CHAPTER 5

CONCLUSIONS

5.1 GENERAL

The runoff of a watershed is of great value for better management and provides major source of water to the ecosystem. Since runoff is a peculiar component in a hydrological cycle, the selection of a suitable runoff modelling is important to explore the factors that contribute runoff generation in a watershed. Hence, in the present study, the three modelling approaches were performed for ungauged Kundahpallam watershed, namely SCS-CN, modified SCS-CN and Green-Ampt method. Comparison of these models was made and the best method was selected based on the least difference between the measured and calculated results. Also the erosion modelling was done for the watershed to identify areas susceptible to erosion by considering the soil properties. The remote sensing and GIS techniques were effectively used for capturing the data, database creation, data storage and retrieving, qualitative and quantitative data analysis and exploring the results in an efficient manner. Runoff and erosion modelling were integrated using remote sensing and GIS to achieve the best watershed management procedure for the study area.

5.2 SUMMARY AND CONCLUSIONS OF THE PRESENT STUDY

The following conclusions were drawn from the present study:

A ten year rainfall data was used to determine the rainfall pattern in the Kundahpalam ungauged watershed.
• The rainfall of the study area ranged from 109.2 cm to 152.4 cm with the standard deviation of 133.6 cm.

• The study area received maximum rainfall from the southwest monsoon (35.35%) and minimum rainfall from the winter season (9.32%). Also, summer and northeast monsoon provide a rainfall of 31.27% and 24.05% respectively to the watershed.

The thematic maps such as land use and soil were prepared for the calculation of runoff of the study area.

• The land uses of the study area were classified into eight categories and among these categories the forest plantation occupies more area (58.14%) and the built-up land occupies less area (0.11%).

• The other categories such as agro-horticultural plantation, dense forest, land without scrub, open forest, tea plantation and water body occupied 14.01%, 1.65%, 3.72%, 16.35%, 5.86%, 0.16% of area respectively.

• The soil of the study area was classified into three hydrological soil groups. The hydrological soil group HSG C covered more area (59%) than the HSG B (32%) and HSG D (9%).

• The curve number of the study area varied from 40 to 100 for the various land use categories. The curve numbers ranging from 65 to 73 and occupied more coverage area (41.51%). Also 40.93% of the area was covered with curve numbers ranging from 45 to 64. The 1.75% and 0.27% of study area was covered with curve numbers ranging from 40 to 44 and 86 to 100 respectively.
The DEM was used to prepare the contour map, slope map, flow direction and flow accumulation map.

- The elevation of the study area was increased from 1526 m in eastern side to 2411 m towards western side. Steep slope was observed in the western region and moderate slope was observed in eastern region. The settlements were found in moderate slope and agricultural practices were found in steep slope.

- The Flow direction map of the study area had eight direction of flow such as east, southeast, south, southwest, west, northwest, north and northeast. The percentage of flow for each direction was 16.53, 13.98, 12.78, 5.25, 5.93, 10.9, 19.61, and 15.01 respectively. The flow towards north direction (19.61%) was predominant in the study area. The flow towards southwest direction was very less (5.25%) in the study area.

- Flow accumulation derived from the flow direction map had the value ranging from 0 to 2793. The ridges in the study area had the flow accumulation value of zero. The highest value in the flow accumulation map represented the stream channels in the study area.

The soil physical properties and fraction of soil particles were determined from the soil samples of sixteen locations. The percentage of sand, silt and clay determined the soil texture of the study area.

- The percentage of coverage of clay loam, loam, clay, sandy clay loam, loamy sand and silty clay were 24.63, 34.99, 5.98, 30.39, 1.97, 3.04 respectively.
The open forest and tea plantation had the highest coverage of loam soil with the percentage of 77 and 74 respectively. Agro horticulture, forest plantation and dense forest had the highest coverage of sandy loam soil with the percentage of 44, 39 and 53 respectively. Land without scrub had highest coverage of clay loam with the percentage of 72.

The infiltration rate and hydraulic conductivity were measured by infiltrometer for the sixteen sample locations.

- The infiltration rate varied from 6.91 cm/h to 0.14 cm/h. The loamy sand had the highest rate of infiltration (6.91 cm/h) with lower moisture content (29.3%). The clay soil had the lowest rate of infiltration (0.14 cm/h) with higher moisture content (34.5%) in the study area.

- The hydraulic conductivity varied from 2.39 cm/h to 0.01 cm/h in the study area. Loam soil had the highest rate of hydraulic conductivity (2.395 cm/h). The clay soil had the lowest rate of hydraulic conductivity (0.01 cm/h).

The slope, flow accumulation, saturated hydraulic conductivity and soil depth were used to estimate the soil wetness index of the study area.

