COMPARISON OF SNOWMELT RUNOFF ESTIMATION USING SRM AND HEC-HMS MODELS FOR CHENAB RIVER BASIN

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ABSTRACT

The perennial rivers that originate from high Himalayas are the major source of water during dry seasons. The flow in such rivers during dry seasons is supplied by melting of snow, the natural frozen water reserves in the high altitudes, so the estimation of runoff is very important for the planning and effective management of water. An attempt has been made in this study, to estimate the Chenab basin's daily discharge in the Himalayan region. In this study, HEC-HMS and SRM models were chosen to estimate the snow melt runoff for a period of 2005 to 2008.The calibration is done for the period 2005 to 2006 and validation is done for the period of 2007 to 2008 respectively. The simulation is done on a daily time step. The model performance is assessed using the R^2 and NSE coefficient. The R^2 values for HEC-HMS model for daily and monthly time steps are 0.56 and 0.79 respectively. The R^2 value for SRM model in daily and monthly time steps are 0.62 and 0.83 respectively. Similarly, the NSE for HEC-HMS in daily and monthly time steps are 0.69 and 0.79 respectively. The NSE value for the SRM model for daily and monthly time steps are 0.81 and 0.82 respectively. Comparison of both the SRM and HEC-HMS models shows that the daily runoff from SRM model yields higher R^2 value than the HEC-HMS models.

Keywords: *Hydrological model, MODIS, Melting of Snow, hydrograph, Daily runoff, Himalayan region.*

1. INTRODUCTION

In the Himalayan region, precipitation occurs in the form of both rainfall and snowfall (Ajai, et al., 2011). The seasonal snow cover and glacier melt leads to the water flow in the Himalayan rivers especially in the summer, when temperatures are higher and there is a greater demand for water (Nosheen; Begum, 2012). Past few decades due to climate change there is direct effect on the snowmelt runoff in the Himalayan region (Negi, et al., 2009). As the population is growing, with the limited water resources, planning for effective management of water resources is very crucial. Particularly during dry periods when the flow is very less, management of water for various sectors such as agriculture, power generation, industries, domestic, etc., is essential. Information on availability of water resources during different seasons is useful for reservoir managers for planning their operations (Alam, et al., 2011). Estimation of runoff in a basin will be useful for basin level planning of water resources. Hydrological modeling (Wang, et al., 2005) is one efficient way for estimating of runoff in a basin. The basin's water and energy balances are governed by natural process through the hydrological modelling and is typically depicted using mathematical techniques. Understanding the hydrological system in order to produce trustworthy data for long-term water resource management is the main goal of this modeling. Snowmelt runoff is estimated using two methods they are energy budget and temperature index method.

Temperature index method is frequently used in snowmelt modeling and river forecasting since the data needed is air temperature which is commonly available to hydrologists in historical and real-time databases. The objective of this study is to estimate the snowmelt runoff for Chenab basin (Roy, et al., 2013) (Sanjay K.J, et al., 2013) using hydrological models. HEC-HMS model was used to find out the flood hydrograph for the Zard watershed in Khuzestan province Iran (Bahmani, et al., 2013). Similarly, HEC-HMS model was used to estimate runoff for Wocchu river basin (Nag, et al., 2013). The model was calibrated with the parameters for 10 years and also compared estimated value with the observed runoff value. SRM model was used to estimate the snowmelt runoff for the data-sparse watershed in the northwestern China (Abudu, et al., 2012). Also the SRM model was used to estimate the snowmelt and rainfall runoff (Fuladipanah, et al., 2012) and runoff for the western Himalayan region (Prasad, et al., 2005).. SRM model used to estimate the snowmelt runoff for the Kolahoi watershed in the western Himalayas revealed a volume difference of only 7.8% between measured and computed runoff (Alam, et al., 2011). There is a good agreement between measured and computed runoff. The model was calibrated using the two criteria namely R^2 and D_v are to estimate the model accuracy. These criteria were (0.7811, -14.24%) and (0.796, -9.21%) during calibration and validation periods respectively. The HEC-HMS model was used to estimate the scarce hydrological gauging area to estimate the runoff. The result shows a good agreement between the observed and estimated runoff (García, et al., 2008).

