CHAPTER – 7

SUMMARY AND CONCLUSION
7.1 Summary

Landslides constitute a major natural hazard in India, which account for considerable loss of life and damage to communication routes, human settlements, agricultural fields and forest lands. Landslides are quite common along a section of Western Ghats during the monsoon seasons and the repeated series of landslide incidence causes great damage to the environment, people and other infrastructure. Therefore, sites that are prone to landslides should be identified in advance to reduce such damages.

The primary aim of this thesis is to prepare a landslide susceptibility zonation (LSZ) map at a scale of 1:50,000 for the study area covering parts of Meenachil river basin in the Western Ghats, using remote sensing and GIS. Remote sensing and GIS technologies are powerful tools to model the landslide hazards for their spatial analysis and prediction. This is because the collection, manipulation and analysis of the environmental data on landslide hazard can be accomplished much more efficiently and cost effectively. To reduce the number of casualties and damage to property caused by landslides, the factors that affect landslide occurrence should be understood, and the hazard or risk associated with the landslides should be determined. Landslides cannot be predicted accurately; however, the susceptibility of a given area to landslides can be determined and depicted using hazard zonation. Before the commencement of the work, a thorough review of the available literature on landslide susceptibility/hazard assessment techniques was carried out to understand the advances in landslide susceptibility zonation techniques using remote sensing and GIS.

A systematic methodology has been developed to identify and extract significant preparatory factors as input to deriving areas susceptible to landslides in the region. Fourteen terrain parameters namely, geomorphology, drainage density, soil type, soil thickness, land use, NDVI, slope, aspect, relative relief, slope length, profile curvature, plan curvature, flowpath length and topographic wetness index were generated from the primary and available secondary datasets. The most crucial information, palaeoslide locations were collected by systematic field work. In this study the weights-of-evidence (WofE) modeling technique implemented through the ArcSDM software was applied for deriving landslide susceptibility map. WofE is a probabilistic approach that calculates statistical relationships between provided input data and landslide locations. Before the weight calculation the whole landslide database was divided into two groups by random selection criteria and one
was kept for prediction and other for validation. To proceed with the analysis, the continuous parameter maps were converted into discrete by expert classification. Using the weights-of-evidence method, the spatial relationship and the contrast value between landslide occurrence location and each preparatory factor was derived.

Qualitative examination of the weights and contrast thus derived suggests that the correlation between landslides and drainage density, NDVI and profile curvature are not significant and these variables are excluded from the preparation of final LSZ map. Before the integration of the weighted evidential themes, a conditional independence test was carried out between all possible combinations of evidential themes using the omnibus test. It was noted that none of the tested pairs of evidential themes show conditional dependency. To assess the accuracy of the produced LSZ map quantitatively, the result was validated with a slide location dataset, using the receiver operating characteristic (ROC) curve by assessing the sensitivity and specificity. Finally, a four fold classification scheme, ranging from very high susceptibility to low was employed for the predicted susceptibilities. A panchayath-wise landslide susceptibility map was produced by overlying the panchyath boundary over the classified LSZ map and the susceptible areas in various panchyaths were assessed quantitatively.

The salient findings of the study are,

1. Spatial association analysis between the preparatory variables and the known landslide locations aided the recognition of significant preparatory variables.

2. The study revealed that no landslide incidence occurs in the study area below a slope of 16°. Areas coming under this zone are treated as an analysis mask.

3. The weights of evidence modelling shows that the geomorphology, soil type, soil thickness, land use, slope, aspect, relative relief, slope length, plan curvature, flowpath length and topographic wetness index have positive statistical correlation with landslide occurrence.
4. The final LSZ map generated by the integration of eleven weighted evidential themes shows susceptibility values ranging from -9.88 (low susceptibility) to 8.68 (high susceptibility).

5. A fourfold classification scheme using the expert opinion was implemented to yield four levels of susceptibility classes – very high, high, moderate and low. The proportion of area coming under the various susceptibility classes was as follows:
   - very high susceptibility : 4.54%
   - high susceptibility : 4.85%
   - moderate susceptibility : 17.18%
   - low susceptibility : 27.21%

Majority of the area (46.22%) comes under the category of stable region. Areas with slope less than 16° fall in this class.

6. The validation result of the final LSZ map using the ROC analysis gives an area of 0.892 under ROC curve, which is of high predictive accuracy. This shows a quantitative accuracy of 89.2%.

7. To enhance the applicability of the produced LSZ map, a panchayath-wise LSZ map was generated. The statistical assessment of panchayath-wise LSZ map shows that, areas with very high landslide susceptibility are concentrated in Munnilavu, Talanad, Tikoy and Poonjar Thekkekkara panchayaths.

8. Analysis of past 11 year’s rainfall data shows that the area receives a monthly average rainfall of 500 mm – 715mm during monsoon seasons. Heavy rainfall during the monsoon season and associated hydrologic behaviour of the terrain can be considered as the triggering mechanism for the landslide occurrence in the area.

9. The highlands and the foothills of mountains fall in either low or moderate susceptible zones. Very high susceptibility is found to be a characteristic of side-slope plateau where the geomorphic process is more active.
10. The study reveals that combinations of the following factors make the areas of side-slope plateau and denudational hill more susceptible to landsliding.
   a). slope gradient ranging between 16° - 45°, facing southwest, west and northwest directions
   b). relative relief <125 m and slope length < 50m.
   c). flow path length < 250 m and

12. The study also shows that remote sensing and GIS based analysis can be employed to examine the role of various parameters in conditioning the terrains for landsliding. The accuracy of the produced LSZ map indicates the suitability of the WofE method for regional scale landslide susceptibility analysis.

7.2 Conclusion

Satellite remote sensing and GIS are extremely useful tools in data acquisition and analysis for landslide hazard quantification, risk reduction, planning and post disaster management. The reliability of the results depend on a multitude of factors ranging from the quality of the data base, the introduction of potential errors associated with data entry, and manipulation and analysis with in the GIS, to the limitations and assumptions inherent in the statistical techniques. From the research it can be concluded that bivariate statistical methods are highly suitable for regional-scale landslide susceptibility analysis.

The results and findings of the present study can help the developers, planners, and engineers for slope management and land-use planning at regional scale. However, one must be careful while using the models for site specific development. This is due to the fact that the scale (1:50,000) of the analysis, cannot fully reflect the micro-topographic conditions prerequisite for the occurrence of landslides. The landslide occurrence in the study area is characterized by small failure volumes and a slight change in micro scale landform may have strong influence on the occurrence of landslides.

7.2.1 Scope for future work

The methodology used for the preparation of landslide susceptibility zonation map using RS & GIS and WofE method is readily applicable for regional scale landslide susceptibility analysis. However, some parts require further investigation in order to
optimize the methodology and results. Following issues may be taken up for future research:

1. High resolution remote sensing products can be used to identify and map the debris flows in the study area to quantify the areal extent and severity, which will aid in the reconstruction of highly accurate susceptible zones. However, the application of optical and near infrared satellite data is limited in real time monitoring of landslides in the study area due to the cloud cover. So the use of microwave remote sensing data with improved spatial resolution is recommended for real time monitoring.

2. The debris flow initiation probabilities, material volume and run-out distances should be assessed for a micro scale landslide hazard zonation of the region.

3. More number of observation stations should be implemented in complex terrains to monitor the rainfall patterns and associated increase of pore water pressure in the region. This will be useful in developing an early warning system that relies on rainfall and pore pressure thresholds.