- The three classes of soil wetness index were generated for the study area. The study area was covered with SWI 1, SWI 2, and SWI 3 by the percentage of 38, 44 and 18 respectively.

- The SWI 1 had lower moisture content and the SWI 3 had higher moisture content. The SWI decreased towards boundary of the study area from the stream channels.
The runoff generation mechanisms in the watershed were determined with the percentage of SWI classes falling over the watershed. From the soil wetness index, 82% of the study area was found to produce saturation excess runoff and 18% of the study area was produce infiltration excess runoff.

The soil analysis was performed for the soil samples taken at 15 cm and 30 cm depth to determine the soil properties such as bulk density, particle density, water holding capacity, organic carbon and porosity.

- The bulk density of the study area varied from 0.79 g/cm$^3$ to 1.06 g/cm$^3$. The particle density varied from 1.47 g/cm$^3$ to 1.65 g/cm$^3$. The sandy clay loam had high bulk density as well as particle density and clay had low bulk density and particle density in the study area.

- The water holding capacity varied from 43.54% to 56.39%. The clay loam had highest water holding capacity and loam had low water holding capacity in the study area.

- The organic carbon in the study area varied from 1.23% to 1.58% and the clay had low organic carbon and loamy sand has high organic carbon in the study area.

- The land use and soil properties relationship showed that the water holding capacity, porosity, infiltration rate and hydraulic conductivity were more in dense forest and less in tea plantation.

- The statistical analysis between infiltration and hydraulic conductivity had strong positive correlation with a coefficient of determination of 0.94. The bulk density and porosity had
strong negative correlation with a coefficient of determination of 0.39. The porosity had positive correlation with infiltration rate and hydraulic conductivity. The bulk density had negative correlation with infiltration rate and hydraulic conductivity.

The three models namely SCS-CN, modified SCS-CN and Green-Ampt methods were used to quantify the surface runoff in the study area.

- Soil, land use, potential maximum retention and curve number were the main factors that define the runoff volume generation by the concept of SCS-CN method.

- The 3.31 cm of runoff was predicted from the rainfall event of 7.23 cm. The water body produced 100% of runoff for the given rainfall event. The built-up land produced 87% of runoff next to water body.

- The land without scrub had 67% of runoff with 72% coverage of clay loam. Tea plantation produced runoff depth of 58% with soil coverage of loam soil (74%). The dense forest has lowest runoff producing capacity of 19% due to more coverage of sandy loam (53%).

- The major difficulty of conventional SCS-CN model is selection of value for initial abstraction and the curve number distribution.

- The modified SCS-CN method defined the curve number based on land use and soil wetness index.

- In this approach, the definition of curve number was similar as SCS-CN method but the location of curve numbers distribution were different for the study area.
• The 3.47 cm of runoff was predicted from the rainfall event of 7.23 cm. 65 % of SWI 3 fell in the water body and it was prone to highest saturation and produced more runoff of 90%. The built-up land produced more runoff of 87% with the coverage of SWI 2 (87%).

• By this method, the runoff quantity estimated was nearly equal to runoff estimated by SCS-CN, but the location of runoff generation was varied with respect to soil wetness index of the study area.

• The tea plantation has 55%, 34% and 24% of SWI 1, SWI 2 and SWI 3 respectively, and produces 65 % of runoff in the watershed. The dense forest with SWI 2 (48%) and least coverage of SWI 3 (5%) produced 20 % of runoff.

• The standard SCS-CN and modified SCS-CN were used to produce the runoff by considering the single factor called curve number. The resulted runoff from the standard SCS-CN and modified SCS-CN model by defined infiltration classes did not reflect the field measured values. These approaches were very simple and require little data.

• Although simple, these methods were unsatisfactory for the ungauged Kundahpalam watershed due to their basic assumption on curve number generation.

• The Green-Ampt model was based on the soil inbuilt characteristics and land use, and it followed the physical laws that contribute runoff calculation in the study area.

• The 5.12 cm of runoff was calculated from the rainfall event of 7.23 cm. The loamy sand had highest infiltration rate (6.74
cm/h) and lowest runoff rate (0.49 cm/h). The lowest infiltration rate was found in clay loam (0.54 cm/h) and clay (0.49 cm/h) soil and these soils had highest runoff rate of 6.74 cm/h.

- The forest plantation was found to be produced more runoff (35%) and built-up land produced less runoff (2 %) of total runoff. The agro horticulture plantation had 22% of runoff production and open forest produced 16% of runoff. Tea plantation had 11% of runoff production and land without scrub produced 7% of runoff.

- The dense forest and water body produced same percentage of runoff (3%). The water body and built up land are located in low elevated area and the runoff gets accumulated in these areas rather than the runoff production.