Recent developments in hydrological and environmental modeling increasingly highlight the role of data driven techniques, optimization methods, and remote sensing in improving prediction accuracy under data scarce conditions, as noted by Subramanian et al. (2024), Karthik et al. (2024), Sivasubramanian et al. (2024), and Maruthai et al. (2025), while additional studies further emphasize the importance of sustainable water resource management, environmental monitoring, and integrated modeling approaches for improving hydrological assessments in complex systems (Pasha et al., 2023; Ismayilov & Suleymanov, 2024; Sayed et al., 2024). Optimized deep learning models have shown strong capability in enhancing long term rainfall prediction across India, particularly in regions with limited observational data, thereby highlighting the need for robust calibration, and neural network based flood prediction studies in Chennai demonstrate that accurate runoff estimation is highly dependent on the quality and spatial representativeness of rainfall inputs. At the same time, nature inspired optimization approaches have improved the interpretation of remote sensing derived environmental variables, including snow cover dynamics in mountainous basins, while hybrid computational frameworks are increasingly used to address uncertainties in environmental systems (Maruthai et al., 2025). In addition, recent work by Sayed et al. (2024) on integrated environmental treatment systems further supports the importance of combining multiple data sources and modeling approaches to improve system efficiency and reduce uncertainty, which is relevant to hydrological model applications. These advancements are complemented by research focusing on sustainability and resilience, which stresses the importance of accounting for variability, uncertainty, and spatial heterogeneity in hydrological modeling, particularly under changing climatic conditions. Despite these developments, physically based and conceptual models such as the Snowmelt Runoff Model and HEC HMS remain widely applied in snowmelt dominated basins due to their relatively low data requirements and physical interpretability. In the Chenab River Basin, previous studies have generally applied either SRM or HEC HMS independently with limited calibration strategies or coarse resolution inputs, and comprehensive comparative evaluations under consistent data scarce conditions are still lacking. Therefore, the present study provides a more integrated and systematic assessment by comparing SRM and HEC HMS using uniform datasets, incorporating remote sensing based snow cover information, and applying structured calibration and validation procedures to evaluate their performance, reliability, and suitability for snowmelt runoff estimation in data constrained Himalayan environments, thereby positioning the study within recent advancements in hydrological modeling and environmental analysis.

2. STUDY AREA

The Chenab river is originated from the upper Himalayan region near Thandi and then flow into the plains of the Punjab, forming the boundary between the Rechna and Jech interfluves (*Doabs* in Persian). The study area starts from the upper Himalayan region at an elevation of 869 m above the Mean Sea Level (MSL) to 7077m above MSL in the Bara Lacha. For the current study area, the discharge station up to Premnagar is chosen at altitude of 1700m MSL. The precipitation in the upper region will received as snow and in lower region as rainfall. The snow lines various from 2000-3000m altitude in summer and increase up to 5000 m altitude in winter. The rainfall is classified as three zone outer Himalayan region rainfall was 1066mm, middle of Himalayan region 407mm and in grater Himalayan region 145mm. The minimum and the maximum temperature are -2ºc and 40ºc respectively. The soil type in the present study area is mainly classified in to five soil group they are mainly rock out crop, glacier & rock out crop, sandy, loam, loamy skeletal according to National Bureau of Soil Survey and Land Use Planning (NBSS LUP). The predominant soil type found in the upper Himalayan region is glacier & rock out crop and rock out crop. In the middle of the Himalayan region rock out crop and sandy soil is present. In the lower region loamy soil is found. Figure 1 shows the location of the study area with rain gauge and discharge station.

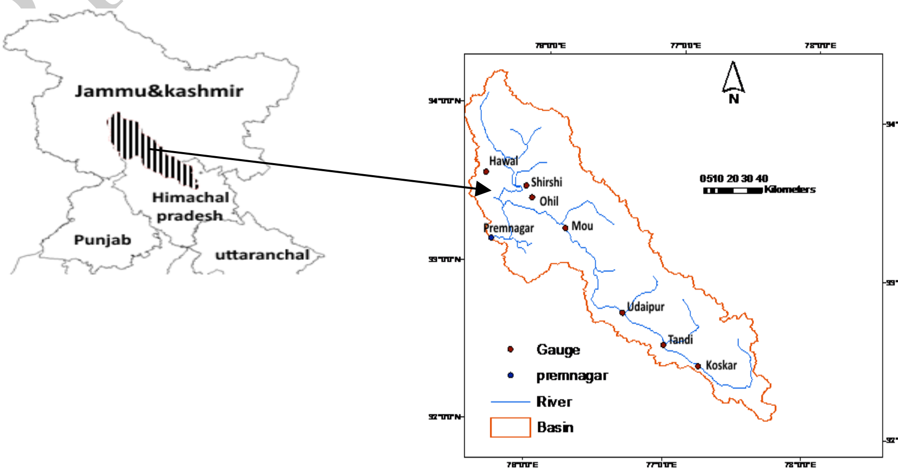

Figure 1 Location of study area and precipitation gauges' location (part of Chenab basin up to Premnagar)

The Chenab River Basin is primarily affected by snowmelt in its upper reaches, where a large amount of annual flow comes from seasonal snow accumulation and subsequent melting. This results in low discharge during winter due to freezing conditions, followed by a gradual increase in spring as temperatures rise and peak flows in late spring to early summer driven by intensified snowmelt, while monsoonal rainfall contributes to secondary peaks, particularly in the lower elevations, creating a mixed hydrological regime. Additionally, elevation plays a critical role in regulating runoff response, with lower regions responding to rainfall events more quickly. this strong dependence on temperature-controlled processes alongside spatial variability in runoff generation highlights the importance of incorporating such hydrological dynamics when evaluating the performance and applicability of SRM and HEC-HMS models under data-scarce conditions.

