Satellite snow cover mapping and snowmelt runoff modelling in Beas basin

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ABSTRACT The Snowmelt Runoff Model (SRM) has been successfully applied in different catchment areas worldwide. As input to the model periodic snow cover maps and meteorological data, such as temperature and precipitation, have to be provided. For the present application in the Himalayas (Beas basin) it has been shown that even with incomplete or fragmented ground data snowmelt runoff simulations can be carried out with adequate accuracy.

INTRODUCTION

Most of the rivers in Northern India originate from the Himalayas, and their major source of flow in summer is due to snowmelt runoff. These snow-fed catchments offer an excellent opportunity to study the physical processes of snow accumulation, snowmelt and runoff. At the same time, due to its rugged and inhospitable terrain, these basins provide little scope to set up an appropriate network of snow and meteorological stations. Nevertheless, forecasting of snowmelt runoff, seasonal or short-term, is of utmost importance for planning water regulation of reservoirs. Accurate prediction of inflow into reservoirs is needed for a reliable management of the water resources for power generation, irrigation and drinking, especially during the lean season.

Development of short-term runoff models is essential where the reservoir operators require a very high accuracy. The irrigation-project
operators, for example, are interested in the highest possible accuracy of the total inflow during the low flow season. Managers of hydropower projects, in addition, require a very accurate assessment of the minimum inflows during the snowmelt season.

In order to apply the Snowmelt Runoff Model (SRM) (Martinec et al., 1983) for seasonal runoff simulations, snow cover depletion curves together with meteorological data such as temperature and precipitation are needed as inputs. For the initiation phase, the basin descriptive parameters such as recession coefficients, critical temperatures, etc. have to be evaluated carefully. It is the aim of the study to demonstrate the applicability of the SRM in a Himalayan basin where ground information, control measurements and meteorological auxiliary data are rare.

STUDY AREA

The Snowmelt Runoff Model (SRM) has been successfully employed in different catchment areas worldwide (WMO, 1986). In this study the SRM has been applied with parameters adjusted for a basin in the Himalayas in India. The Beas basin in Himachal Pradesh was selected for this purpose. The river Beas has its origin at Beas Kund near the Rohtang pass in the Pir Panjal range to the north of Kulu, at an elevation of 4085 m a.s.l. The total length of the river is 256 km, with 101.3 km upto Larji. The basin has high mountain ranges varying from 2700 to 3600 m in the south to 4500 to 6000 m along the northern boundary. The marks of glaciation are evident along the Beas valley upstream to Kulu and towards the heads of high streams. Generally, the valley is deep-lying, bowl-shaped and sparsely settled.

The major tributaries of the Beas are Beas Kud nallah near Kothi, Manalsu nallah, Parbati river near Bhuntar, Hurla nallah near Bajora, Tirthan and Sainj rivers near Larji. All these tributaries have perennial flow, but the flow varies during different months.

The catchment covers an area of 5144 km². In addition, in order to investigate the contributions of different subregions, the catchment has been divided into five subbasins, namely Kulant (205 km²), Bhuntar (1370 km²), Parbati (1154 km²), Sainj (705 km²) and Thalot (1710 km²), as indicated in Fig. 1.

SNOW COVER MAPPING

The seasonal depletion of the snow cover is required as input to the SRM. In order to improve the quality, the snow cover evaluation has to be carried out in several elevation ranges. Due to the large altitudinal
differences in the Himalayas, six elevation zones have been selected, ranging between A: 1025-2000 m a.s.l.; B: 2001-2700 m a.s.l.; C: 2701-3375 m a.s.l.; D: 3376-4100 m a.s.l.; E: 4101-4775 m a.s.l. and F: 4776-6800 m a.s.l.

For the snow cover mapping Landsat-MSS data of the seasons 1986 and 1987 have been used. A sophisticated analysis and registration of the multispectral satellite recordings has been based on a digital terrain model (DTM) (Seidel et al. 1983).

The images were geometrically corrected to be included into a simplified Geographic Information System (GIS) of the Beas basin. Then the geocoded images were classified to determine the snow covered area, the transition zone and the snow-free (=aper) area. As a supervised classification method, the parallel-epiped (PPD) algorithm was used. The snow cover mapping was carried out in steps as follows:

- Supervised feature selection in order to distinguish between various classes of interest
- identification of the areas which are to be masked out for separate analysis (due to illumination anomalies by relief, clouds, etc.)
- selecting boundaries for PPD-algorithm for each class in each channel
- merging the individually classified parts of a scene
- interactive control of the classification results
- correction of misclassified areas
evaluation of the relative snow coverage for the entire basin and for each subbasin in each elevation zone.

All available images of the snowmelt periods 1986 and 1987 were evaluated to determine the relative snow covered area for each elevation zone. The results (Tab. 1) express the relative snow covered area (SCA) in the entire basin up to Thalot.

TABLE 1 Snow covered areas in Beas basin and its subbasins 1986 and 1987.

