



Carrying Capacity of Mountainous Watershed in Himalayan Region

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Abstract Hydrological processes are very important process and need to be considered during water resources planning and management. Assessment of snowmelt runoff and sediment yield in Himalayan mountainous watershed is most important for planning hydropower generation. The main aim of study is to identify suitable hydrological model suitable for mountainous watershed. The study area comprises of Arwa Watershed situated in Alaknanda sub-basin in Uttarakhand, India. The hydrological components of Arwa watershed are characterized by area covered by snow and are below the snowline. Analysis of satellite data indicates that more than 60% of area is covered by snow and remaining area is below snowline. Swat model is useful for estimation of runoff occurring due to precipitation and sediment yield due to upland erosion in mountainous region. While SRM model is useful for snowmelt runoff evaluation. Integration of these two hydrological models will provide more reliable results for evaluation of mountainous watershed.

Keywords: Surface Runoff, Snowmelt Runoff, Sediment Yield, SWAT, SRM, RS and GIS, Mountainous Watershed.

I. INTRODUCTION

Water is the elixir for all living things and greatest gift of mankind. In water resources it is vital renewable source, important limiting factor to growth and most important for the survival and development of any society. A watershed is an area that contains all the water from rain and snow at downward side in a single outlet point. Sustainable development of watershed, carrying capacity is most important. It is a measure of sustainability within changing conditions. Carrying Capacity refers to the maximum Quantity of things that can be sustained. In present study focus on the rainfall, runoff and sediment yield in watershed for mountainous region. Proper planning and management of watershed runoff and soil erosion are important process taking into consideration. The upland erosion leads not only to long term losses of upland productivity, but also losses the storage capacity of reservoir, so evaluation of runoff and sediment yield is required. Precipitation occurs on hilly region that increase the higher possibility of soil erosion, runoff flows on earth surface and taking this sediment with the water to the common outlet point of watershed and these all drains from the watershed accumulate in the river so it reduces the carrying capacity of river and reservoir.

Himalayan mountainous watershed the spatial and temporal variability in terms of land use/land cover, soil, topography, rainfall and temperature effect on snow covered area as well as geologic materials have interventions is large. The steep Slope in mountainous watershed has been major factor for soil erosion and sediment discharge in the rivers [5] [13]. Hydrological parameters like runoff, snowmelt runoff and sediment yield is difficult task remote and inaccessible areas. Basically the hydrological models can partially solve the hydrological evaluation of mountainous watershed problem in limited and unavailable data condition to find discharge and sediment yield. A physical based spatially distributed and semi distributed hydrological models are available for the hydrological evaluation.

Soil and Water Assessment Tool (SWAT) is a physically based, spatially distributed model used to access hydrological behaviour of the large and complex watersheds. Model proven to be an effective tool for assessing Water resources problem and no point source pollution problem for a wide range of environmental condition. Daily, Monthly and annual basis Runoff has been carried out by SWAT model and widely used in various region and climate condition for various size and scales.

Snowmelt runoff model (SRM) [12] is designed to simulate and forecast snowmelt runoff in mountainous region almost any size (0.76 to 120,000 km²), the two pragmatic approaches are accessible and they are energy balance approach and degree day

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method. In comparison to the energy balance approach, degree day approach is more practicable and needs minimum parameters for simulating snow & glacier melt runoff. It is widely used due to its being less complicated. Precipitation and temperature are the major factors for generating runoff in mountainous regions which are covered with snow and glaciers. SRM model monitoring snow covered area with satellite images and meteorological data, improves the standard method and hydrological using spatial analysis. Snow covered is an import input for the model therefore IRS-P6 Awifs data were used for computation of stream flow.

II. STUDY AREA

Himalaya is tallest water tower and largest store house of snow and ice outside the polar region. It contains enormous water reservoirs of perennial snow and ice at highest elevations. There is a high variability in precipitation across the Himalaya. Climate of the Chamoli district varies from sub-tropical monsoon type to tropical upland type, the northern, northern-western, northern-eastern and western part of district covered by snow. . The year may have divided in four viz. cold winter season (Dec to Feb), hot weather season (March to May), southwest monsoon season (Jun to Sept) and post monsoon season (Oct to Nov) Maximum and minimum temperature varies between 31 and -2.9°C and average annual rainfall is 1230.80 mm. Arwa watershed is situated between $30^{\circ} 33'$ to $31^{\circ} 4' \text{N}$ and $79^{\circ} 13'$ to $79^{\circ} 42' \text{E}$ in Chamoli district, Uttarakhand, India. Total area of watershed is 1529 km^2 . Alaknanda River flowing from Arwa watershed at higher altitude in Himalaya. Figure 1, 2 and 3 shows the Arwa watershed.