3. DATA USED AND METHODOLOGY

Hydro-Meteorological Data

For calculating the rainfall of the study area, average rainfall data from nine rain gauge stations are collected which are varying from an altitude of 4404m to 863m (Koskar, Tandi, Udaipur, Mou, Hawal, Sirshi, Ohli, Doda, and Bhadarwah) (García, et al., 2008) were used. The data are collected for the period of 2005 to 2008. Daily temperature data are obtained from the IMD gridded data. The values are interpolated using the Arc GIS by using the Kring method and the Kriging parameters were selected based on the spatial behavior of the IMD temperature data through initial exploratory analysis in ArcGIS. Four locations were selected based on the elevation (temp1-3359, tepm2-3427, temp3-2425, temp4-2606) and temperature data were extracted is shown in Table 3.1. In both SRM and HEC-HMS models, the threshold temperature was selected based on standard practices in snowmelt modeling, where a value around 0 °C is commonly adopted as the critical point separating snowfall and snowmelt processes, further verified during calibration to match with the observed runoff. A basic sensitivity analysis was executed by varying the parameters such as the threshold temperature and degree-day factor, to evaluate its influence on model output, which confirmed that runoff estimation is sensitive to temperature-related parameters. Additionally, the use of linear interpolation for MODIS snow cover causes some uncertainty due to cloud cover, temporal gaps, and simplification of spatial variability. However, this approach was adopted to maintain continuity in the dataset, and its impact is considered moderate as the overall seasonal snow trends remain well represented. The daily discharge data were obtained from CWC Premnagar discharge station which is located at an altitude of 1700 m above MSL for the year 2005 to 2008 (Archer, et al., 2008).

Table 3.1 Location of the Temperature Gauge for Current Study Area

Name	Latitude	Longitude	Elevation
Temp1	33.73	75.63	3359
Temp2	33.32	76.08	3247
Temp3	32.76	76.69	2425
Temp4	32.31	77.5	2606

Basin characteristics

The digital elevation model version 2 (ASTER GDEM V2) data were collected from the USGS website (Spacesystems, et al., 2011). The horizontal resolution is 30 m and vertical resolution is 17 m. The boundary delineation process is done using the HEC-GeoHMS tool in the Arc GIS. Various steps are carried out in order to delineation the catchment in to small Hydrological Response Unit (HRU'S). There are 50 HRU'S which represents the entire study area. The 50 HRUs were aggregated into two sub-basins to maintain model simplicity and avoid unnecessary complexity under limited data conditions, ensuring stable calibration and reliable results in HEC-HMS model. Although HEC-HMS is mainly a rainfall–runoff model, it is suitable to simulate the high-altitude snowmelt simulation when combined with temperature-index methods, as it can effectively represent both snowmelt and rainfall contributions under data-scarce conditions.

Remote sensing data

The snow cover extent for the study area is extracted from (Yadav, et al., 2013) MODIS 8-day snow cover data product (MODIS10A2) which is downloaded for a period of 2005-2008 from the MODIS website (Riggs, et al., 2019). These products are in sinusoidal projection, each tile is of 1200 km by 1200 km size (Dressler, et al., 2006). These products are reprojected to the required projection and then subsetted to the study area using ERDAS imagine software (Stehr, et al., 2009). Snow cover extent for every eight days' period is then linearly interpolated to get the daily snow cover extent by using the following equation (3.1)

$$S_n = S_1 + \frac{S_2 - S_1}{t_2 - t_1}(t_n - t_1) \tag{3.1}$$

Where, S_n snow cover at n^{th} day, S1 is snow cover derived from first imagery, S_2 is snow cover derived from the second imagery, t_n is number of n^{th} day, t_1 is Julian date of first image and t_2 is Julian date of second image.

Methodology

There are two methods to estimate the runoff in the snow cover area they are energy balance and temperature index method. There are various models used this method to estimate the snowmelt runoff they are as follows. The models which uses temperature index method to estimate the snowmelt runoff are HEC-HMS, SRM, SWAT etc. The models which uses energy balance methods to estimate the snowmelt runoff are UEB, VIC, SSAR, CREST, GSFLOW etc. The runoff created by the snow cover area are depends on snow and glacier melt and also the rainfall occurring in the snow cover area. Energy balance models need more data but the index based model need only air temperature data for the process. Although the temperature plays the major role in the snow melt it is enough to calculate the runoff and also the availability of air temperature data is reality good so that index method is used in a large extent. For this study area, the availability of data is limited, hence the index method is used for calculating the runoff and the models which are working under the principle of index methods are considered. The two models used for this study are Snowmelt Runoff Model (SRM) and HEC-HMS (Hari Prasad et al., 2014). The detailed methodology is given in Figure 2.

