14 per cent currently and 9.04 per cent abandoned) of the area in and around Aizawl city is covered under shifting cultivation and 10.05 per cent under dense forest. Sandstones are the only resistant rock in the area which is less prone to landslides whereas shaly sandstones, crumpled shale and siltstones are more prone to landslide hazard in the area. Sandstone occupies 4.98 sq. km (17.65 per cent) whereas crumpled shale occupies 2.10 sq. km (7.44 per cent) of area. The remaining area is occupied by siltstone-sandstone (6.64 sq. km 23.53 per cent), shale-siltstone (9.96 sq. km 35.29 per cent) and sandstone-shale (4.54 sq. km 16.08 per cent) alternations. Among many types of discontinuities, faults and lineaments are the most prominent ones in the study area. Four faults namely Chite fault, Chamhari fault, Selesih fault and Sihpui fault have been delineated in the study area. Among these Chite fault is the most prominent one. All these fault broadly trend
in NW-SE direction. Higher concentration of landslides along these faults indicates their active nature. Several lineaments have also been mapped in the study area and many of these have been highly ranked for slope instability. Most of these lineaments have four preferred orientations i.e. NW-SF, NNW-SSE and NE-SW and ENE-WSW. It has been also been noticed that many of the higher order streams follow the courses of these lineaments. High incidence of landslides in the study area may be attributed to the higher concentration of faults and lineaments. The slope aspect of the study area is categorized into ten classes viz. flat, north, northeast, east, southeast, south, southwest, west, northwest and north. Although landslides occur on all slope-aspect classes excepting flat one, major occurrences of the landslides have been recorded in Northeast, East, Southeast, Southwest, West and Northwest slope aspects. This may be because of the fact that rock beds within Aizawl city are more or less dipping either eastward or westward. The slopes in these aspects are also found to have higher values than the other slope aspect classes.

The study area has been divided into 46 micro geo-hydrological units for the purpose of landslide hazard zonation. Total length of streams, number of streams, drainage density and drainage frequency in each micro geo-hydrological unit has been calculated. Eight micro geohydrological units covering 5.591 sq. km area having drainage density more than 6 may be considered to belong to very high category whereas twenty four units covering 17.299 sq km area having density between 4 to 6 may be considered to belong to high category. Ten (4.40 sq. km) and four (0.90 sq. km) units have densities between 2 to 4 and <2 respectively and may be considered to belong to medium and low drainage densities respectively. Five units having 2.123 sq. km area have drainage frequency >30 and are said to belong to very high category whereas 13 units with 6.795 sq. km area have frequency between 20 to 30 and are said to belong to high frequency category. Twenty five units with an area of 12.356 sq. km have frequency in the range of 10 to 20 and belong to medium category whereas two units with an area of 0.281 sq. km have frequency < 10 and thus belong to low category. It has been deciphered from the landslide population map that high incidences of landslides are known to occur in the units having high and very high drainage density and frequency as well.
Five hazard zones namely, Very Low Hazard, Low Hazard, Moderate Hazard, High Hazard and Very High Hazard have been shown in the hazard zonation map. Very High and High hazard zones together constitute 6.43 sq. km (22.80 per cent) of Aizawl City out of this very high hazard zone covers only about 5.78 % of the total study area. It covers localities around the faults like Armed Veng South, Bawngkawn, Thuampui, Ngaizel, Chamari, West, Ramthar, Dinhthar, Hunthar and neighbouring localities. It is amply clear from the Fig. 4.13 that very high and high hazards zones are mostly confined to road sides in the study area. Moderate hazard zones cover nearly 38.66 per cent of the study area whereas low and very low hazard zones are occupied by 33.75 per cent and 4.78 per cent of the area.