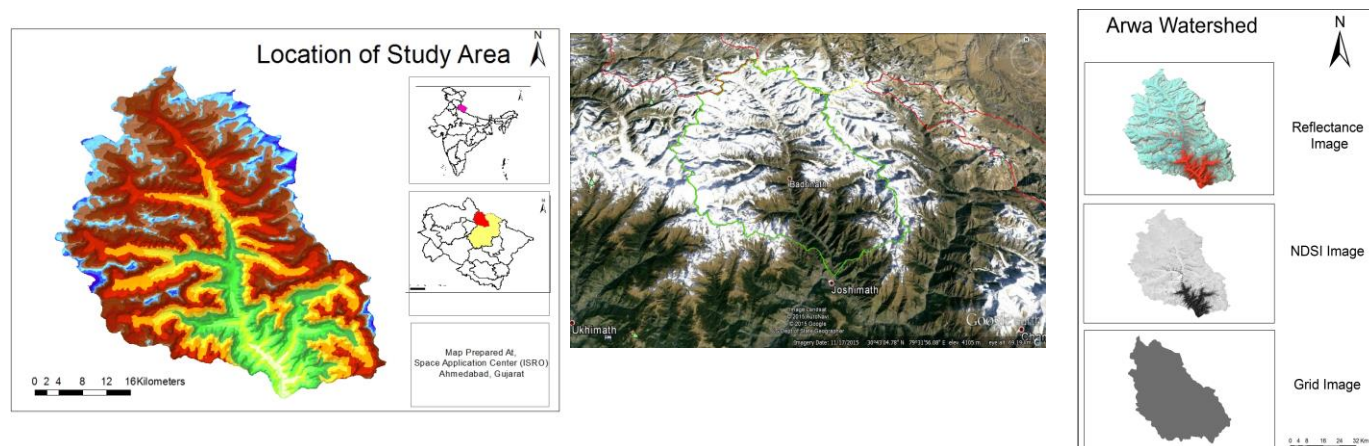


Fig. 1: Location Map of Study Area showing Arwa Watershed (classified DEM), Fig. 2: Google earth image, Fig. 3, Reflectance, NDSI and grid image.

III. DATA COLLECTION AND DATA GENERATION

A. Data Collection:

The detailed study of hydrological model various satellite and ancillary data used. Aster DEM 30 m globally available, land use/land cover, soil and weather data used for SWAT model and Satellite (IRS P-6) Advanced wide field sensor (AWiFS) data, Reflectance and NDSI image for snow cover area for SRM model. It provides a spatial resolution of 56 m and covering a swath of 740 Km. to cover this wide swath, the AWiFS camera is split into two separate electro optic modules, AWiFS-A and AWiFS-B. Because of its large swath the repetivity of the AWiFS is 8 to 10 days. These data are imported from NRSC (National Remote Sensing Centre), Hyderabad. Reflectance, NDSI images are generated using NDSI algorithm Kulkarni et al. (2006).

B. Data Generation:

Hydrological model inputs like watershed map, land use/land cover map, soil map and slope maps were generated in Arc GIS for SWAT Model. DEM should be in Projected Coordination system so before proceeding define PCS of Study area and then converted into Grid format. Land use/land cover use same projection as DEM and then converted into polygon to raster for SWAT model input data shows in Figure 4 & 5. Meteorological data, precipitation and temperature are for estimation of runoff in snow & glacier covered area been taken from Joshimath, Chamoli District of Uttarakhand for this present study. For utilizing and for fulfilling the requirements of the model precipitation data from 2013-2014 available in daily format are converted in to 10-daily format specifically for SRM model. These considerable parameters which have high contribution in snow & glacier melt runoff have for clarity, maximum and minimum air temperatures.