HEC-HMS Model

The hydrological modeling system which is developed by US Army crop is used to simulate both the event and continuous simulation (Bartles, et al., 2023). Large numbers of studies were conducted to estimate the flood runoff which is an event based simulation mostly in the plain region (Anderson, et al., 2012). In the current study this model is used to estimate the snow melt runoff which is a continuous based simulation model. In the current study the model is used to estimate the runoff in the high mountainous region like Himalayas. This model needs the precipitation, temperature, discharge and snow cover data in addition to that it needs the topography of the soil and type of soil. The model is semi-lumped model so it is divided in to sub-basin for the current study two sub-basins are used for runoff estimation and other sub-basin characteristics are shown in the Table 3.2. The following are the equations used to estimate the snowmelt runoff in the HEC-HMS model.

$$M = C_m\ (T_a - T_b) \tag{3.2}$$

M is snowmelt, in. per period *s, Cm is* melt-rate coefficient that is often variable, in./(degree/period), T_a *is a*ir temperature, °F, T_b *is* base temperature, °F.
The various parameters such as critical temperature, lapse rate, melt rate and other parameters derived from the (Alam, et al., 2011) are used in the current study to run the HEC-HMS model.

Table 3.2 Sub-basin characteristic for HEC-HMS model

Sub Basin	Area Sq.km	Canopy	Surface	Loss Method	Transformation	Base Flow
1	5921	No	No	Deficit and Constant	SCS unit hydrograph	Recession
2	11357	yes	yes	SCS Curve Number	SCS Unit Hydrograph	Recession

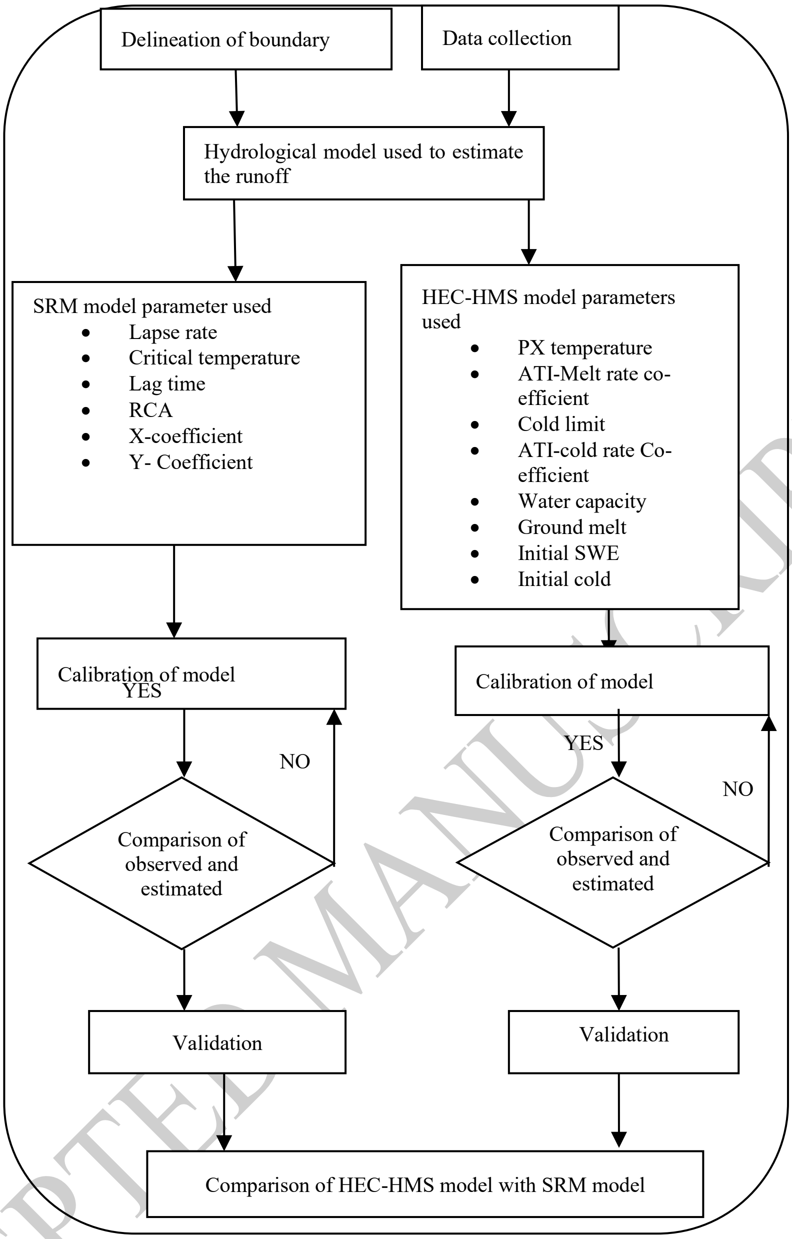

Figure 2 Methodology Flowchart

SRM Model

SRM model is a conceptual, deterministic and degree-day hydrological model. It was developed by the Martinec in 1994 (Martinec, et al., 2008). It is mainly used in the mountainous region where the availability of data is very sparse. This model is suitable for the Himalayan region where there is scant data availability. It only uses the data on temperature, precipitation, area of snow covers and discharge. The snow cover data for this model is obtained from MODIS 10A2 data. The following equation is used to estimate the snowmelt runoff.