<table>
<thead>
<tr>
<th>Date of image</th>
<th>Percentage snow cover up to Thalot</th>
<th>Date of image</th>
<th>Percentage snow cover up to Thalot</th>
</tr>
</thead>
<tbody>
<tr>
<td>27.03.86</td>
<td>51.52</td>
<td>18.03.87</td>
<td>51.78</td>
</tr>
<tr>
<td>26.05.86</td>
<td>41.44</td>
<td>19.04.87</td>
<td>51.12</td>
</tr>
<tr>
<td>11.06.86</td>
<td>37.49</td>
<td>05.05.87</td>
<td>50.49</td>
</tr>
<tr>
<td>13.07.86</td>
<td>19.73</td>
<td>06.06.87</td>
<td>40.06</td>
</tr>
<tr>
<td>30.08.86</td>
<td>5.85</td>
<td>14.06.87</td>
<td>37.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16.07.87</td>
<td>28.32</td>
</tr>
<tr>
<td></td>
<td></td>
<td>01.08.87</td>
<td>19.89</td>
</tr>
</tbody>
</table>

The SCA in each zone was plotted against the time. Then the depletion curves for the basin were developed by joining the points in a smooth curve (Fig. 2). From these depletion curves the daily SCA can be determined as required for the SRM.

SIMULATIONS AND RESULTS

Main difficulties in an area with limited ground observation are the availability of sufficient and continuous weather records as well as reliable knowledge of its physiographic settings for the adjustment of the various parameters such as the recession coefficient, the degree-day factor, the runoff coefficients for snow and rain, the temperature lapse rate, the critical temperature and the lag time. Weather records could be obtained from two observatories within the basin while runoff is recorded near Thalot.

The first simulation attempt was done using the parameters, as adjusted in accordance with the User Manual (Martinec et al., 1983), the
SCA of 1986 and the Solang weather records. The results (Fig. 3) show in comparison to the actual runoff a relative seasonal difference of 18.1% and a goodness of fit ($R^2$) of 0.557.

FIG. 3 Hydrograph showing simulated versus actual streamflow of Beas at Thalot using 1986 data and the original parameters.
Due to the large variation in the elevation levels in the basin, most of the parameters were determined zonewise. The high runoff coefficient for snow and rainfall is a reflection of the steep rugged terrain and hence values of 0.9 to 0.7 were chosen. The runoff coefficients were lowered during the later part of the snowmelt season as losses were more extensive. The recession coefficient was calculated based on the relationship:

$$k_{B2} = k_{B1} \sqrt[4]{A_{B1}/A_{B2}}$$

where $A_{B1}$ and $A_{B2}$ are the respective areas of the basins, $B1$ and $B2$ and $k_{B1}$ and $k_{B2}$ are the recession coefficients for the corresponding runoff conditions. The temperature lapse rate was adjusted to 0.6°C per 100 metres. A constant lag time of 18 hours was assumed.

In addition, the tests revealed that the weather data from the second station (Bhuntar), even though originating from a rather low elevation, were more representative for the entire basin than the ones from the first station. The values of all parameters ultimately used are listed in Table 2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree Day Factor</td>
<td>0.4. to 0.65</td>
</tr>
<tr>
<td>Snow Runoff</td>
<td>0.9/0.8</td>
</tr>
<tr>
<td>Coefficient Rain Runoff</td>
<td>0.9/0.8/0.7</td>
</tr>
<tr>
<td>Coefficient Temperature</td>
<td></td>
</tr>
<tr>
<td>Lapse Rate</td>
<td>0.6°C / 100m</td>
</tr>
<tr>
<td>Critical Temperature</td>
<td>3/2/0.75°C</td>
</tr>
<tr>
<td>Lag Time</td>
<td>18 hours</td>
</tr>
</tbody>
</table>

With these adjustments the simulation of the runoff improved considerably as presented in Fig. 4. The seasonal difference narrowed down to 1.03% and the goodness of fit reached 0.78.

It has to be concluded that this process of adjusting the model parameters in areas of sparse ground truth has to be undertaken as carefully and thoroughly as possible. In addition, not only one melting period
alone has to be considered but at least two or even more.
Therefore the 1987 data were analysed as well. Seven Landsat scenes of the period March to August could be classified and the daily SCA determined (Tab. 1). The simulated runs resulted in a goodness of fit of 0.84 and a seasonal difference of 5.4% as shown in Fig. 5.

CONCLUSIONS AND OUTLOOK

The first results from a Himalayan catchment area (Beas) show that the SRM provides quite accurate simulation results even with very little historical data. But the adjustment of the model parameters represents a crucial task.

Since there are a number of hydro-electric schemes proposed on Beas and other rivers originating in the Himalayas, there is a definite need to extend this study towards an operational forecasting mode for additional basins. The hydro-electric potential in the Indus basin (comprising of the rivers Indus, Jhelum, Chenab, Ravi, Beas and Sutlej) is estimated to be about 20'000 MW, of which only a third has been harnessed so far. Short-term runoff models, such as the SRM, can be effectively put to use in schemes already in operation or can be developed for projects under construction.
SNOWMELT RUNOFF MODEL (SRM)
STREAM FLOW OF RIVER BEAS AT THALOT, 1987

SIMULATION

FIG. 5 Hydrograph showing simulated versus actual streamflow of Beas river at Thalot using 1987 data and the adjusted parameters.

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REFERENCES