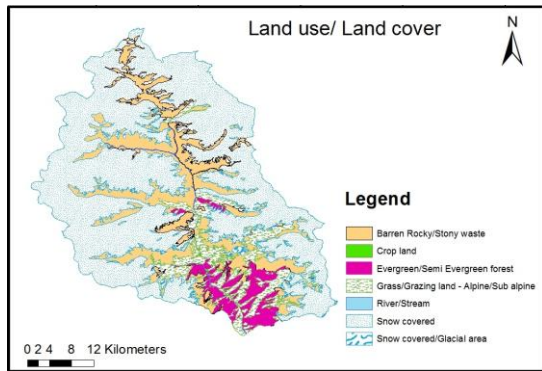


Figure. 4: Landuse map

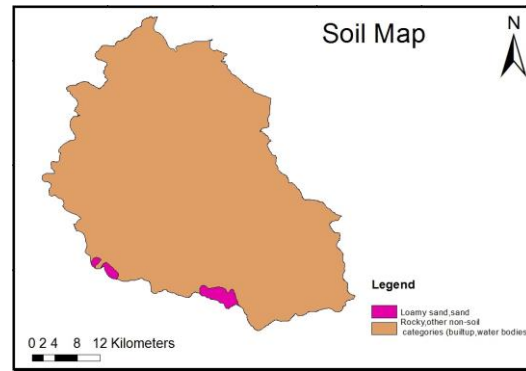


Figure. 5: Soil Map

Using ARC GIS 9.3, distribution of the Arwa watershed (1523 Km²) is done by fabricating a grid of the same size and laying it over the watershed. So consequently, the watershed is distributed into a number of small grid cells. In this way, the Arwa watershed is divided respectively in to small grid cells. The fabricated grid (ArcCoverage) of same size also laying on the NDSI, Reflectance and ASTER DEM image and find each cell value for NDSI image, Reflectance Image and DEM image in ERDAS 9.1. After that making of grid file including the Area, NDSI, Reflectance and Aster value for each cell. Figure 3 shows the reflectance, NDSI and grid image of study area.

IV. METHODOLOGY

A. SWAT Model

The USDA - Agriculture Research Service (ARS) and Agricultural Experiments stations in Temple, Texas [11] developed SWAT to predict the impact of land management practice on water, sediment and agricultural chemical yields in large complex watershed with varying soils, land use and management condition over long periods of time. SWAT requires the specific information about weather, Soil properties, topography, vegetation and land management practices occurring in watershed. The hydrological model used in the present study is ArcSWAT with Arc GIS interface. Quick parameterization of hydrologic models can be evaluating with the use of remote sensing (RS) and geographic information system (GIS) as remotely sensed data provides valuable and up to date spatial information on natural resources and terrain parameters (Tyagi et al.2014)

$$SW_t = SW_o + \sum_{i=1}^t (R_{day} - Q_{Surf} - E_a - w_{seep} - Q_{gw})$$

Where, SW_t is the final soil water content (mm H₂O), SW_o is the initial soil water content (mm H₂O), R_{day} is the amount of precipitation on day i (mm H₂O), E_a is the amount of Evapotranspiration on day i (mm H₂O), w_{seep} is the amount of percolation and bypass flow existing the soil profile bottom on day i (mm H₂O) and Q_{gw} is amount of return flow day i (mm H₂O). Since the model maintain a continuous water balance, complex basin are sub divided to reflect difference in ET for various crops, soils, etc. Thus, runoff is predicted separately for such areas, which in turn are routed to obtain the total runoff for the basin. This increase accuracy and gives better physical descriptions of the water balance.

SWAT uses Green and Ampt equation and empirical SCS curve number method for runoff computation. Peak runoff rate is measured by rational method. Daily evapotranspiration calculated by using Penman-Monteith method. Kinematic Storage model using to determine lateral subsurface flow. Muskingum method is based on flow routing for variable storage. Sediment yield can be obtained from the Modified universal soil loss equation (MUSLE).