$$Q_{n+1} = [C_{sn}\, a_n(T_n + \Delta T_n)S_n + C_{Rn}P_n]\,\frac{A.10000}{86400}(1 - k_{n+1}) + Q_n K_{n+1} \qquad (3.3)$$

Q_{n+1} is Average Daily Discharge [$m^3 s^{-1}$] for n+1 day, C_{sn} is snowmelt coefficient for n days ,C_{Rn} is rainfall coefficient for n days ,a_n is Degree-Day Factor [$cm\ {}^oC^{-1} d^{-1}$] for n days, T_n is Number of Degree-Days [^oC d] for n days, ΔT_n is the adjustment by temperature lapse rate [^oC d] for n days, S_n is Ratio of the snow covered area to the total area for n days, P_n is Precipitation contributing to runoff [cm] for n days, A is area of the basin or zone [km^2] , k_{n+1} is recession coefficient indicating the decline of discharge in a period without snowmelt or rainfall for n days n is sequence of days during the discharge computation period, Qn – Average daily discharge on day *n* [m^3/ s] The various parameters such as critical temperature, lapse rate, melt rate and other parameters derived from the (Bashir, et al., 2010) in the current study area are used to run the SRM model.

4. RESULT AND DISCUSSION

HEC-HMS MODEL

First the model was run with the initial values and then the computed runoff at the outlet of the basin is compared with observed runoff (Cunderlik, et al., 2004). If the computed runoff is deviating with respect to observed runoff the parameter values is fine-tuned and the model is run again (Roy, et al., 2013). In the present study the calibration is done for the period 2005 (to) 2006 and validation is done for the period of 2007 (to) 2008 respectively. The simulation is done on a daily time step. In HEC-HMS model, first the sensitive parameters for the model are found using the optimization technique such as percentage error peak and percentage error volume are used and finally manual calibrations is also done and arrived at values where there is a best fit between the estimated and observed data. The parameters adjusted are given in Table 4.1. Figure 3 shows the observed and estimated runoff for year 2005 (to) 2006 and Figure 4 shows the scatter plot between the observed and estimated runoff for 2005 (to) 2006.

Table 4.1 Initial and Calibration values of parameter for HEC-HMS model

Parameters	Initial Value	Calibrated Value
PX temperatures (deg C)	2.5	1.5
ATI – Melt rate Coefficient	0.85	0.65
Cold Limit Coefficient	20	10
ATI – Cold rate Coefficient	0.85	0.65
Water Capacity (%)	2	4
Ground Melt (mm/day)	5	0
Initial SWE (mm)	30	150-80
Initial Cold (mm)	0	3-5

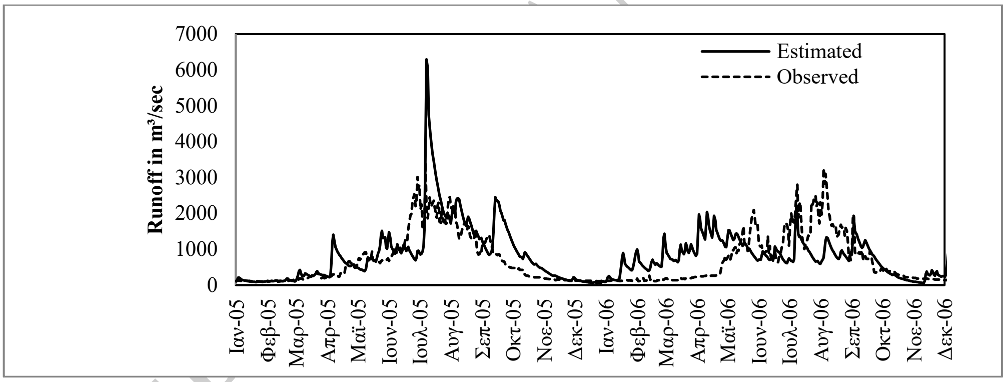

Figure 3 Comparison calibrated values of Observed and Estimated Daily Flow for the years 2005 and 2006 at Premnagar. (Using HEC-HMS model)

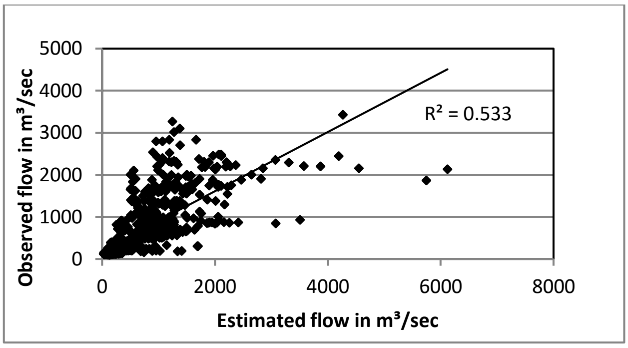

Figure 4 Scatter Plot between Observed and Estimated Daily Runoff for Year 2005 And 2006

