Kohima Town and its surroundings are made up of a young geologic terrain with pervious soils and unstable rocks. Landslides and mass movements are very common particularly during the monsoon. They occur due to adverse geology, heavy and prolonged rainfall, indiscriminate cutting of slopes, unplanned developmental activities, and deforestation. Increasing population and rapid urbanization has added to landslide incidences that has lead to huge loss of property. Therefore, it is necessary to determine the causative factors by analyzing the geological and geomorphologic parameters, and human activity. Many integrated studies have been carried out on the impact of population density, urban growth, and land use/land cover changes on landslides using remote sensing and GIS. The present study is carried out to evaluate the factors responsible for land instability and to generate a LHZ map. This will help assess the vulnerability and risk.

The rock types of this area include the argillaceous sediments of the Disang Group and some arenaceous Barail sediments. These rocks trend NNE-SSW to NE-SW. The Disang Group of sediments is the oldest in the study area. They are a monotonously thick sequence of splintery shales that are usually dark grey in colour. They exhibit concretionary structures and box-work weathering. They are also highly jointed, folded, and faulted. The shale alternate with minor siltstones and fine grained sandstones. Reddish brown colour is noted at places which are due to leaching of iron oxide. The dark grey and black shales that are organically rich are weathered to clays at numerous places. On saturation with water these clays become slimy and act as lubricants. This also leads to the building up of high pore water pressure that reduces inter-grain friction. This causes loss in their shearing strength and collapse of the soil structure. Sharda and Bhambay (1980) opine that the shear strength of the saturated Disang shale and soils of Kohima is very low. Crumpling of the shale and excessive
saturation generates conditions favourable for shear failure of slopes due to in
of pore pressure and consequent decrease in shear resistance of the slope material.
Lithology, structure, and slope play an important role in causing weakness in the area.
The drainage system in the area is also poorly developed. Surface runoff is very high
because of the impervious nature of the shale and their weathered products, the clays.
This causes the erosion of the top soil, particularly along those slopes with
unconsolidated overburden. However, in areas of mixed soil and highly jointed and
fractured rocks abundant percolation of rain water is noted. The shale in the area are
highly puckered and fissile due to which, on exposure to air, they disintegrate and
weather easily. On saturation, they start flowing to cause debris and mud flows. Soil
creep is a very common phenomenon in the Disang. This is observed by the curved
trunks of trees, bulging retaining walls, etc.

The Disang Group is conformably overlain by the Barail Group of rocks that consist
of well bedded greywacke. The Barail, as a whole, are made up of sandstones with
alternations of siltstones and occasionally, papery shale. They are confined to a small
patch on the southern part of the area. As sandstones are tough in nature landslides are
not frequent in this area. However, due to the presence of prominent joint planes and
vertical rock faces caused by road cutting, etc., rock falls occur in the steeper areas.

A number of faults are noted in this area. Many thrusts too probably cut through the
Disang. However, due to the monotonous nature of the Disang sediments it is difficult
to map such thrusts. The fault zones are marked by the presence of crushed material
and displacement of beds. Deposits of dark grey clay are noted along some fault zones
in the Disang.

Structure and lithology are the main geologic factors contributing to landslide
incidences in Kohima town. Rocks of the area have been affected by small-scale
folding and faulting and are intensely sheared. Most of the rocks of this area have also
been rendered weak due to three to four sets of joints. Many of the slides in this area
are deep-seated, multiple rotational slumps of old surfaces of weathered and jointed
rocks. The joints are responsible for giving the Disang shale its splintery nature.
Extensive leaching of limonite along the joint planes of shales and thin-bedded
siltstones and sandstones are noted. The fissile nature of the shales coupled with the
joint planes have made this terrain highly susceptible to mass wasting. Crushed zones are numerous in this area. These consist of colluvial debris comprising rocks of various sizes mixed with clayey and sandy soils. These crushed zones, in a number of cases, have been identified as palaeoslide sites. Landslides commonly occur in areas where the rocks are intensely fractured and sheared. As most thrusts, faults, and shear zones are associated with the presence of breccia and other crushed material, the shearing strength of such material is reduced in the presence of water.

Investigations have revealed numerous faults in the Disang sediments. Numerous well-defined lineaments are very prominent in the satellite images of the area. Most of these are faults that occur in parallel groups. Numerous streams have cut deep channels along some fault and other planes of weakness. Vuichard (1986), while studying the lower vegetated areas of the Nepal Himalayas, has observed that fracturing caused by the intersection of folds and faults are often responsible for steeply cut gullies. During the monsoon, these youthful streams vigorously erode the highly jointed Disang sediments and transport the debris to lower lying areas. Streams frequently run through shear zones in the Disang. These are responsible for some of the slides and general sinking of these areas.