B. SRM Model

Snowmelt-Runoff Model (SRM) is designed to simulate and forecast daily stream flow in mountain basins where snowmelt is a major runoff factor. Recently, it has been applied to evaluate the effect of changed climate on seasonal snow cover and snow melt runoff. Different remote sensing and GIS techniques are used for developed this model. Catchments are distributed using grid NDSI used to estimate snow cover and on reflectance use to estimate melt factor. From time to time, runoff generated from

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snow and glacier melt and also from rainfall is computed using the following equation, inspired from Martinec et al. (1975); Soni et al., (2014)[12] SRM can be applied in mountain basins of almost any size and any elevation range. A model run starts with a known or estimated discharge value and can proceed for an unlimited number of days, as long as the input variables - temperature, precipitation and snow covered area and input parameters viz. Runoff coefficient, Degree day factor, Temperature lapse rate, Critical temperature, Rainfall contributing Area, Recession coefficient and Time lag. Runoff computation SRM appear to be relatively easy understood and successfully gave real time runoff forecast.

$$Q = \sum_{i=1}^n \{ C_1 \{ a (T * G) \} + C_2 (P * B) + C_3 \{ a (T * S) \} \} * 10000 / 86400 * A (1 - K) + Q_{last} * K$$

where: Q = average daily discharge [$m^3 s^{-1}$], C_1 = Runoff coefficient for glaciated areas, C_2 = Runoff coefficient for nonsnow and non-glaciated areas, C_3 = Runoff coefficient for seasonal snow covered areas, a = Melt factor [$cm ^\circ C^{-1} d^{-1}$] indicating the snowmelt depth resulting from 1 degree-day, T = Average 10-daily degree-days [$^\circ C d$], G = Grid cell area of glaciers, permanent and 10-daily snow [km^2], S = ratio of the snow covered area to the total area, P = Average 10-daily rainfall [cm], B = Grid cell area without snow/glacial cover [km^2], A = area of the basin or zone [km^2], k = recession coefficient indicating the decline of discharge in a period without snowmelt or rainfall = Number of cells, Q_{last} = Last average 10-daily discharge, $\frac{10000}{86400}$ = conversion from $cm \cdot km^2 d^{-1}$ to $m^3 s^{-1}$

V. RESULT AND DISCUSSION

The monthly and annual runoff has been estimated for the mountainous Arwa watershed in Himalayas using two different hydrological model viz. SWAT and SRM. SWAT model is capable to estimate runoff and sediment yield on monthly basis shown in the figure 6 and 7 for entire study area. Surface runoff for swat model is 140.23 mm/yr and maximum upland sediment yield for watershed area is 2.2 mg/ha.

A. Swat Result

In land use map 1026.05 km^2 area is snow covered area or glacierised area which is considered as a waterbody. Rocky and barren land covered area is 313.17 km^2 and D-type hydrological soil group, rocky soil is available. The surface runoff from such land use is generally excessive and very less sediment erosion occurred. Range land area, within the watershed covered with grassland and vegetation occupies 124.68 km^2 area so less runoff occurred also it prevents upland erosion take place and it reduce the sediment yield at outlet of watershed. A small portion of the watershed 58.89 km^2 area is covered by forest viz. Evergreen and semi evergreen densed forest area, it reveals that less surface runoff and less soil transportation occurred. Soil map shows that as per hydrological soil group 98.79 % area covered by rocky soil or D group soil. Hence, very less soil particle flow with the runoff and drain into the channel.