SRM Model

In SRM model, the parameters are distributed for various zones by dividing the basin into seven elevation zones ranging from 1359 m to 6359 m to capture the variation in temperature, snow accumulation, and melt processes with altitude, as elevation is a main controlling factor in snowmelt-driven hydrology. The number of zones was selected to provide sufficient representation of altitudinal variability for maintaining computational simplicity and data consistency. and parameters for each zone are given separately. The model is calibrated for the period of 2005 to 2006 and validated for the period of 2007 (to) 2008. Similar to the HEC-HMS model here also first the model is run with the initial values and then the model is calibrated until the good fit between the estimated and observed flow. The parameters adjusted are given in the table 4.2. The Figure 5 shows the observed and estimated runoff for year 2005 to 2006 and Figure 6 shows scatter plot between the observed and estimated daily runoff for 2005 to 2006.

Table 4.2 Initial and Calibrated Values of Parameters for SRM Model

Parameter	Initial value	Calibrated value
C_S	0.7	0.43-0.98
C_R	0.6	0.51-0.8
x-coefficient	1.0200	1.2-1.9
y-coefficient	0.0860	0.033-0.1
AN (a) (cm °C-1d-1]	0.65	0.2-1

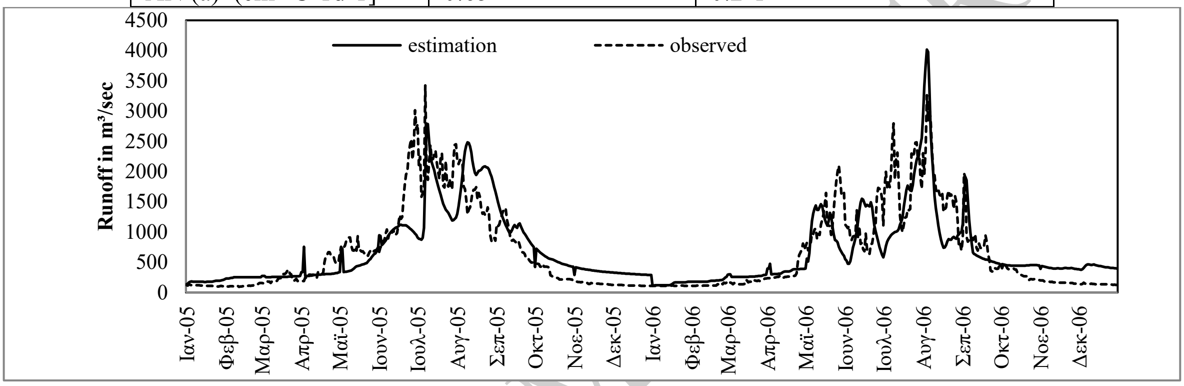

Figure 5 Comparison of calibrated values of Observed and Estimated Daily Runoff for the years 2005 and 2006 at Premnagar (SRM model)

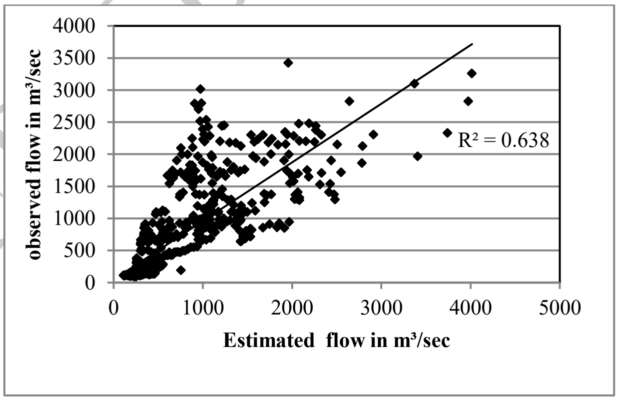

Figure 6 Scatter Plot for calibrated value between Observed and Estimated Daily Runoff for Year 2005 and 2006 (using SRM model)

Validation

Model is validated for period of two years from 2007 to 2008 years. The computed runoff is closely matched with the observed runoff for the years 2007 and 2008. Runoff is high during the month of July. The runoff Peak is high in the year 2007 when compared to the peak occurred in the year 2008. Figure 7 and 8 shows the observed and estimated runoff daily runoff for 2007 to 2008 and Figure 9 and 10 shows the scatter plot between the observed and estimated runoff for 2007 to 2008. As per the published literature, where rain gauge is very less, Correlation factor can be less than 0.7 which is the case in this study, Results in low R^2 value.