- By the validation of runoff models, the Green-Ampt model is satisfactory with Nash Sutcliffe efficiency equal to 0.68 for runoff modelling of the study area.

- Therefore, the Green-Ampt loss method can be effectively applied to generate spatially distributed runoff for the ungauged Kundahpalam watershed by using the geographic information system.

The type of land cover which influenced the runoff generation of the study area was identified based on the soil properties.

- The tea plantation with loam soil had generated high runoff depth and dense forest with loamy sand had generated low runoff depth in the study area. The increasing area of tea plantation by deforestation had become more threat to the
study area and produced more runoff and low infiltration depth.

- The results showed that 25% of rainfall got infiltrated into the ground and remaining 75% of rainfall flowed over the land as runoff. Since the infiltration capacity was lower than the rainfall intensity, infiltration excess runoff was the dominant process responsible for the predicted runoff in the study area than the saturation excess runoff.

The sensitivity analysis was carried out to determine the influences of model parameters to the runoff generation by calculating the condition number.

- The runoff generation was more sensitive to moisture content and hydraulic conductivity and less sensitive to changes in wetting front capillary pressure.

- The runoff was found to be higher at 50% of the base value of the moisture content, hydraulic conductivity and wetting front capillary pressure. The clay soil with 50% of base value of hydraulic conductivity was found more sensitive to the runoff model.

- The loam soil with 50% of base value of moisture content and wetting front capillary pressure were found more sensitive to the runoff model. The loamy sand with moisture content, hydraulic conductivity and wetting front capillary pressure had less sensitive to the runoff model.

The area vulnerable to soil erosion was determined by the soil inbuilt properties related to slope, soil and land use of the study area.
The dispersion ratio was found more in surface soil (15 cm depth) and less in sub surface soil (30 cm). The dispersion ratio was high (3.92) in moderately sloping area and low (2.21) in extremely sloping area of the study area. The dispersion ratio of the dense forest was found to be low (2.83). The built up land (3.91) and plantation land (3.35) have high dispersion ratio.

The soil erosion index was high in steeply sloping land with loam soil and low in the moderately sloping terrain with clay soil in the study area. The land without scrub had more capability to produce high erosion and built-up land produced less soil erosion.

The study area was delineated by 21 sub-basins with efficient gauging locations. The effective gauging locations can make ungauged Kundahpalam watershed as a gauged watershed. The terrain and hydrological properties of sub-basins will provide a selection of hydro electric power stations in the study area.

The runoff, dispersion ratio, soil erosion index, rainfall, terrain properties and soil properties of study area were interlinked by using multi linear regression analysis. From the results, performance of the model was found to be satisfactory with the inclusion of soil physical properties compared to basin characteristics.

5.3 SUGGESTIONS FROM THE PRESENT STUDY

Kundahpalam watershed is environmentally sensitive and economically revenue generating watershed to the government of Tamil Nadu. It hosts the state’s biggest hydroelectric power station with power generation capacity of 60 MW. The various water users in the basin are
electricity board, plantation and agriculture sectors and tourism industry. The suggestions for the management of surface water resources of Kundapallam ungauged watershed are given as follows:

- The watershed does not have sufficient dams and weirs to store surface water for meeting the demand of local communities.
- The study of rainfall runoff relationship in the basin can be used for the identification of locations and types of surface water utilizable structures.
- There was no study undertaken to model the runoff with respect to soil properties in the study area.
- The soil characterization in the study area can be used to understand the runoff and erosion for better watershed management.
- Hence the integrated model clubbed with rainfall, soil characters, runoff and erosion are made to reduce the impacts of surface runoff and erosion towards the downstream side of watershed.
- The integrated model developed for this study area can be extended for other environmentally similar watersheds in the Western Ghats of Nilgiris district.

5.4 SCOPE FOR FUTURE STUDY

- The study of rainfall and runoff pattern was not done previously due to limitations in the availability of the data for the watershed. Hence the periodic measurements of rainfall
and runoff values by proper gauging stations may improve the runoff modelling for the study area.

- This study can be extended to the high altitude nature of other ungauged watershed to get more modelling efficiency.

- The use of radar rainfall data can be studied to improve the performance of the model output.

- The observation locations can be extended more with sub basin wise locations and it may improve the detailed characterization of runoff with respect to soil and land use categories.

- The development of web based GIS data management system can help to support the recent updates of the study area for effective planning and developing of water resources with public participation.

This study is effectively applied to the Kundahpalam waterashed to generate rainfall runoff relationship by using the remote sensing data and GIS. The rainfall runoff relationship is effectively achieved by Green-Ampt model through the inclusion of land use properties, soil properties and basin properties. Therefore the Green-Ampt model can be a valuable one to have information from different sites in order to make a stronger assessment of surface water flow and soil erosion for the study area.