5.1 INTRODUCTION

Landslides occur frequently in Kundha Watershed, Nilgiri district, Tamil Nadu, which makes a significant constraint to developmental activities. Hence, a landslide susceptibility map for this study area is extremely vital for the administration and the well being of the local inhabitants. A series of Government funded research projects had been carried out, to study the occurrence of landslides and identify the appropriate method for the landslide susceptibility mapping in this district. However, a number of significant problems remain over the use of the appropriate landslide susceptibility model because of the inherent uncertainties present in the data. This study has mapped the factors responsible for triggering the landslides in the study area. A data mining approach to estimate the area susceptible to landslides using GIS and remote sensing with fuzzy logic system is presented in the study, and an application is also developed to calculate the landslide susceptibility index of any watershed and tested in the nearby watershed.

5.2 HIGHLIGHTS OF THE WORK DONE

A landslide susceptibility map ranks the slope stability of an area from low (stable) to very high (unstable) categories. A novel approach which combines the expert knowledge and the fuzzy system is used in this study. This method proved to have a better accuracy than other traditional systems in spite of the inadequacies and the uncertainties present in the factors.
A brief review of literature pertaining to the topics of research considered in this work is reported, and the motivation for the present work is also brought out in the introduction chapter.

The knowledge of the landslides in an area is expressed by a landslide inventory map which shows the locations. The landslide inventory map of this study area reveals the location of the landslides in the watershed and also provides an overview of the causative factors responsible for landslides in this locality. From the observations made in the field, it was noticed that most of the landslides observed in the study area were shallow in nature. The notable conclusion drawn from the inventory map is that the majority of the landslides occur near the road sides. Landslides are also observed near the settlement in and around the power houses and the tea plantations. This clearly reveals that the human interference plays a significant role in the occurrence of landslides. Thus, the landslide inventory map is used to draw the influence of the factors related to landslide.

Ten factors are identified in the study area (slope, soil type, soil depth, land use, drainage density, lineament density, geomorphology, runoff, proximity to the road and geology) and these factors influence the occurrence of landslides. Each factor is weighed according to their significance towards landslide. The following interaction between the factors and landslide occurrence has been found.

- Slope angle in the range of 10° to 35° indicate a high probability of landslide occurrence (43%).

- Slopes steeper than 35° is found to have very low landslide frequency.
- The combination of very steep slope with less soil cover was found to be less vulnerable for landslide occurrence compared to the combination of steep slope (10 to 35 degrees) and very deep soil cover (>100 cm).

- Sixty three percentage of the landslides have occurred in the low lineament density area, and 31% of the landslides have occurred in the medium lineament density area, which indicates that the frequency of landslide occurrence does not present a significant trend to indicate a strong association between lineament density and landslide occurrence.

- Sixty percent of the landslides fall closer to the road authenticating the relationship between landslide and proximity to the road.

- Forty one percent of the landslides have occurred within the zone of 50 to 100 m on both sides of the road.

- Geology remains same throughout the study area, and their contribution is given due weight, irrespective of its variability over the study area.

- An assessment of drainage density of the study area indicated that the rivers and streams have contributed significantly to soil erosion, triggering landslides.

- Frequency of landslide occurrence is comparatively high in very high drainage density areas than the areas with high, medium and low drainage densities. This indicates that the landslide frequency does not increase linearly with drainage density and
presence of an optimal drainage density for the occurrence of landslides.

- Open forest shows the highest frequency of landslides (29%) compared to other land cover categories.

- Next to open forest, forest plantations showed higher landslide frequency (23%).

- Next to forest plantations, tea plantations show a high incidence of landslide frequency (20%).

- In the study area, 44% of landslide occurrence falls in the shallow pediments.

- Next to shallow pediments colluvial fill has the high frequency of landslide (29%) incidence.

- Highly eroded gravelly clay soil shows a high correlation with landslide incidence i.e., 44% of the landslides have occurred in this area.

- Twenty three percent of landslides fall in gravelly loamy soil with escarpments.

- The runoff classes show peculiar variability with the number of landslides occurring in the very high and low run off categories.

- Thirty six percent of frequency of landslides fall under the low category of runoff. This area was also found to have highly eroded clay soil.
• The moderate runoff has zero occurrence of landslide because of the balance that exists between the water flowing as runoff and the water infiltrating into the soil.

• The very high runoff area has the highest frequency of landslide (59%). This is because the area under high runoff category has gravelly loamy soil with escarpment and very steep slope.