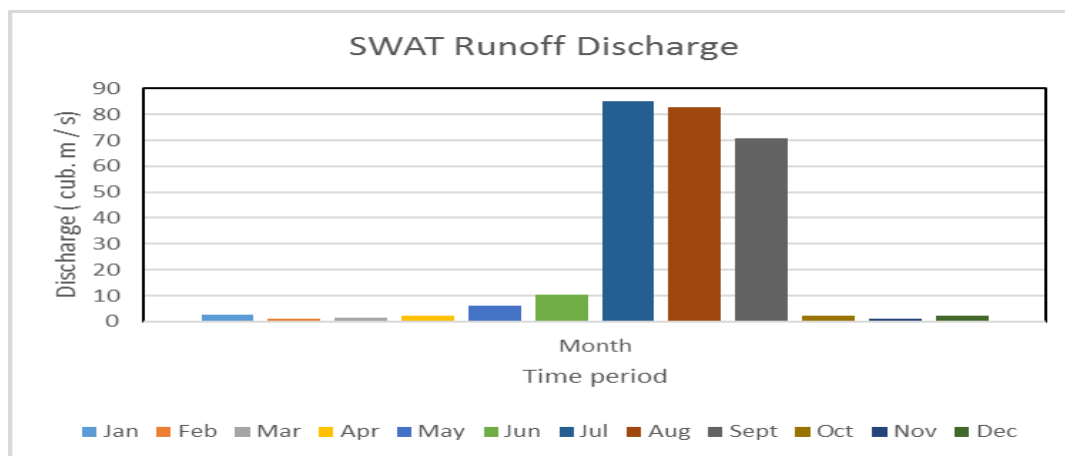


Figure 6 : SWAT model runoff discharge

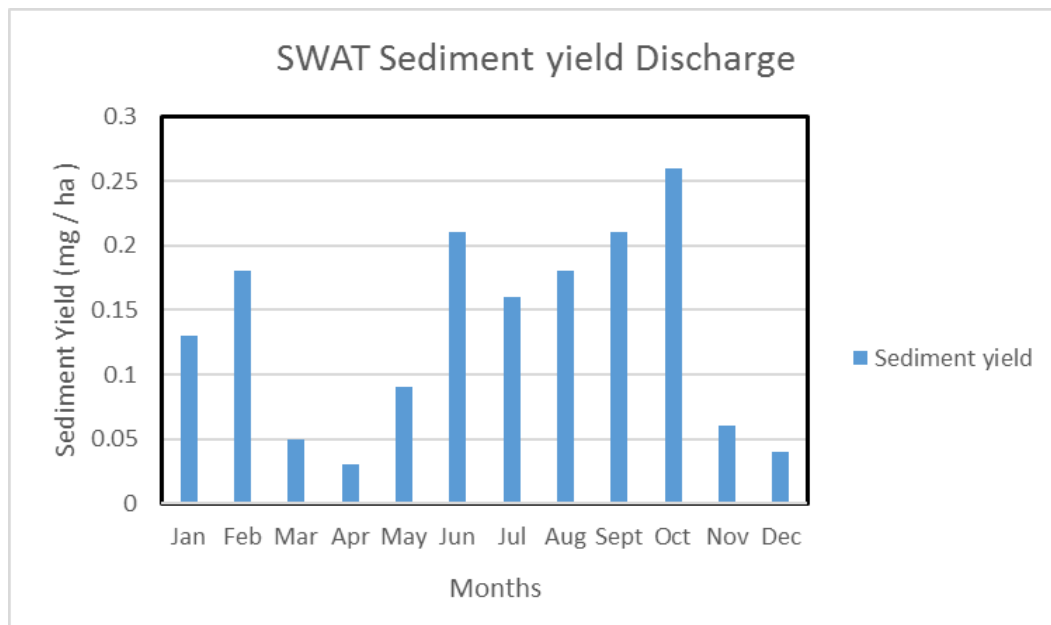


Figure 7 : SWAT model sediment yield discharge

B. SRM result

SRM model is degree day approach model it evaluated snow melt runoff 10 daily basis and snow covered area in Arwa watershed. Parameters such as melt factor, runoff coefficients and recession coefficient for the model are derived from satellite, topographic and hydrometeorological data. Snow covered area increasing during January to march and then after snow covered area gradually decrease. During winter season the Arwa watershed almost covered with snow because the watershed situated at higher altitude. During monsoon least snow covered found. Temperature and rainfall are main reason for the runoff and snowmelt runoff. Runoff due to rain is noted high during monsoon while it is very low in winter. Runoff generated from snow and glaciers is noted high in summer and monsoon than winter and autumn. By using grid of smaller size cells, physical processes can be represented easily and the results are found to be accurate and reliable. Figure 8 shows the snow melt runoff discharge from SRM model and Figure 9 shows snow covered area.