Geological structures control stream channel configurations in the area of investigation. The higher order streams commonly follow major joint patterns and fault traces. These channels meet larger streams at various angles forming irregular branches. The drainage pattern includes dendritic, parallel, trellis, and intermediate forms. Zernitz (1932) opines that, development of dendritic patterns is due to the uniform resistance of rocks on a regional slope. A number of deep gullies have dissected the hill slopes. Toe cutting by streams is active at the lower levels. The area experiences heavy rainfall which causes abundant percolation of rain water through the soils and highly jointed shale. Because of high saturation the weathered Disang shale is unstable. This leads to mud and debris flows. Such material, made up of slurries of soil, rock, and organic matter combined with air and water, flow very rapidly. In movement they resemble viscous fluids. Such flows are facilitated by the steep gullies in this area.
Rising groundwater tables, particularly during the monsoon, unlined gullies, and naked slopes together allow rainwater to saturate the subsurface. This results in the development of undesirable pore pressure that reduces the shear strength of slope forming material. Hence, it is imperative that the naked slopes be covered by vegetation. Priority should be given to stabilise slopes by improving the surface and subsurface drainage conditions. Undesirable surface waters should be drained into natural stream channels using lined drains. The area should also be reshaped so as to control surface runoff. Tension cracks and other permeable zones at and around the crests of slopes may be temporarily or permanently sealed by mortar, asphalt, etc.

The two triggering factors of landslides include human activity and excessive rainfall. The frequency of natural disasters seems to have greatly increased in recent decades due to environmental degradation (Vincent, 1997). The magnitude of disasters is dependent on the susceptibility of land and vulnerability of society (Versstappen, 1995). In Nagaland the age long practise of jhum or shifting cultivation still continues rampanty. Agricultural practices of any given area have determined the degree of mass wasting, soil erosion, siltation, and other ecological imbalances. In any area faulty land use practices such as jhum cultivation, water storage in paddy fields and lower areas, constructional activities on steep slopes, etc. have caused irreparable loss to the environment and aggravated the problem of landslides. Anthropogenic activity has helped bare the slopes thereby aiding the natural processes to cause landslides. The sharp increase in population aided by rapid unplanned constructional activities has also contributed in destabilising the area. Most road constructions are substandard and have greatly increased landslide incidences. The combined effect of erosion of the steep slopes, weight and vibrations caused by vehicular traffic on the semi-consolidated mass, and build-up of pore pressure are major factors that contribute to slope failure. The existing vegetation cover too has been disrupted by landslides and gullying in areas where erosion is initiated or accelerated by activities including road constructions and depletion of natural vegetation by clearing, grazing, and burning. Thus, any activity that increases hillside gradients, undercut earth materials, adds weight to the slopes, or produces more water, can lead to instability and set the stage for land sliding. Road constructions have directly or indirectly caused landslides. The soil cover in the area can support a luxuriant growth of vegetation, but the rapid growth of population and other activities of man have disturbed the natural processes
thereby exposing the soil to water action which ultimately results in extensive erosion and slope instability. Terrace cultivation along slopes where shale is predominant have a disastrous effect upon soil stability. This is because the water stored in paddy fields generates great pore pressure on the soils thereby inducing landslides. It is noted that most areas under terrace cultivation are actually palaeoslide zones.

Water action on soils is the major factor for initiation of landslides. However, the presence and action of water is frequently overlooked in soil exploration and safety calculations. The absence of water during a certain period does not rule out the damage that may be caused at a later date. 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). The size, permeability, and transmissivity of pervious zones and orientation of discontinuities will determine the effectiveness of drains. Dry surfaces are not indications that favourable groundwater conditions exist as groundwater evaporates rapidly, especially in dry climates.

Intense monsoon precipitation sometimes accompanied by cloudbursts is a factor that has initiated most of the landslides in the area. The downpour is so heavy that large-scale devastation occurs during cloudbursts. Occasionally they are noted to continue for up to two hours in the region (Aier, 2005). Investigations of the phenomena have revealed that this damage is worse than that inflicted by the combined effect of rainfall of the whole year. Continued rainfall of lesser intensities has also triggered off landslides at numerous places. Because of the high amounts of rainfall and the occasional cloudbursts, surface run-off is very high as also the case with waters percolating into the subsurface.

Under different geological, meteorological, and hydrological conditions rocks and soils behave differently. The reduction of the impact of landslides is possible with careful monitoring of the behaviour of material under adverse conditions. Bhandari (1984) has given importance to instrumentation and field monitoring of landslides and other mass movements. The emphasis is on multi-functional monitoring instruments
that are capable of measuring movements ranging from slow creep to rapid sliding of material, as well as direction of movement and vertical subsidence.

