CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Based on walkover surveys, field and laboratory investigations and data evaluation using statistical models based on Fuzzy logic technique during the course of this study, following conclusions are drawn:

- The causal factors affecting the slope stability in the study area fall in the category of conditioning and triggering factors. These are enumerated below:
  - **Conditioning Factors**
    - Aggressive Weathering Environment
    - Weatherable / Erosion susceptible Rocks
    - Poor Surface Drainage
    - Poor Subsurface Drainage
    - Insufficient and Inefficient Slope Retaining Structures
    - Removal of Trees / Vegetation
  - **Triggering Factors**
    - Intense / Long Duration Rainfalls
    - Rapid Snowmelt
    - Sudden Change in Slope Configuration: Slope Toe Cutting, Slope Steepening (during construction etc.)

- Aggressive weathering environment prevails in the study area. Areas having elevations ranging between 2000 to 2200m fall under Maritime climatic region; characterized by 'strong chemical weathering' and 'maximum mass movements'. Higher altitudes come under Boreal climatic zone; dominant by 'freeze thaw weathering' action. Lower altitudes have moderate climate and due to high temperature and less rainfall suffer 'maximum pluvial erosion'.

- Weathering and erosion susceptible shale rocks are in abundance in the study area. Shale is found to be to be highly slakable and least durable of all the mudrocks in the area. Siltstone present in the study area is found to be highly resistant to the weathering and slaking processes. Shale and its weathered product, clay, are directly or indirectly responsible for the slope instabilities in the area. Shale strata when coupled with poor drainage conditions create optimal environments in which maximum landslides occur.

- Properly designed and maintained surface and subsurface drainage system is non-existent in the area. Poor drainage measures for storm water, snowmelt water, and wastewater drainage are resulting in high moisture saturation levels in the slopes. Geophysical testing results have indicated high water saturation levels at various depth horizons in the subsurface strata of the study area. High saturation levels of water sensitive strata are causing substantial reduction in their strength properties.

- Vegetation removal in the study area is resulting in facilitation of landslides.

- Massive sandstone rock boulders lying in close vicinity towards hill side of the roads are acting as damming structures for the surface flowing water, causing it to pond and percolate in the strata and flow through the strata underlying the road structure. This process is washing out the fines and resulting in road settlements and failures. Electric resistivity test

values have indicated high to very high saturation levels underneath the road structure at these locations.

- Landslide Hazard Potential (LHP) maps produced as a result of this study are an excellent tool for the decision makers, planners, developers and designers, and can help at macro and micro level planning and construction of infrastructure, communication and building projects in the area. These maps can also be utilized for mitigation of general and localized processes responsible for slope instability in the area.

- The slope stability in the area can only be achieved by formulating a comprehensive long-term strategy, encompassing all aspects related to land-use, environment and disaster management. Short-term stabilization measures applied to the chronic landslide locations are not helping in stabilizing these areas. Till the time root cause(s) of the problems are not addressed / eradicated, the localized efforts will result in extending the instability processes to the areas adjacent to the existing landslide zones.

- The tectonic boundary between Indian Plate and Eurasian Plate known as Main Boundary Thrust (MBT) passes in close proximity to the study area. The earthquake of Oct 08, 2005 in the neighboring areas of Azad Jammu and Kashmir and NWFP was the manifestation of this thrust fault. Presence of MBT and its associated faults makes the area highly vulnerable to high intensity earthquakes.

- The population density is not uniform in the study area. It has both spatial and temporal variation.

- Concentration of population over a small location is a major factor in increased landslide induced risk.

- Construction of uncontrolled multistorey buildings, violating building codes are contributing maximum in creating landslide risk.

- Concentration of multistorey buildings and high population density are producing high risk zones that otherwise are medium zones.
- Landslide risk of the area is not uniform through out the year. It varies with population density and subsurface saturation levels.
- Areas around GPO chowk fall in both high hazard and high risk zones.
- Few locations between Station Headquarter and Sunny Bank Road are falling in high hazard zone. One of the contributing factors is flow / disposal of sewerage and wastewater of hotels and restaurants located at Mall Road towards this area. It has made the whole clayey / shale strata very soft / fragile.
- Lower Jhika Gali Road is facing threat of boulder fall slides.

5.2 RECOMMENDATIONS

Murree and surrounding area has fragile geologic strata subjected to aggressive weathering environment. Fragile stratum coupled with unplanned and uncontrolled human activity could result in major landslides in the area. The results of the study highlight that the complete area is susceptible to future landslide hazards. Due to high probability of future landslides / slope instability, landslide associated risks are also very high. There is an immediate need to address the issue and prepare a comprehensive long-term strategy, encompassing all aspects related to land-use, environment and disaster management.

The mitigation efforts to control landslide hazard and risk in the area should include the following:

- Formulation and application of land use, building design / construction and environmental by-laws addressing all the vulnerabilities of the area.
- Provision of proper surface / subsurface drainage system.
- Provision of proper sewerage and wastewater disposal system.

- Control over deforestation and promotion of tree plantation efforts.
- No further construction to be allowed in high slope failure probability and high risk zones. Until slope instability and risk associated factors are addressed.
- Construction of multistorey buildings should not be encouraged and even single-storey buildings should have proper structural and foundation design, based on detailed geotechnical investigations. To reduce burden on the slopes, builders be encouraged to use lightweight high strength construction materials.
- An awareness campaign is required to educate the concerned agencies, local population and the tourists visiting the area regarding causes and devastating effects of landslides. All stakeholders need to be aware of this reality and its consequences. Only then mitigation / control measures are going to be meaningful and sustainable.
- Landslide Hazard Potential and Risk Maps prepared as an outcome of this study are an excellent tool and should be utilized in land use planning, building control regulations, provision of services, design / construction, rehabilitation measures and disaster management in urban Murree area.

5.3 RECOMMENDATION FOR FUTURE STUDY

The tectonic boundary between Indian Plate and Eurasian Plate known as Main Boundary Thrust (MBT) passes in close proximity to the study area. The 7.6 magnitude earthquake of October 8, 2005 triggered innumerable landslides in the neighboring areas of Azad Jammu and Kashmir and NWFP, resulting in death of approximately 80,000 people and severe injuries / disabilities to almost the same number. Over 2.8 million people were left without shelter. All of it was the manifestation of this thrust fault. Presence of MBT and its associated faults make Murree area highly vulnerable to high intensity earthquakes. Murree hills and its adjoining Galliat areas in northern Pakistan fall under “High” seismic risk zone. More than 45 known active faults are passing very

near to the area (GSP, 2005). *It is feared that a magnitude of 8+ on the Richter scale earthquake may hit the area.* The October 8, 2005 earthquake generated a medium range ground acceleration of 0.2-0.3g, which resulted in considerable property damage in Murree Tehsil area (Lower Dewal, Kotli Sattian etc.). The results of this study clearly indicate high to very high probability of slope failures under static conditions in urban Murree area. The high vulnerability of Murree area highlights the importance of undertaking dynamic stability study of the area incorporating geotechnical behavior of slopes / soils influenced by earthquake generated ground acceleration.

It is recommended that a detailed study of the area should be carried out to evaluate and map the Geo-seismic hazard of Urban Murree to avoid and / or minimize affects of such disaster.