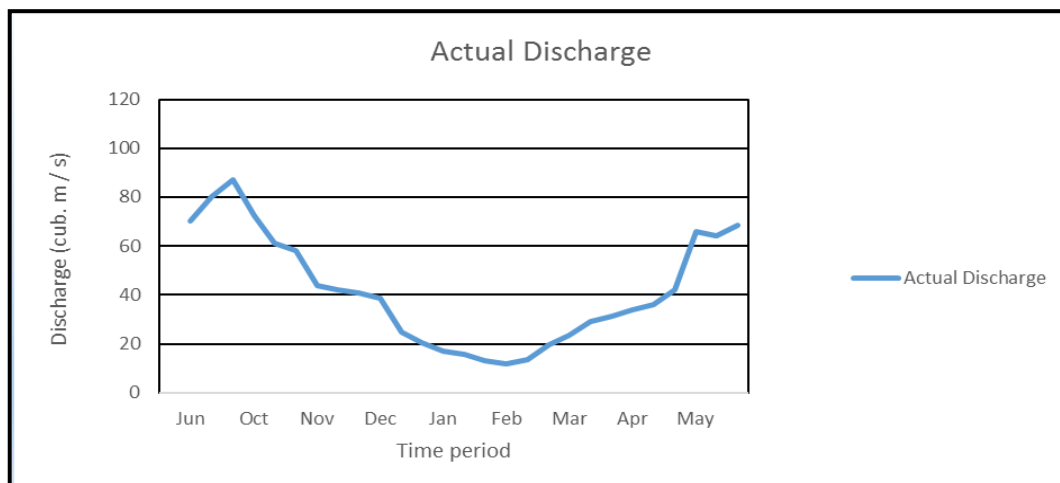


Figure 8: Measured Snow melt runoff

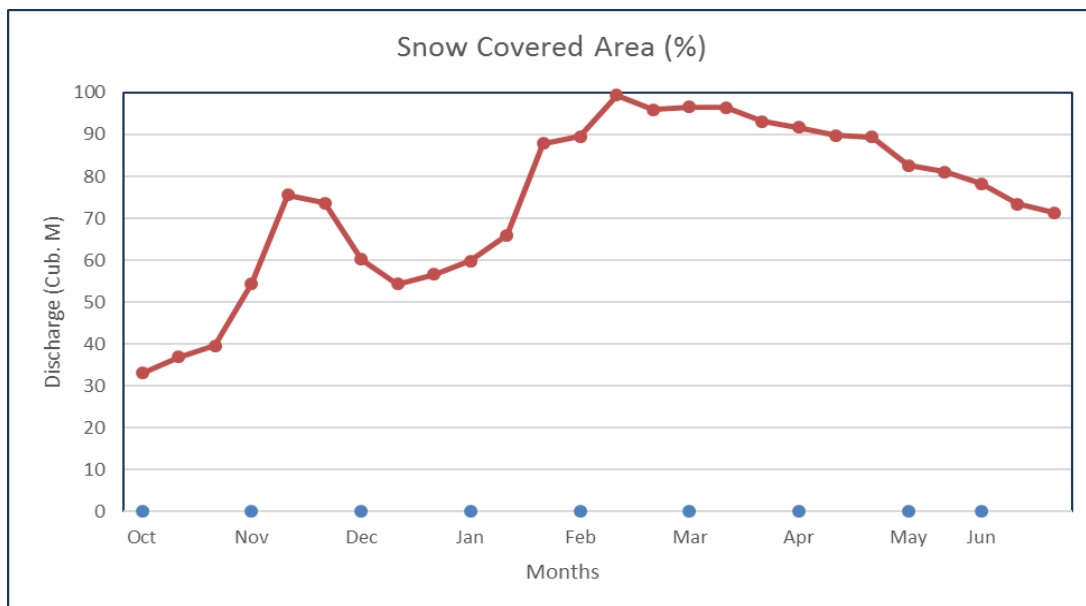


Figure 9 : Measured Snow covered area in percentage

VI. CONCLUSION

The present study carried out couple approach for two hydrological models for assessment of runoff and sediment yield from the mountainous Arwa watershed in Chamoli district, Uttarakhand, India. This study has utility in Sustainable Watershed Management, Watershed planning and conservation management in mountainous watershed in Himalayan region and to calculate requirements for Hydropower generation. Result concluded that SWAT model has capability to estimate Surface runoff and Sediment yield while SRM model is effective in simulating and forecast of snowmelt runoff.

As per published literature the SWAT model gave good result for runoff and sediment yield discharge. However, but during calibration and validation of our results with published results from similar region the SWAT results are found to be less satisfactory. This could be because SWAT does not consider the snow melt runoff from snow covered area. Therefore, SRM model is ideally more suitable in snow covered mountainous watershed.

There are number of models which use RS and GIS techniques for runoff estimation. Remote Sensing and GIS techniques are effective tools for preparation of various thematic maps that are essential inputs for hydrological modeling. Accurate and good quality observation data is an important input required for deriving reliable result.

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