Bhandari (1987) insists that planners must now be able to recognize and appreciate the problems of hilly regions and that authorities should ensure that no plans are cleared unless adequate provisions are made for fullest investigation and protective measures. In landslide prone areas it is necessary to determine whether the driving forces that seek to change hillside equilibrium exceed the resisting forces that operate to maintain slope stability. This means that rock excavation should be minimised. In the investigation of sites for townships, highways, mines, etc. geologists and engineers should be able to compute the safety factor of material and predict rock and soil behaviour along slopes. Brazil passed National decrees as early as in 1955 that stipulate the requirement of investigations to determine the stability of sloping land before any construction. The rational design of rock slopes is particularly important where slopes are steep and cost of slope design is optimum. The resultant long-term savings would probably justify the greater initial investments in time and money, in as much as maintenance and repair costs for land sliding and landslide-caused damage have been shown to be high and commonly recurrent (Nilsen and Brabb, 1972; Taylor and Brabb, 1972). According to Alcedo (1998) well implemented disaster mitigation programs will effectively contribute to reduce the physical, social, and economic vulnerability of disaster prone areas.

CONCLUSION

The present investigation is an attempt to create a landslide database based on field investigations and using topographical maps and satellite data in a GIS environment as there is lack of information on landslides. A landslide database is necessary for proper planning and coordination, the ultimate aim of which is to reduce the impact of this natural phenomenon. 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 3-D perspective. The landslide hazard maps generated for this area using GIS can serve as
management tools. Such data can be replicated for use elsewhere under similar
environments.

Landslide investigations should be aimed to the promotion of disaster preparedness to
establish a network for efficient operation for all disaster related activities in the pre-
disaster period, during an actual disaster, and afterwards. From the Landslide Hazard
Zonation maps generated the highly susceptible areas identified should be marked
clearly. These areas must be considered in terms of possible risk to property and
human lives. Management programs must be planned for both short and long term
remedial measures for the areas identified as high risk zones. Thus it is necessary to
have implement-able plans in place and for which resources are available. Disaster
preparedness is necessary for protection of lives and property from immediate threats.
Disaster mitigation techniques are important to reduce the impact of landslides in the
long run and to anticipate future situations and requirements.

Geotechnical investigations are very important for the prediction of landslides. Such
investigations will help device appropriate control and preventive measures.
Geotechnical investigations should aim at analyzing the shearing strengths of the
various clays and soils. The safety factor for all types of soils should be calculated
before the execution of any developmental work. Investigations should include
detailed analyses of slope stability characteristics of the terrain and incorporate 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 the water conditions of the
area. Thus, a combination of geologic, geomorphic, and hydrologic studies with soil
and rock mechanics is necessary. Such data should be evaluated in terms of a total
benefit-cost ratio.

With adequate weather forecasting and careful analyses of cumulative rainfall
patterns it may be possible to predict to a reasonable degree of accuracy the potential
hazards due to landslides. The threat of an oncoming storm well into the monsoon that
may be disastrous in terms of landslide hazards should be viewed seriously and public
warnings should be issued of the potential danger. Structures situated in areas of
former slide zones and adjacent areas are in great risk. People in such areas should be
evacuated without delay during intense monsoons.
In the present investigation an attempt was made to correlate landslides with rainfall. However, the exact temporal relation could not be derived due to the lack of landslide data. Moreover, rainfall data is available from just one station. In this area the monsoon is a long and monotonous event that continues for several months. Long spells of rain are broken with very short dry intervals. However, such dry intervals are not enough to dry out the ground which remains fully saturated. For efficient investigations leading to better planning it is necessary to install more rain gauges at various places to obtain more accurate and detailed data.

Surface water should be efficiently dealt with as it is one of the important slide inducing factors. Water should be prevented from entering present and old landslide zones as far as possible. The present study has revealed that most landslides occur in very hazardous zones most of which are palaeoslide areas. The loss of shearing strength of the material in such zones causes failure. Thus, such zones including the palaeoslides should be thoroughly mapped as they are highly disaster prone. Water should not be allowed to penetrate into the subsurface but must be drained into proper lined surface channels particularly around the crown of slides to prevent sheet-wash from entering slide zones. The water table should be lowered to reduce the pore-water pressure below that which can cause failure. For this it is necessary to remove excess water from the subsurface.