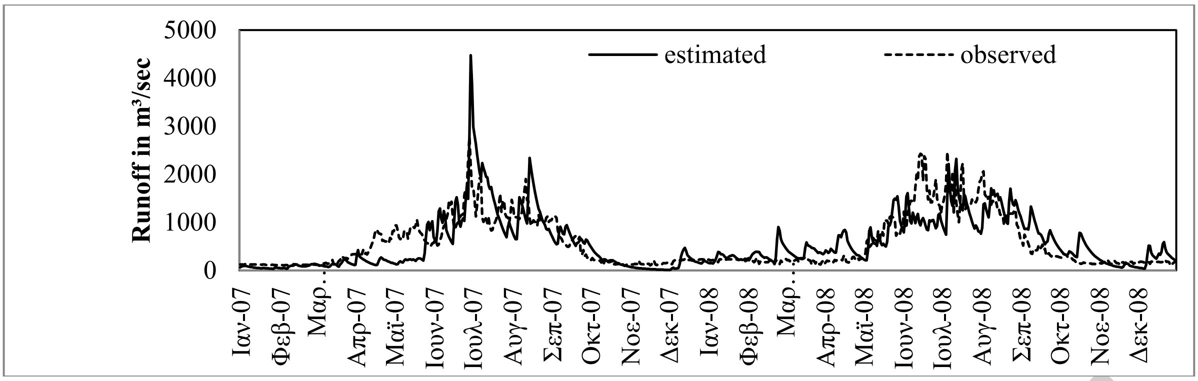

Figure 7 Comparison of Observed and Estimated Daily Runoff for the years 2007 and 2008 at Premnagar (Using HEC-HMS Model)

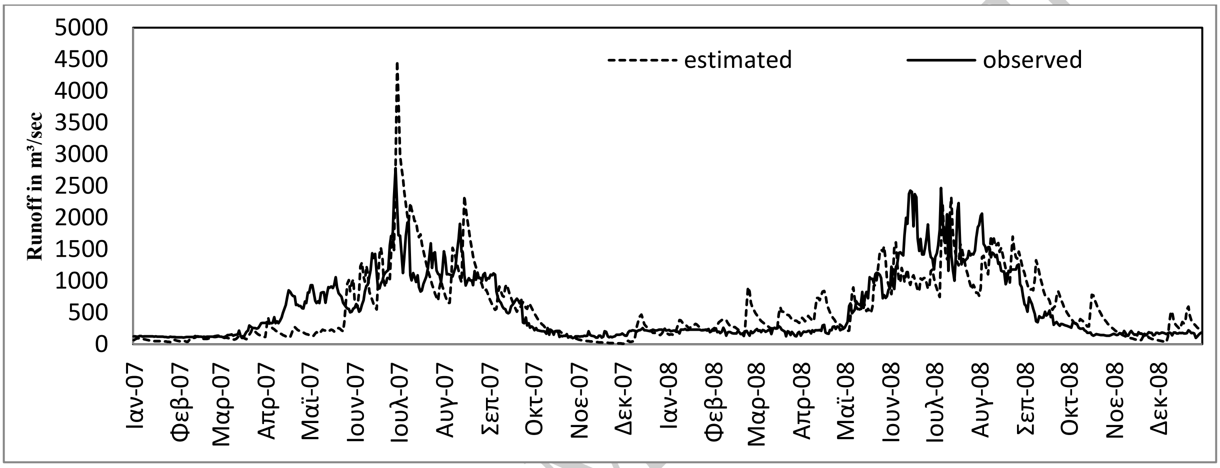

Figure 8 Comparison values of Observed and Estimated Daily Runoff for the years 2007&2008 at Premnagar (Using SRM Model)

The runoff estimation from the HEC-HMS model shows the trend of the curve is similar for both the estimated and observed data. In the beginning the snowmelt runoff is less and increases later and it reaches a high peak discharge during the months of June and July which shows that there is very high snowmelt runoff in that period. Again the runoff decreases in the month of November and December. The estimation of runoff using HEC-HMS model mainly depends up on the rainfall and snowfall. The parameter value plays an important role starting from separating the rain from snow to converting the snow fall as the snowmelt. Melt factor given for increase in the ATI found to be different for the snowmelt period from non-snowmelt season.

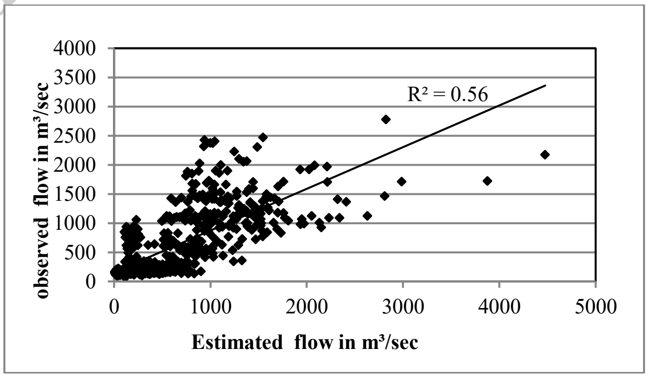

Figure 9 Scatter Plot between Observed and Estimated Daily Runoff for Year 2007 and 2008 for HEC-HMS Model