• Eighty one percent of the study area has very deep soil depth.

• Fourteen percent of the area has deeper soil depth.

Thus, different factors and their subclasses show different relationship towards the landslide occurrence in the study area. Although the factors investigated in this study area have observed at many places in the whole world, it is vital to propose effective and accurate landslide susceptibility map.

The landslide susceptibility map generated using fuzzy system is divided into low, medium, high and very high categories. The performance of the model is checked by overlaying with the inventory map. The following results are concluded.

• It is notable that only six percent of the total area of the watershed has low susceptibility of landslide. This part of the watershed has less probability for the occurrence of landslide. This area is suitable for settlement and developmental activities. But, the developmental activities should not increase to such an extent affecting the slope stability of the area.
Thirty nine percent of the watershed is characterized by medium landslide susceptibility. This portion of the watershed is also suitable for developmental activities. When planning the developmental activities in this area steep slope regions should be avoided. Building on top of highly eroded clayey soil should be avoided. Proper facilities should be created for the drainage of the rain water and natural water drainage patterns should not be disturbed.

Fifty percent of the area has a high probability for the occurrence of landslides. In a broad way, the slope stability condition of that region may be considerably increased, when new cuts and fills and other activities alter the natural topographical and hydrological conditions. Therefore, the developers and planners have to take this into consideration when planning the developmental activities of the district. If not the fragile environment of the western Ghats would trigger frequent landslides.

Five percent of the very high landslide category of the area has the highest probability for the occurrence of landslides compared to other categories of landslide susceptible areas. Eleven settlements are found to fall under this susceptibility zone. New developmental activities should be avoided in this zone. The people living near the road sides should be educated about the vulnerability of the land on which they are living. Rainfall is found to be the triggering factor in this study area. Therefore, when there is continuous rain in this region, warning should be given to the people living in this region.
The landslide susceptibility is also calculated using frequency ratio method. The following conclusions are drawn from the analysis.

- Majority of the watershed falls under the category of medium susceptibility (56%).
- Together the very high and high category form 28.13% of the watershed.
- Sixteen percent of the watershed is predicted to be less vulnerable to landslide.

The percentage of occurrence of landslide within the classes of the landslide susceptibility is found as follows.

- Seven percent of the landslides fall under low category of susceptibility.
- Twenty percent of the landslides fall under medium category of susceptibility.
- The majority of the landslides fall under high category (60%).
- Only 7% of the landslides fall under very high category.

The results obtained from the fuzzy systems is compared with the results obtained using frequency system. When the landslide susceptibility index value was above 0.5, the cumulative landslide percentage is 94.27% in case of fuzzy systems. But, the cumulative landslide percentage is 65.7% only in case of the frequency ratio method. The landslide occurrence ratio for fuzzy systems is higher than the frequency ratio method by 28.57%. The prediction accuracy of fuzzy system is found to be 94.27%. Thus, fuzzy system proves to be comparatively accurate than the frequency ratio method.
The model unique in its nature because it combines both the experts opinion and data driven method.

An application is developed using #C.NET to calculate and classify the landslide susceptibility index. The application is developed in such a way that it can be universally extended to any watershed with any number of factors and subclasses. The application is user friendly. The application is tested for Kuruvenuhalla watershed. The following results were obtained when the landslide susceptibility map of Kuruvenuhalla watershed was validated with the inventory map and proves the application to be accurate.

- Zero percent of the watershed fall under the low category.
- Only eight percent of the landslides fall under the medium category.
- Fifty percent of the watershed falls under the high category
- Forty two percent of the watershed fall under very high category of landslide susceptibility.

The landslide susceptibility map and the application developed in this work will be used by planners, engineers, emergency response staff, bankers, mortgage lenders, and insurance agents and will have a positive impact on the developmental activities and the lives of the people of the locality.

5.3 SCOPE FOR FUTURE WORK

- The model developed in this study, can be applied to all the watersheds present in Nilgiris, Western Ghats and other such areas located elsewhere.
Suitable remedial measures can be formulated in the areas identified as vulnerable to landslides.

New tools can be developed for landslide inventory mapping to improve the accuracy of assessment.

5.4 CONCLUSION

The objectives of this study have been carried out successfully in the selected area and findings reveal the susceptibility status of the area to landslides, which are confirmed by applying suitable methodology. The model proposed seems to be valid not only in this study area but also it shall be applied elsewhere for assessment of landslide susceptibility.