High incidences of landslides have been noticed in the eastern flank of the study area (i.e. Siphir, Durlang, Ramhlun, Ramthar, Armed Veng, Bethlehem Veng, Venglui and Ngaizel and Melthum) and also in the western flanks (Hunthar, Dinhthar, Company Peng, Vaivakawn, Mission Vengthlang and South Hlimen). This may be due to the fact that slopes are steeper in these parts as compared to other parts. Relief is also high and very high in these areas. Landslides are mostly concentrated along the road sides in the above areas and also in the areas where shifting cultivation is being practiced giving a very high degree of correlation between landslide occurrences and anthropogenic activities.

Disaster Management (DM) attains great importance in landslide prone hilly state of Mizoram. DM should be a part of the total development perspective of the state. Development needs of the state should be assessed and specific planning approaches be evolved keeping in view its physical characteristics, resources endowments, population pressure and the types of disasters. States level board should be established to co-ordinate the activities of disaster management. Accordingly, a comprehensive Landslide Disaster Management (DM) plan for the study area has been prepared. This plan focuses on various aspects of disaster management including preparedness, mitigation and response. It aims to clearly identify the roles of key stakeholders for each disaster level and also include assessments of their own response capacities. Since the study area is one of the highly landslide affected areas within the state, the Government of Mizoram and the NGO’s within the area have to encourage the preparation of community preparedness plans to address their own
special features, outlining the linkages of the various state support systems, and the jurisdictions of each of these departments in order to avoid confusion and conflicts during the disaster. The plan has pre-landslide, during landslide and post-landslide components since these three phases involve different initiatives and requirements.

Important components of Pre-Landslide Phase are: Preparation of landslide inventory and creation of data-base on existing landslides on watershed basis ought to be taken up. Aerial photographs, satellite imageries, GIS may be used for this purpose together with extensive fields work. Preparation of Landslide Hazard Zonation (LHZ) maps by integrating knowledge and information from various disciplines like geology, geomorphology, geophysics, engineering, meteorology and hydrology should be taken up. This in turn will help in identifying slide-prone areas in the state; Identification of control and corrective measures and forewarning system for landslides; Construction should be planned on the basis of LHZ maps on very low and low landslides hazard zones. It has to be avoided on medium, high and very high hazard zones which are generally steep and distressed hill slopes. It should also be avoided near active landslides and on the valley fill materials. It should follow general principles of seismic designs; Hill slopes should be provided with proper drainage measures because water seepage causes stability problem. Hillside catch water drains and culverts should be constructed. Quarrying for construction material need to be constructed with suitable cut slope for stability and retaining wall should be build wherever slopes are steep; Deforestation should be avoided. Jhuming have to be replaced by Agro-forestry models suited to local conditions. Use of fire wood should be replaced by hydro-electricity for safety and environmental protection; and Training programmes in landslides for user agencies should be organized. Awareness campaigns need to be launched to educate the public about disastrous effects of landslides. Mass media have to pay leading roles in this context. Volunteer groups and search and rescue teams should be formed to work during landslides. The activities assigned for During Landslide Phase are: Warning signals for the public should be posted using mass particularly during rainy seasons when landslides are more frequent. Public have to be advised not to visit landslide-prone areas during heavy rain. People from the prone areas need to be evacuated to safe places during prolonged heavy rain; Emergency respond procedures should be activated. Volunteer groups, search and rescue teams need to be made operational to provide support to the
victims. Fastest means of communications should be used to monitor the functioning of such terms; Supply of essential items like food stuff and medicines should be started and maintained till normalcy is restored; and Monitoring of landslides ought to be done and day to day developments should be brought to the notice of the public.

"Post Landslide Measures" are: Posting of warning signals should be continued. Reconstruction of damaged structures ought to be taken up on war footing. However, construction on slide-prone areas should be avoided; Critical evaluation of emergency response procedures need to be taken up in order to bring improvement on it; Aforestation schemes in the surroundings of major landslides using site specific species may be taken up in order to stabilize the slopes. This will also improve the aesthetic value and micro-environment of the area; and Monitoring of some most problematic landslides using instrumentation should be done. Research and development work need to be conducted for evolving control and corrective measures and for modeling of risk assessment.