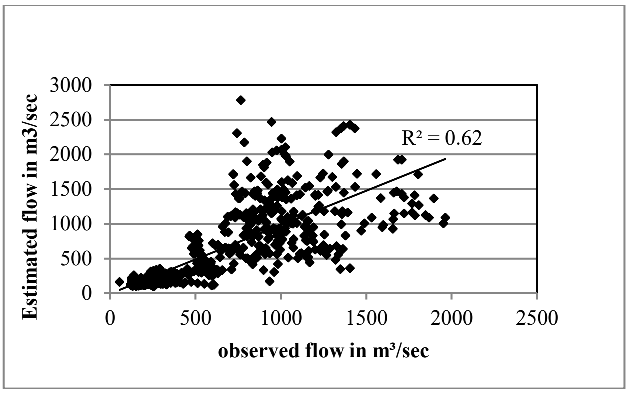

Figure 10 Scatter Plot between Observed and Estimated Daily Runoff for Year 2007 and 2008 for SRM Model

The runoff estimation from the SRM model shows the trend of the curve is similar for both the estimated runoff and the observed runoff data. The runoff is high during the period of May to October and the hydrograph reaches the peak during the period of July and shows decreasing trend in the discharge during the period of November and December. The SRM model parameters are adjusted to correctly predict the runoff using trial and error method. Since the SRM typically results in a noise-free, smooth-retreating limb, runoff did not increase during hydrograph recession as a result of snowmelt or precipitation events. This implies that during hydrograph rise and hydrograph recession, runoff simulations were most sensitive to runoff coefficients and recession coefficients, respectively. Recession coefficients increased during hydrograph recession and decreased during hydrograph rise, resembling the shape of an inverse hydrograph, since (1 – k) is the percentage of daily melt water that appears as runoff immediately.

Discussion

A summary comparison table of calibration and validation statistics for both SRM and HEC-HMS models has been included to improve clarity (Refer Table 4.3). The SRM model performs relatively better with R^2 values of 0.62 (daily) and 0.83 (monthly) compared to 0.56 (daily) and 0.79 (monthly) for HEC-HMS, while NSE values are 0.81 (daily) and 0.82 (monthly) for SRM and 0.69 (daily) and 0.79 (monthly) for HEC-HMS. The R^2value for both the models are quite low. The snowmelt and rainfall contributions to groundwater, as well as the delayed base flow contribution to streamflow, are not taken into account by the SRM model. It is the reason for low R^2value. Similarly, in HEC-HMS model the value of R^2 is low because it is an event based model and parameters flexibility is very less specially the snow parameters. In these study HEC-HMS model is compared with the SRM model (which is consider as a standard model for snowmelt estimation) to estimate its capacity of calculating snowmelt runoff.

Table 4.3 Comparison of SRM and HEC-HMS Model Performance

Model	Time Scale	R^2	NSE	Performance Interpretation
HEC-HMS	Daily	0.56	0.69	Moderate performance; affected by daily variability
HEC-HMS	Monthly	0.79	0.79	Good performance with reduced variability
SRM	Daily	0.62	0.81	Better performance in snowmelt simulation
SRM	Monthly	0.83	0.82	Very good agreement with observed runoff

5. CONCLUSION

Snow cover mapping are done using the MODIS image to estimate the snow cover. In this Study MOD10A2 data is used to estimate the Snowmelt runoff with help of SRM and HEC-HMS model for Chenab basin. The HEC-HMS model results yielded reasonable runoff. The SRM model yielded comparatively good results than HEC-HMS model. In the HEC-HMS model threshold temperature is kept the same as 1.5 for all the month. But in the SRM model the threshold value from 1.5-4.5 are given for different months. This has lead, the SRM model to predict the runoff more accurate than the HEC-HMS Model. This comparative analysis shows that the SRM model has improved performance over the HEC-HMS model with higher R^2 values by 0.06 at the daily scale and 0.04 at the monthly scale and NSE improvements of 0.12 and 0.03, indicating better concurrence with observed runoff. This shows that the HEC-HMS and SRM models are highly sensitive to the input parameters; understanding the parameter implementation will help to get more reliable results. Sufficient data availability in the higher elevation ranges will improve the results as the elevation range is upto 7500 m in the basin. It can be done by improving the availability of the satellite image data.

The future work will focus on improving the model accuracy and its performance by adding more input datasets, particularly rainfall and temperature records. The use of advanced remote sensing and reanalysis of datasets are expected to reduce the uncertainty in the results of snow cover and precipitation estimation. Additionally, the use of hybrid models integrating ANN/LSTM with SRM/HEC-HMS and climate change scenarios will be explored to enhance the runoff estimation and support sustainable water resource management in Himalayan River Basin.

Acknowledgements

The author acknowledges with thanks for the help received from ISRO and Centre for Water Resources, Anna University, Chennai.

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