Terrace cultivation and horticulture may be practiced on slopes ranging from 15°-35°. The area should be properly afforested through proper schemes with suitable fast growing, deep rooted trees like eucalyptus, alder, and willows including *Salix tetrasperma* and *Salix ichtnostachya Lindl*. For the other areas the type of activities to be carried out should be clearly defined. Activities that could be hazardous should be prevented. Slopes that are greater than 35° should be left undisturbed as far as possible. Construction and allied activities in the high hazard areas should be regulated and monitored. The techniques of road construction in high hazard zones should be improved. In such areas it would be worthwhile to avoid earth cutting for new roads. In badly deformed areas realignment of roads may be a better option.
Innovations are essential to reduce cost, improve speed of construction, and promote utilization of slope waste to the extent practicable so that strain on scarce materials and the need for their long distance transportation could be reduced or even eliminated.

ADDITIONAL RECOMMENDATIONS

The frequency and adverse effects due to landslides can be minimized to a great extent by adopting certain additional remedial measures. Based on the analysis of the results, certain additional recommendations are made.

Legal / Regulatiorhy Approach

1. It is necessary that the Government set up a Landslide Management and Regulatory Board. This Apex Committee should be supported by regional committees and subcommittees with online networking systems.
2. The Government should establish research programs for landslide assessment, landslide hazard zonation mapping, and collection and dissemination of information using modern technologies such as Geoinformatics.
3. Real-time monitoring of active landslides by GPS networking methodology is a must.

Environmental Approach

4. For any management plan an Environmental Impact Assessment (EIA) must carried out before execution of works.
5. Buffer zones should be created around landslide sensitive areas to prevent any human activity. This will effectively help land use and EIA planning activities simultaneously.

Land Use Planning Approach

6. Biotechnical slope stabilization should be encouraged as it is cost effective as compared to the use of structural elements. This will increase environmental compatibility and allow the use of locally available materials.
Engineering Approach

7. Loose debris should be removed from the head of weak zones to reduce the dead load. Terracing or benching may be taken up for slope reduction.

8. The drainage system should be improved by constructing catch-water drains at the crown, body, and toe of slide zones to channelise rainwater. The drainage system should be so planned that surface runoff should be led to such sites where running water will not affect the area. Subsurface waters should be properly drained so that the soil is not allowed to saturate. Water from above the slide should be channelised along drains on either side of roads.

9. Toe and surface erosion must be controlled by constructing grip walls at the lower reaches of slide zones.

10. The drainage at the feet of fault scarps and at the heads of slide zones should be carefully diverted. Water should be prevented from seeping through. Surface and subsurface drainage are important to divert undesirable surface flows.

11. It is recommended that impermeable material such as mortar or asphalt be sprayed at the crown and head regions to seal or plug tension cracks and other permeable zones that provide avenues for excessive water infiltration. Polythene sheets have been successfully used as temporary measures.

12. Affected slopes have unconsoliated overburden which offer easy access to percolating waters. Surface runoff easily saturates such slope forming material thereby leading to instability. Grasses and bushes on slopes should not be removed as far as practicable to keep the area covered with natural vegetation.

13. Catch-water and deep trench drains are effective in certain slide zones as they help prevent further sliding and erosion of debris. They should be interconnected to intercept and divert surface waters along hill slopes. Such drains should be properly lined. Waters flowing along such drains should be led into properly lined culverts at road level from where waters can be led into surface stream channels.

14. The stability of affected slopes can be improved by installation of bamboo or wooden stakes. Such measures are purely temporary and are to be used for short term benefits only. Such nails or stakes help in stabilizing slopes by
preventing surface erosion of material in slide areas. Bamboo-check-dams help check the downhill slide of material.

15. Retaining walls increase the resistance to slide movements. Such structures should have deep foundations with weep holes for smooth passage of water. To increase their efficiency they must be anchored with tie rods to adjacent stable terrain. The backside of retaining walls must contain adequate drainage to divert water build up. Retaining walls of appropriate design should be constructed to protect slopes.

16. Retaining walls should be constructed along the sides of roads to prevent debris from flowing down. Such structures should penetrate beyond the surface of sliding. Provisions should also be made to allow excess groundwater to flow out thereby lowering the water table during the monsoon. This may also be achieved by siphoning out excess water. This will considerably increase the shear resistance of soils.

17. Most landslides are directly related to flowing water including surface flows and underground seepage. Construction of watertight drains to collect surface and seepage water and their release through culverts or diversion into nearby streams can be undertaken.

18. Construction of heavy structures, particularly on unstable slopes should be avoided in order to reduce the load on slopes. Care should be taken at excavations so that slopes are made gentle.

19. Mitigation measures and maintenance should be cost effective. Economic feasibility should take into account the cost of the remedial action to the benefits.

Social Approach

20. Awareness should be created amongst the people about the hazards.

21. Warning should be given to the public of potentially hazardous areas.

22. The public should be educated about landslides so that personal safety measures may be taken.

23. Public participation in disaster management programs is necessary.