The causes of slope failure near Sairang are the presence of bedding shears and clay pockets/beds with swelling and shrinkage properties. This in conjunction with the poor shear strength of the slope forming material in natural moisture content caused frequent slope failure at this locality. Further, decrease in the shear strength of overburden and bed rocks during rainy season due to water saturation also contributed significantly to the frequent failure of slope at this point. Frequent lithological variations lead to frequent change in the stability conditions. Factor of safety for sandstone is 0.62, which is less than that of shale i.e. 0.89. This can be understood by the several factors. Among which most conspicuous one is the fact that slope height at the sandstone horizon (22.5 m) is considerably higher than height at shale horizon (5.5 m). Despite the fact that average cohesion of sandstone horizon which is 5 x 105 Pa, is double than that of shale horizon, the slope at sandstone site is more vulnerable than shale site. Removal of shale horizons by scouring action during heavy rains adds to the instability of the slope in this area. Stereo plot indicates planar failure because it is along the prevalent and continuous joint set (J1) dipping towards the slope. Moreover, the strike of this joint set is near parallel to the dip of the slope face and dip is less than the dip of the slope. Thus, joint set J1 (=S0) is most critical for the stability of the slope. Suggested remedial measures for this land slide include provision for suitably lined catch water drains of adequate capacity sloping towards
hill with chute for channeling surface water flow from slide zone; provision for deep
drains to minimize saturation of debris material; lining of rala that is formed at the
middle of the slide zone to keep free flowing condition, to prevent toe erosion and
also to prevent water percolation through debris; checking of toe erosion by providing
suitably designed breast and retaining structures as a guard against toe erosion and
aforestation in the slide mass using fast growing trees and grasses.

Slope stability problem at South Hlimen quarry arises mainly due to the
blocky nature of the sandstones. In fact, the huge blocks of sandstones have been
formed as a result of two intersecting planes of structural discontinuities, viz., roughly
N-S trending bedding joint planes (77°/45°) and E-W trending vertical joint planes.
With the continuous removal of the toe material, the natural support for the uphill
blocks was loosing strength and thus the stability got disturbed and ultimately these
were subjected to free fall along the bedding plans. Moreover, tropical climate and
heavy rainfall had further reduced the cohesive strength of the joint planes. Shaly
intercalations between the sandstone beds might have provided active slippage
surfaces to the failure. Additionally, the explosive are being used to speed up the
excavation operation. As a result of excessive blasting, a number of minor and major
cracks have developed. These also facilitated the fall of huge sandstone boulders. As
this is the biggest stone quarry in the neighborhood of fast urbanizing Aizawl city,
quarry operation may not be stopped here. In order to enhance the stability of the
slope, the explosives should be used within permissible limit and quarry operations
should start form top towards bottom making benches in order to check landslide in
this locality.

The problem of instability at Bawngkawn stems from the intersection of three
sets of joints dividing the rock beds into blocks of varying dimensions. The critical
joint set (J2) provides a continuous plane for failure and dips towards the slope at a
lower angle. Along this plane soil debris and rock blocks rapidly fell down the slope
due to gravity pull. The feldspathic sandstones under the influence of warm and
humid climate were subjected to weathering and decomposition due to percolation of
surface water along the planes of discontinuities leading to formation of clayey bands
along such planes. These clay bands and thinly laminated shaly intercalations were
responsible for increasing pore water pressure and in turn reducing the shear strength
of the rocks. Rock excavation and repeated blasting were frequently carried out to accommodate a petrol pump along the road side in the left flank of the slide area, this facilitated erosion and widening of discontinuity planes. Removal of slided debris to reduce the dead load; improvement of drainage by providing catch water drains at the crown, toe and two sides of the slide area for channelizing the rain water has improved stability conditions at this site.